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12TH ANNUAL RESEARCH SYMPOSIUM - 2022

Building Resilience amidst
Economic Challenges

SYMPOSIUM PROCEEDINGS

26th January 2023
Colombo, Sri Lanka

Building Resilience amidst
Economic Challenges

PROCEEDINGS OF 12TH ANNUAL RESEARCH SYMPOSIUM - 2022

BUILDING RESILIENCE AMIDST ECONOMIC CHALLENGES

26TH JANUARY 2023
COLOMBO, SRI LANKA

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Foreword

ENG. (DR.) ASIRI KARUNAWARDENA
Director General
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January 2023

The annual research symposium organized by the NBRO provides a yearly update of the research outputs of NBRO's research and development program and other research projects. The year 2022, being a challenging year for Sri Lanka at many levels, taught us the significance of the ability to make real-world adaptations in response to constantly evolving and highly uncertain ground realities, while building safer and resilient communities in pursuit of sustainable development. Realizing the need of the hour, the 12th Annual Research Symposium 2022, specifically aims to put a spotlight on economically plausible solutions in disaster management under the overarching theme of **"Building Resilience amidst Economic Challenges"**.

This symposium proceedings volume is this year's extension of the annually-published culmination of research findings, encompassing research work belonging to the broader themes of Understanding Disaster Risk, Risk Reduction for Resilience, Regulating Development for Resilience, Long term Resilience Building through Climate and Disaster Risk Finance and Quality Assurance for Resilience.

In keeping with the tradition, this year also, NBRO has partnered with researchers, practitioners, policymakers, and renowned experts in the field of disaster management from acclaimed local and international institutions to produce timely, relevant, and high-calibre research outputs.

This year's symposium, being consistent with the previous years, will provide a tremendous opportunity not only for researchers affiliated with NBRO but also for their counterparts in the productive exchange of ideas, knowledge, and experiences.

We take this opportunity to extend our gratitude to the Government of Sri Lanka, all the authorities, agencies, universities, and individuals for their immense support extended, and especially grateful to the stakeholder agencies that financially assisted in making this symposium a successful event.

Also, our sincere appreciation is extended to authors, presenters, panel members, moderators, our Editorial Board, the Organizing Committee of the 12th Annual Research Symposium of NBRO, and local and international research enthusiasts.

We deeply believe the 12th Annual Research Symposium of NBRO contributes to prompting key scientific dialogues and promoting inclusive disaster-resilient actions, at the event and beyond.

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Building Resilience amidst
Economic Challenges

Spatial autocorrelation technique for landslide hotspot analysis in Kandy District

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Abstract

Landslides are one of the main natural hazards that affect humans and their livelihoods, especially in the mountainous areas all over the world which are also experienced in Sri Lanka very often. In particular, Kandy District in the Central Highlands faces the growing risk of landslides as a result of demographic pressure necessitating the integration of disaster risk reduction and sustainability management. Therefore, the identification of potential risk of landslides areas in a given region is important to ensure the safety, sustainability of the development and the efficient resource allocations for disaster risk management.

In this research, distribution of landslides is mapped using the multi-temporal records of landslide events during 2014-2020. The spatial autocorrelation technique has been applied to identify spatial patterns of landslide clustering. Landslide clusters in the study area were mapped based on the hot-spot analysis (Getis-ord Gi*) which calculated landslide hotspots and cold-spots locations with confidence levels of 90%, 95% and 99% along with nonsignificant GN divisions in the Kandy District. Landslide hotspots and cold spots were represented by the z-score and p-values derived from spatial autocorrelation analysis. Moran's index (MI) and incremental spatial autocorrelation were calculated to determine whether or not hot-spot analysis is statistically significant. Four main landslide hotspot results in a hotspot map and 64 GN divisions (out of the 1195 GN divisions of Kandy District) are included in these hotspots with a 99% confidence level. The four major statistically significant landslide hot spots are mainly located in *Ganga Ihala Korale, Delthota, Panvila* and *Madadumbara* Divisional Secretariats in Kandy District. The landslide hotspots map could be successfully used in the decision-making of slope remedial measures, regional planning and hazard mitigation policy making.

Keywords: Landslide hotspots, Landslide clustering, Moran's index, Z-score, P-values

1. Introduction

Landslides have been proven to result in loss of life and destruction of property including infrastructure and lifeline facilities. Landslides occur due to a combination of trigger mechanisms and susceptibility factors such as fragile and complex geology, presence of high slope gradient, rugged topography, variable climatic and microclimatic conditions, prolonged rainfall, earthquake and vegetation degradation (Gerrard and Gardner, 2002, Wobus *et al.*, 2003, Hasegawa *et al.*, 2009). It is very important to identify landslide-prone areas for disaster risk reduction at the community level using tools like land use planning and building regulations (NBRO, 1995). Landslides and Slope failures are the most disastrous phenomenon in Kandy District in past consecutive years, occurring due to prolonged torrential rainfall during NE and SW monsoonal period with increased and loss of lives and property damage. Even though an enormous amounts of landslide records are available in NBRO, they are currently not well organized. It reveals that there is a necessity of spatial analysis of landslides which helps to assess and predict landslide susceptible areas with a view to decreasing the landslide damages through proper planning. In this framework, spatial analysis of landslides is used worldwide.

Landside hot-spot analysis using geospatial technology has provided a very useful tool to interpret an area's potential for landslide hazards. The hot-spot mapping identifies the statistically significant spatial clusters. The higher values indicate hot spots whereas low values denote cold spots. Also, the hot-spot mapping of landslides may serve as a reference for undertaking extensive field studies that have applications in initiating future developmental plans. Spatial autocorrelation and hot-spot analysis have applications in explaining distributional patterns of geographical entities (Wong and Lee 2005). The present study attempts to landslide cluster analysis on *Grama Niladari* (GN) administrative division levels in Kandy District, in an objective to enhance the efficiency of resource utilization to detect vulnerable slopes, slope directions, rainfall seasons and to improve the landslide operation work and risk management.

2. Study area

The study was carried out in Kandy District, which is situated within the Central Province of Sri Lanka. It extends in coordinates from 6° 55' 57.69" N/80° 25' 2.31" E to 7° 29' 7.86" N /81° 1' 39.71"E. Kandy District consists of 20 Divisional Secretariat Divisions (DSD) including 1,188 Grama Niladari (GN) Divisions.

Figure 1: Map of study area (Divisional secretariats divisions of Kandy District)

3. Methodology

Spatial autocorrelation technique has been applied to identify spatial pattern of landslide clustering. Specifically, Moran's index and incremental spatial autocorrelation were calculated to determine whether or not hot-spot analysis is statistically significant. Spatial autocorrelation between landslide locations has been examined using Global Moran's Index. The Moran's index values are calculated using the following equation,

$$I = \frac{n}{So}\frac{\sum_{i=1}^{n}\sum_{j=1}^{n} \mathrm{w_{i,j} z_i z_j}}{\sum_{i=1}^{n} \mathrm{z_i^2}}$$

Where z_i is deviation of an attribute for feature i from its mean ($x_i - \underline{x}$), $w_{i,j}$ is the spatial weight between Feature ı and j, n is the total number of features, and S_o is the aggregate of all the spatial weight.

$$S_o = \sum_{i=1}^{n}\sum_{j=1}^{n} \mathrm{w_{i,j}}$$

Equation to find z_i

$$z_i = \frac{I - E[I]}{\sqrt{V[I]}}$$

Where,

$$E[I] = -1/(n-1)$$

$$V[I] = E[I^2] - E[I]^2$$

Moran's index is based on the null hypothesis. The null hypothesis is a characteristic arithmetic theory suggesting that no statistical relationship and significance exists in a set of given, single, observed variables between two sets of observed data and measured phenomena. If the p-value is non-significant, null hypothesis cannot be rejected. The possibility exist that spatial distribution is the result of random spatial processes. If the p-value is statistically significant and Z-score is positive, reject the null hypothesis. The spatial distribution is more spatially clustered. Statistically significant p-value and negative Z-score means reject the null hypothesis and the spatial distribution is more spatially dispersed. Incremental spatial autocorrelation tool was used to measure appropriate scale for analysis where distance band indicating maximum spatial autocorrelation. This tool measures spatial autocorrelation for a series of distances and optionally develops a line graph showing z-score with several peaks. The highest peak with corresponding value of z-score was used as the ideal distance for further analysis while running a hot-spot tool. Landslide clusters in the study area were mapped based on the hot-spot analysis (Getis-ord Gi*). Landslide hotspots and cold-spots were represented by the z-score and p-values derived from spatial autocorrelation analysis. Using the Getis-ord Gi* statistic, such hotspots were identified using the following algorithm,

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j}x_j - \bar{X}\sum_{j=1}^{n} \mathrm{w_{i,j}}}{S\sqrt{\frac{\left[n\sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j}\right)^2\right]}{n-1}}}$$

Where x_j is the attribute value for feature j, $w_{i,j}$ is the spatial weight between feature i and j, n is the total number of features. $\bar{X}$ and S values were calculated as follows,

$$\bar{X} = \frac{\sum_{j=i}^{n} x_j}{n}$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n}} - (\bar{X})^2$$

4. Results and discussion

The point data inventory was subjected to spatial autocorrelation (Global Moran's I) to determine the significance level of various patterns seen throughout the study area, with the findings displayed in Table 1. The value of the Moran's index (0.055738) is between the desirable range of -1.0 and +1.0, indicating statistically significant patterns. Since the p-value (0.000000) is zero, it means spatial patterns are not an outcome of random process. As a result, the null hypothesis stands rejected. Also, the z-score value (6.807095) that actually represents standard deviation is positive and much higher than +2.5, therefore, it shows a strong presence of landslide clusters. These Moran's index values strongly reject the null hypothesis, indicating the presence of a clustered pattern in the spatial distribution of landslides, making the analysis statistically significant and verifiable.

The incremental spatial autocorrelation results show a peak and having maximum spatial autocorrelation at the distance of 5,747.46 m with corresponding z-score of 14.160882 (Figure 2). Since spatial autocorrelation is high at this distance, this value is deemed as an appropriate distance band for hot-spot analysis tools.

The hot-spots (Getis-ord Gi*) analysis calculated landslide hotspots and cold-spots locations with confidence levels of 90%, 95% and 99% (Figure 3) along with nonsignificant GN divisions in the Kandy District. The resulting hotspot map (Figure 3) shows landslide hotspots (red clusters) have a high degree of confidence and are statistically significant, whereas cold spots (blue clusters) reveal a distributed pattern of landslide incidence. The rest of the area has a random distribution of landslides. Four main landslide hotspots can be observed in resulting hotspot map and 64 GN divisions (out of the 1195 GN divisions of Kandy District) included to these hotspots with 99% confidence and belong to seven different DS divisions in Kandy District (Table 2). They are represented as rectangular areas and named according to the main DSD which mainly the high significant areas included: HS1-GIK, HS2-DOL, HS3-PAN and HS4-UDU (Figure 3).

Hotspot HS1-GIK lies in the *Ganga Ihala Korale* DSD and extended over 61.8 km^2, is intensively affected by slope instabilities. This hotspot is located mainly on granitic gneiss basement and undifferentiated charnokitic gneiss, hornblend biotite gneiss, garnet biotite silimanite gneiss (khondalite), and quartzites present bed rock areas. Failures in granitic rock are more abundant during the advanced stages of decomposition (Osanai *et al.,* 2016). Therefore, landslides are most common in the humid tropics such as this region, where intense chemical weathering occurs. HS2-

DOL lies dominantly in *Doluwa* DSD and partially, toward the east *Delthota* DSD and toward west *Udapalatha* DSD. This high significant area extended over 83.7 km^2. Charnokitic gneiss, garnet biotite silimanite gneiss (khondalite), and quartzites are the main lithologies of the area. GN divisions of *Delthota* DSD having relatively large population density (average: 812 km^{-2}) and anthropogenic activities also impact the occurrence of landslides of this area. HS3-PAN lies mainly on *Panvila* DSD and one GN division encompass to the *Mada Dumbara* DSD. This area covers 43.6 km^2 and mainly consist with charnokitic gneiss, and quartzites. HS4-UDU also contain one GN division from *Mada Dumbara* DSD while other GN divisions lies on *Udadumbara* DSD. This hotspot extended over 66.2 km^2 and main lithologies are charnokitic gneiss, garnet biotite silimanite gneiss (khondalite) and quartzites.

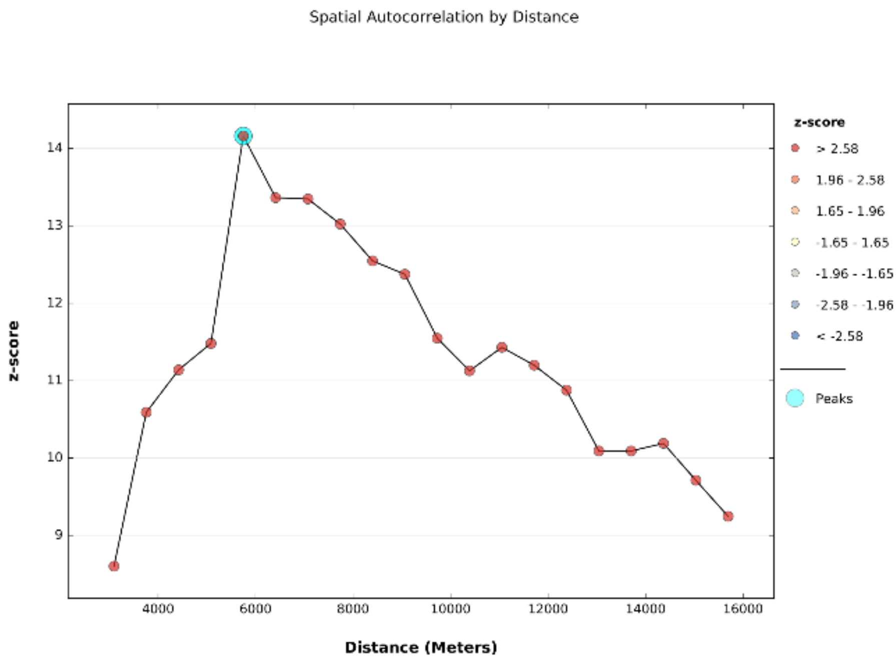

Figure 2: Spatial autocorrelation by distance (spatial autocorrelation (Global Moran's I) to determine the significance level of various patterns seen throughout the study area)

Table 1: Results of spatial autocorrelation

Moran's Index	Expected Index	Variance	z-score	p-score
0.055738	-0.000838	0.000069	6.807095	0.000000

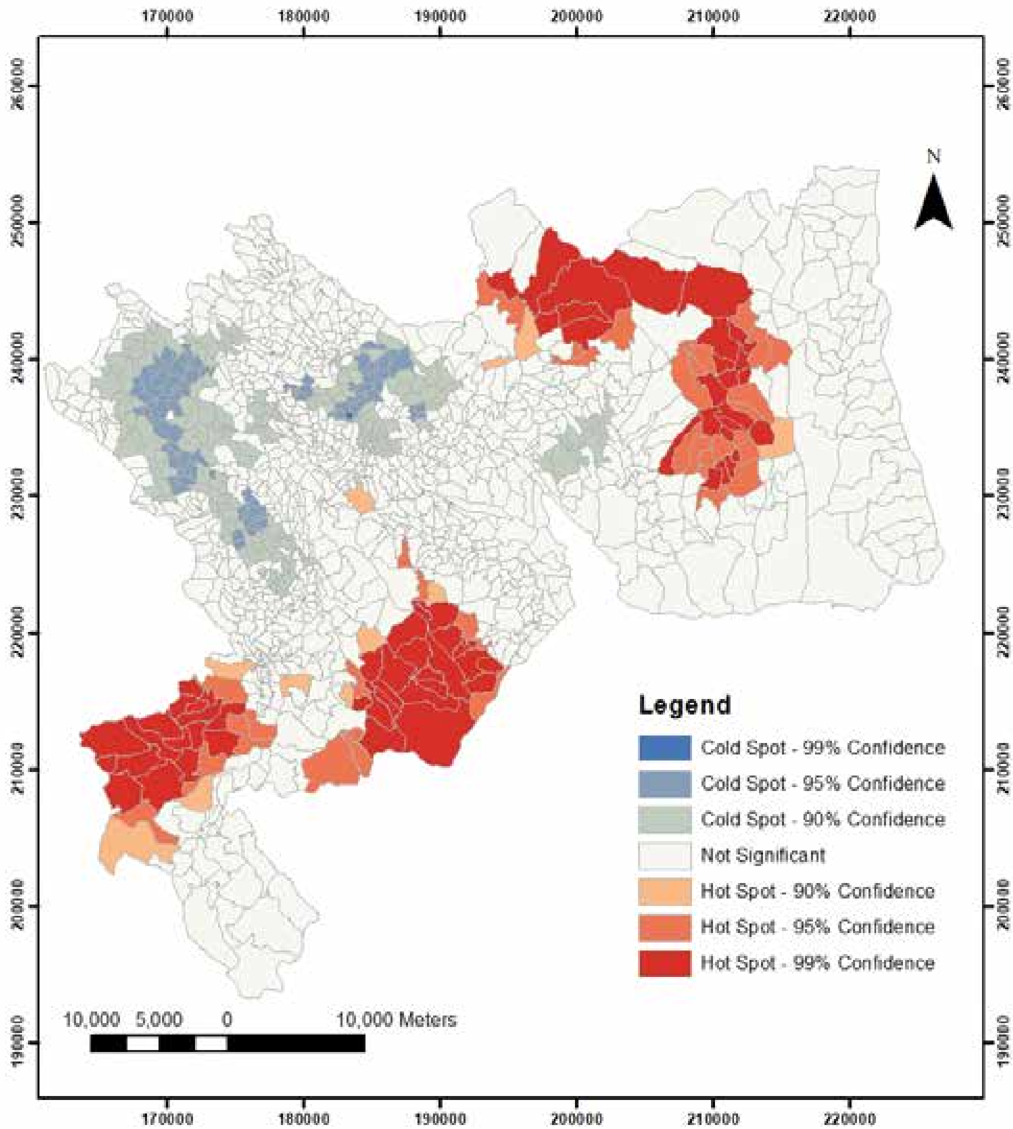

Figure 3: Landslide hot-spot map of the area, (Getis-ord Gi*) analysis calculated landslide hotspots and cold-spots locations with confidence levels of 90%, 95% and 99%

Table 2: Details of GN divisions included in resulted hotspot areas

No.	DSD	GN	Area (km^2)	Population	Population Density (km^{-2})
1	Ganga Ihala Korale	Patithalawa	9.31	1906	205
2		Yatapana	2.11	1120	532
3		Mallwattagama	2.89	2318	802
4		Kohowala	1.79	1151	644
5		Alugolla	5.17	1578	305
6		Kelly Group	1.44	580	403
7		Watakedeniya	4.28	1817	425
8		Gamunupura	1.80	1164	645
9		Udahenthenna	3.34	1748	523
10		Uduwella	4.22	1348	319

11		Pellapitiya South	4.34	1529	353
12		Giraulla	1.09	1317	1211
13		Polmalagama	0.91	845	925
14		Rakshawa	8.02	2369	295
15		Pellapitiya North	2.96	1926	650
16		Miyanagolla	6.05	1707	282
17		Karagala	2.05	1151	561
18	Doluwa	Hunugala	4.91	1397	285
19		Thumpelawaka	4.08	796	195
20		Masgolla	5.58	1687	302
21		Rajathalawa	1.64	990	603
22		Ududeniya	1.79	872	487
23		Palledelthota	5.05	2697	534
24		Pupuressa	19.40	4742	244
25		Mulgama	1.60	769	479
26		Pitawala	6.58	1213	184
27		Panvilathenna	3.13	1055	337
28	Udapalatha	Wanahapuwa	1.45	657	453
29		Pussellawa	6.20	5852	943
30		Ihalagama	1.24	1530	1230
31		Dunukeulla	3.31	1934	584
32	Madadumbara	Thunisgala	5.59	800	143
33		Mangoda	3.28	850	260
34	Udadumbara	Udadumbara	1.11	526	476
35		Rambukwella West	1.05	212	202
36		Udawela	1.47	429	291
37		Kirigankumbura	2.60	585	225
38		Moonamalpelessa	2.21	316	143
39		Pallewela	1.30	476	367
40		Hanwelle	1.70	230	135
41		Kevulgama	1.88	275	146
42		Andideniya	1.03	440	427
43		Kumbukgolla	15.02	247	16
44		Nawanagala	2.66	384	145
45		Karandagolla	0.53	162	304
46		Rambukwella East	0.98	279	284
47		Pallekanda	3.12	212	68
48		Gangoda	2.72	419	154
49		Pusseela	17.01	272	16
50		Halyala	0.83	335	403
51		Gerandigala	5.72	377	66
52	Delthota	Suduwella	3.36	2498	742
53		Karagaskada South	0.36	1311	3672
54		Gonangoda	3.45	2187	633
55		Pattiyagama Gabadama North	2.80	1116	399
56		Pattiyagama Udagama	1.76	512	291
57		Karagaskada North	0.85	1362	1601
58		Galaha	0.91	1873	2064
59		Udadelthota	4.22	3516	832
60	Panwila	Mahapathana	3.08	2305	748
61		Kosgama	11.27	2483	220
62		Thawalanthenna	17.06	2736	160
63		Beddegama	2.44	878	359
64		Gomaraya	4.20	1047	250

5. Conclusion and recommendations

Four main landslide hotspots associate with 64 GN divisions in Kandy District were recognized. This study confirmed that a strong correlation exists between the frequency of occurrence of landslides and main rainfall seasons.

These results imply that the GIS and event-based analyses on the spatial and temporal distribution of landslides provide valuable information with less effort and time consumption in landslide studies. Therefore, NBRO and Disaster Management-related Institutes can deliver their quality and speed landslide risk management services, especially focusing on the vulnerable places with limited resource allocations during the disaster period.

This approach should be more developed in the future especially, regarding the importance of understanding geomorphometric characteristics of the area in creating a disaster risk reduction plan.

The accuracy and prediction ability of the landslide hotspots map offers crucial information for city planning, infrastructure construction and agriculture developments in the future or in other areas with similar conditions.

Therefore, it is concluded that landslide hotspots map could be successfully used in decision making of slope remedial measures, regional planning and hazard mitigation policy making.

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Building Resilience amidst Economic Challenges

Statistical evaluation of selective causative factors on landslide occurrences - A case study in Kandy District

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Abstract

Kandy District in the Central Highlands faces severe effects of landslides with the increasing population and its inherent topography. The frequency and density of occurrence of landslides have increased significantly owing to malpractices in development activities and negligence of causative factors. Landslides and their occurrence are controlled by physical laws that can be analysed empirically, statistically, or deterministically. This research, analyses the relationship between geo-morphometric characteristics and landslide events in order to further comprehend terrain characteristics bearing susceptibility to landslides and to provide basic information on the landslide risk management program.

In this study, landslide inventory was compiled using a total of 475 landslide records which were collected by NBRO from 2014 to 2020. The behaviour of five different morphological factors (elevation, slope, slope aspect, slope angle, and curvature) of past landslides were analysed. Landslide causative factors, slope map, slope aspect map, and curvature map were obtained by ArcMap 10.8 software using SRTM GL1 DEM of Advanced Land Observing Satellite (ALOS), and Alaska Satellite Facility (ASF). Spatial analysis reveals geomorphometric characteristics have the most significant relationship between landslide events. A total of 475 landslide events are unevenly distributed in all DSDs, especially in the hilly and mountainous region. Each of them falls under the typology of slides (20.2%), slope failures (60.6%), and rockfalls (18.3%). The occurrence of landslides shows a strong correlation between the frequency of landslides and main rainfall seasons. Landslide occurrence coincides mostly with an elevation of 500-600 m, with slope angles of 20^0 - 40^0, an east-to-west slope aspect, and a slope with flat and concave curvature.

Keywords: Causative factors, Landslide, Spatial analysis

1. Introduction

Landslides have been proven to result in loss of life and destruction of property including infrastructure and lifeline facilities. Landslides have become a major concern in the hilly regions of Sri Lanka as the demand for the development and expansion of human settlements grows. An area affected by a landslide should undergo rehabilitation which involves massive capital expenditure and can seriously affect a developing country like Sri Lanka. A landslide is seldom attributed to a single causative factor (Terzaghi 1950). Although the causes of landslides are wide-ranging, we can broadly categorize them as natural and anthropogenic factors (Yao *et al.*, 2008). Natural factors include climate, earthquakes and volcanoes, weathering and erosion and forest fires, whereas deforestation, mining, haphazard development activities, bad agricultural and construction practices and poor drainage conditions are the inducing anthropogenic factors (Hamza and Raghuvanshi, 2017). It is of fundamental importance to identify causative factors for landslide occurrences in a region.

In statistical methods, landslide causal factors or parameters are derived and combined with the landslide inventories to predict the future occurrence of landslides (Carrara *et al.*, 1991). All statistical methods were based on the common assumption that ‘‘the past and the present are the key to the future’’ (Carrara et al., 1995). Thus, the probability of a landslide occurring within a landslide-free area was determined by comparing the geo-environmental characteristics of these areas with those in areas where landslides have occurred.

This study, mainly focused on developing a suitable predicting model using predictive analysis data mining techniques by combining the most prominent and rapidly varying causative factors, slope angle, slope aspect, elevation, land use and land overburden and triggering factor rainfall data. This can enhance the efficiency of resource utilization to detect vulnerable slopes, slope directions and rainfall seasons to improve the exploration of new low-cost means of future landslide prediction. One other important objective is to identify the most influential causative factors for landslides in the study area so that more attention of future studies can focus on them.

2. Study area

The study was carried out in Kandy District, which is situated within the Central Province of Sri Lanka. Kandy District has an area of 1,940 km^2 (Department of Census and Statistics, 2011). The Central Highland comprises many multifaceted topographical features such as valleys, plains, ridges, peaks, plateaus, basins and escarpments. The orographic barriers and complex topographical features are highly affected by the seasonal rainfall variations in the Kandy District. The northeast and southwest monsoons bring heavy rainfall to this area from December to late February and May to September, respectively. The mean annual rainfall varies from 2000 mm in the driest parts (eastern part of the district) to over 5000 mm in the wettest parts (southwestern slope of the district) (Meegahakotuwa and Nianthi, 2018). Depressional rain also occurs during the inter-monsoonal periods, particularly during the second inter-monsoon October to November (Meegahakotuwa and Nianthi, 2018).

The soil map of Panabokke, (1988) indicates that the main soil types in the Kandy District are reddish brown lateritic, regosols and alluvial soil, immature brown loams and red-yellow podzoilc soils.

Figure 1: Map of the study area

3. Materials and methodology

Landslide inventory

In this study, landslide inventory was compiled using a total of 475 landslide records which were collected by NBRO from 2014 to 2018. Landslides in the study area include rock slides, rock falls, rotational and translational slides, debris flow and slope failures. The behaviour of five different morphological factors (elevation, slope, slope aspect, slope angle, and curvature) of past landslides was analysed in this study and to analyse these landslide causative factors slope map, slope aspect map, and curvature map were obtained by ArcMap 10.8 software using SRTM GL1 DEM of Advanced Land Observing Satellite (ALOS), Alaska Satellite Facility (ASF) which has 30 m spatial resolution. The elevation map was prepared using DEM ranges from 100 m to 1,300 m and it was reclassified into thirteen classes of heights at intervals of 100 m (Figure 2). The slope aspect was classified into eight classes as North East (NE), East (E), South East (SE), South (S), South West (SW), West (W), North West (NW) and North (N). Slope angles of the study area were classified into twelve classes. General curvature, profile curvature and plan curvature were also generated using Arc Map (version 10.8) software.

Rainfall data obtained from the Meteorological Department and NBRO rain gauges were converted to point data. These spatial data were analysed using the IDW function in ArcMap 10.8 and the rainfall intensity map was prepared. Two -dimensional IDW scheme for a new unknown (interpolated) value Z (s_i^*) at a new location s_i^* is given by,

$$Z\,(s_i^*) = \sum_{k=1}^{m} w(r_{ik}) Z(s_k), \quad s_i^*, s_k \in R$$

Where, Z (s_k) is the observed values at locations s_k, The weight function is defined as $w(r_{ik}) = \frac{\hat{w}(r_{ik})}{\sum \hat{w}(r_{ik})}$, where $\hat{w}(r_{ik}) = 1/r_{ik}^{\beta}$ and $r_{ik} = | s_i^* - s_k |$. (The distance between locations s_i^* and s_k). Note that m k=1 $w(r_{ik}) = 1$. β is an important (distance-decay) parameter for IDW interpolation, and the optimal value β is dependent on the distribution of interest field (Ryu *et al.*, 2021).

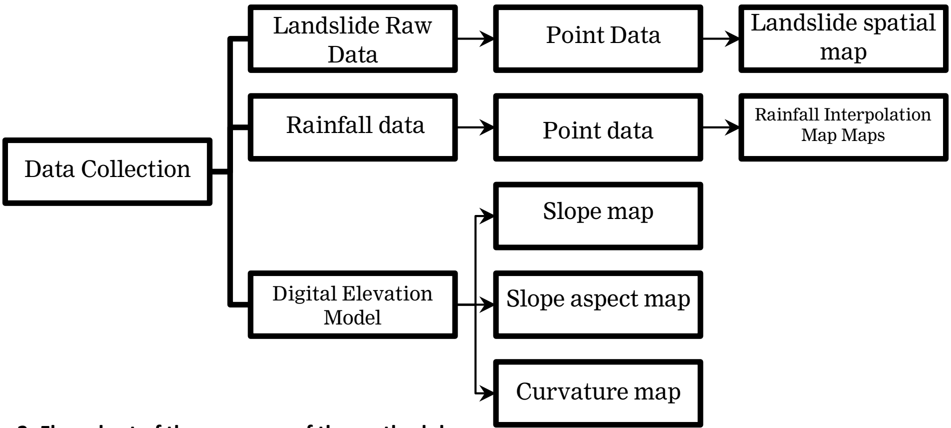
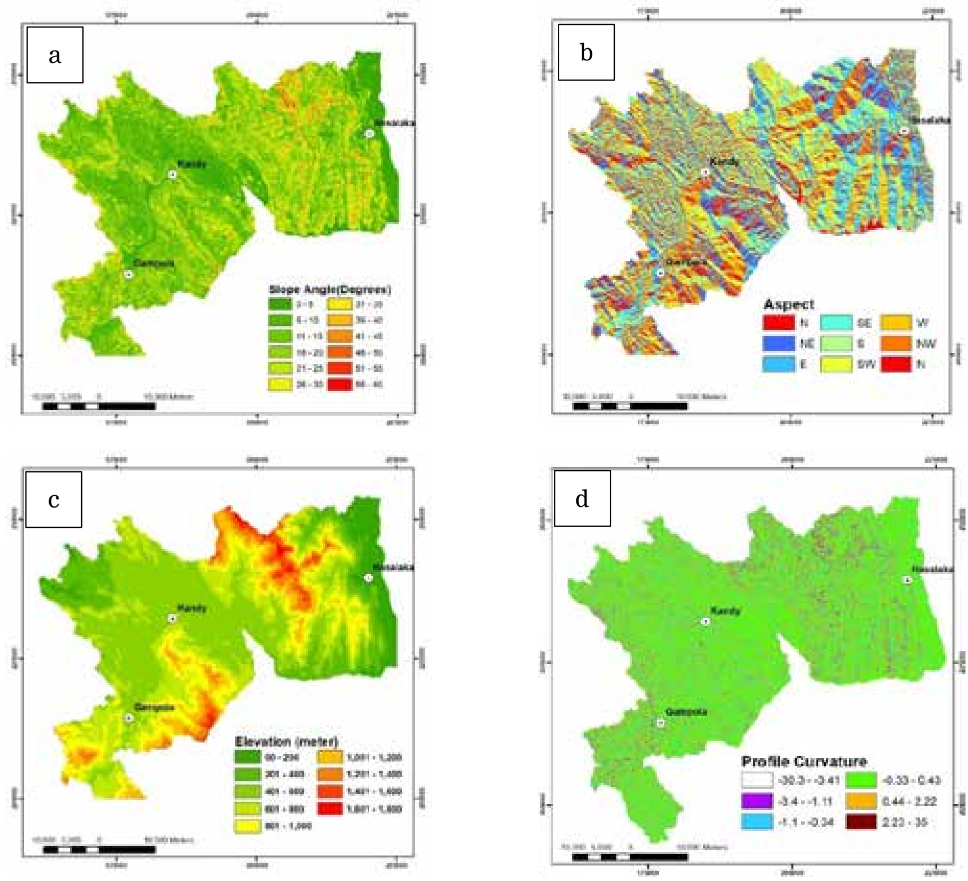


Figure 2: Flow chart of the summary of the methodology



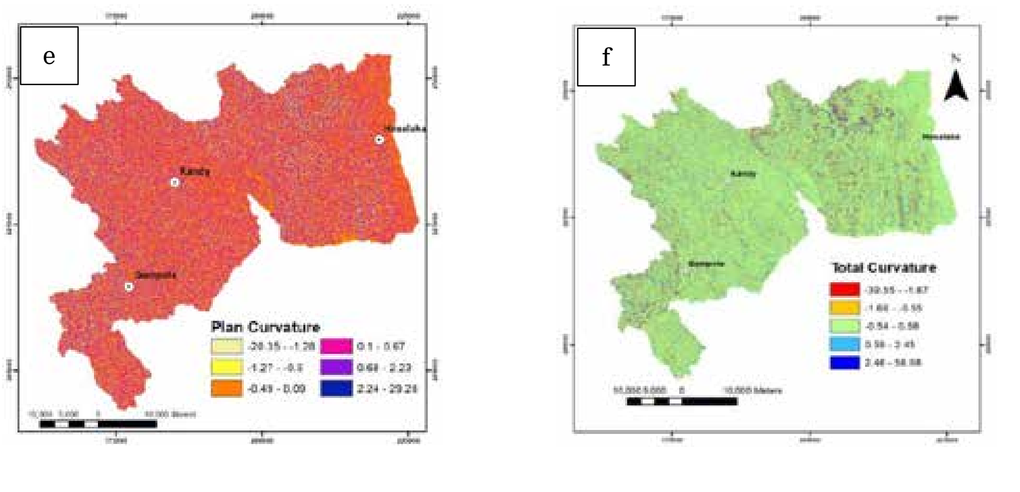


Figure 3: (a) Slope angle map, (b) Slope aspect map, (c) Elevation map (d) Profile curvature map, (e) Plan curvature map, (f) Total curvature map

4. Results and discussion

4.1. Spatial distribution of landslides

Spatial analysis is conducted to comprehend the landslide distribution in the study area (Figure: 10). A total of 475 landslide events are unevenly distributed in all DSDs, especially in the hilly and mountainous region. Each of them falls under the typology of slides (20.2%), slope failures (60.6%), and rockfalls (18.3%).

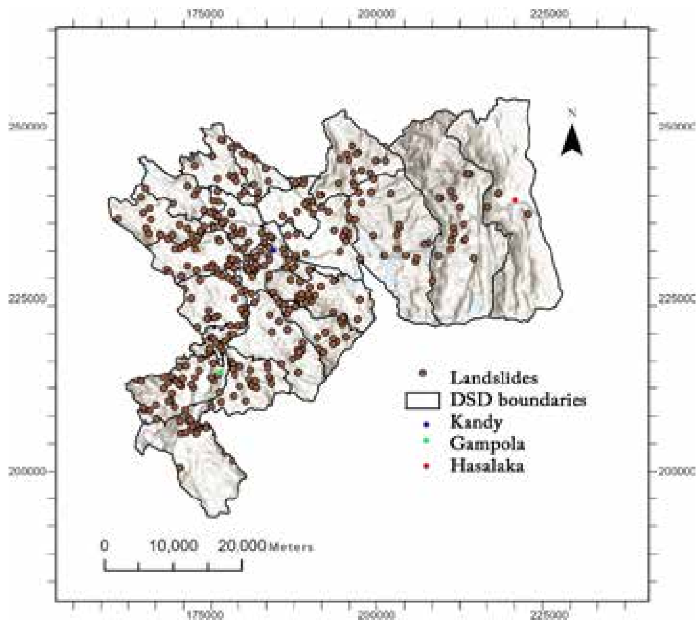


Figure 4: Spatial distributions of landslides in Kandy District

4.2. Rainfall

In the rainfall calendar of Sri Lanka, four distinct periods have been recognized. They are First Inter Monsoon (FIM), South West monsoon (SWM), Second Inter Monsoon (SIM), and North East Monsoon (NEM) (Meegahakotuwa and Nianthi, 2018. SWM period occurs from May to September when depressions and cyclonic wind circulations activate in the low and mid-troposphere of the atmosphere. The southwestern windward side of the Central Highland received the highest rainfall while the eastern leeward side received the lowest rain during the SWM season (Fig. 4). Out of four rainfall seasons, the spatial variation is high in Kandy District mostly during the SWM period. Orography also controls the rainfall distribution in Sri Lanka during this period. When winds originate in the southwest side of Sri Lanka, it brings a large amount of moisture from the Indian ocean. Equatorial westerlies are also activated during this time. When these winds encounter slopes of the Central Highlands, they transport heavy rains onto the mountain slopes and the southwestern sector of the island.

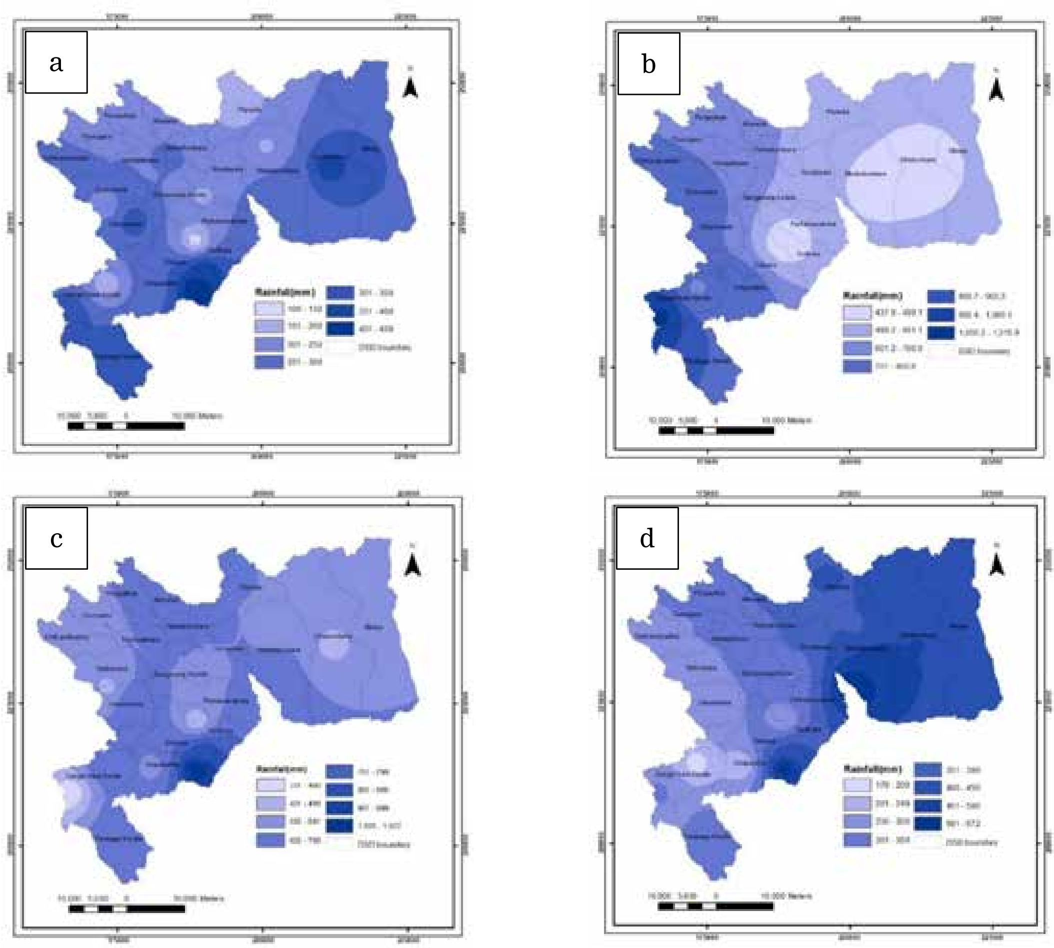


Figure 5: Variations of rainfall during four main rainfall seasons in the Kandy District (a: FIM season, b: SWM season, c: SIM season. d.NEM season)

The SIM period is the period with the most evenly distributed rainfall over Sri Lanka and this characteristic clearly shows in the Kandy District. According to Jeydarushan, 2012 convection, cyclonic wind circulation, and convergence activity make the rainfall widespread due to Inter Tropical Convergence Zone (ITCZ) migrating over Sri Lanka during this period. The tropical depression has the highest frequency during this time. Almost the entire district receives more than 330 mm of rain during this season, with the southwestern slopes receiving higher rainfall in the range of 1,000 mm to 1,100 mm.

The highest rainfall was recorded in the eastern side of the Kandy District during the NEM and the highest rainfall is recorded in and around Victoria rain gauge station (526.5 mm) during this season and the Kuruduwaththa rain gauge (178.21 mm) area received a lower rainfall in the NEM season. NEM occurs from December to February. Monsoon winds come from the north-eastern side, bringing moisture from the Bay of Bengal. Therefore, during the NEM period, the highest rainfall amounts are recorded in the north-eastern slopes of the Central Hills. According to Rekha, 2005, orographic effect of the Central Highlands of Sri Lanka is similar with the global figures of the orographic rainfall in the tropical mountains and highlands. Therefore, considerable spatial differentiation of the rainfall is to be expected in the SWM as well as in the NEM season. As a result of the effects of the Central Highlands, which form an orographic barrier across the path of the monsoonal air masses and winds.

The records of landslides are high in the months of May, and June, and once again from October to January, indicating a clear relationship with monsoon seasons respectively (Figure 6). This confirmed that rainfall is a major causative factor of landslides in the area. The low amount of recorded landslides in the period of February to April and July to September, reflects relatively dry conditions in the area. These results confirm Rathnaweera *et al.*, 2013 that landslide events have mainly followed the path of two monsoons in Sri Lanka. Although the rainfall intensity may be the same in different regions, landslides may or may not occur according to the geological and topographical characteristics.

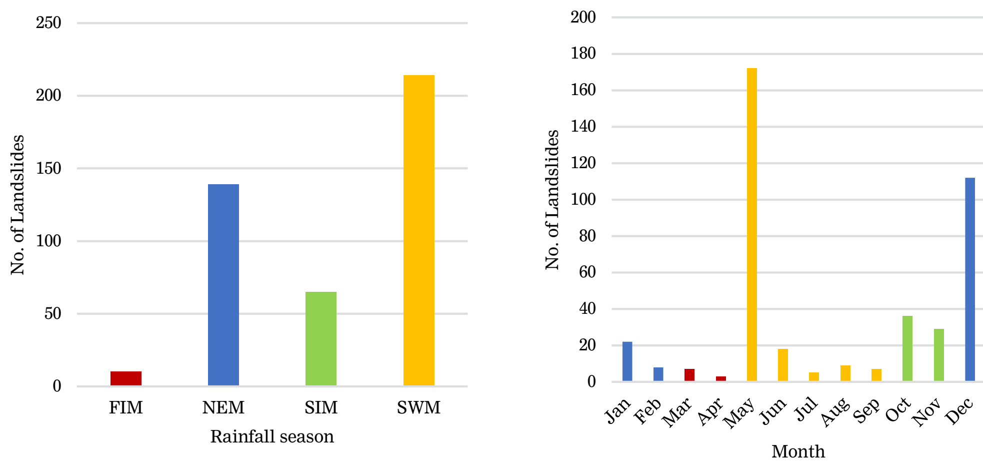


Figure 6: Recorded number of landslides with rainfall seasons and months

4.3. Geomorphometric characteristics

4.3.1. Elevation

Figure 7 shows the results of analysis that explore the relationship between the elevation and landslide occurrence and it shows that landslides are unevenly distributed from an elevation of 100-1,300 m above sea level. It could be seen that the frequency of landslides is less than 10 percent (5.56%) at an elevation of less than 400 m due to the gentle terrain characteristics. At the intermediate elevation (401-500 m), the frequency of landslide occurrences is tending to increase. These results confirm the idea of Cooray, 1984 that "Generally, landslides occur in lands over 300 m above mean sea level of Sri Lanka". As expected, with increasing elevation, the number of occurrences of landslides decreases. It is worth pointing out that for elevation greater than 600 m, the areal extent of land is low and therefore the frequency of landslide occurrences is also lower. At higher elevations of more than 1,110 m, landslide occurrence is very low due to the shallow colluvial materials limit slide occurrences. Also, many researchers reveal that occurrence of landslides is low for higher elevations due to the presence of bedrock resistant to weathering processes (Pourghasemi *et al.*, 2012; Zare *et al.*, 2013). The variation in elevation may be related to different environmental settings such as vegetation types and rainfall. Further studies should be focused on this matter.

4.3.2. Slope angle

The correlation analysis between landslide occurrence and slope angle is shown in Figure 8. The slope values in the study area range between 0° and 50°. Slope angle is typically considered to be one of the influential factors for landslide modelling because it controls the shear forces acting on hill slopes. These results confirm the positive role of an increase in the slope in landslide occurrence. The shear stress of soil and rock increases with the increasing slope angle. It could be observed that gentle slopes have a low landslide frequency because of the lower shear stress at the slope angles 0–10°. It is obvious that the landslide frequency increases for slope angles 20–25°. Followed by this an increase in landslide occurrences at < 40° slope category was observed. A sharp drop is seen in landslide intensity when the slope reaches 40°. According to Jaafari *et al.*, 2014, high slopes comprising durable rocks rather than weathered materials in the nature of ground, these types of slopes comprising are stable. Therefore, landslides are rarely found in a slope inclination of more than 40^0 due to the low amount of colluvium and weathered materials, which imply the absence of materials for landslide generation.

4.3.3. Slope aspect

The steepness and the direction of slope can be clear variables that affect landslides. It mainly depended upon the duration and intensity of sunlight on slopes, the amount of precipitation received and soil moisture retaining capacity, where all the factors have a strong correlation with vegetation cover and landslides. The slope aspect is related to the general physiographic trend of the area and the main precipitation direction.

Land sliding within the Kandy District is most common on east, southwest, or northeast-facing slopes (Figure 9). The hill slopes facing southwest are most susceptible to land sliding and, secondly, those facing east and northeast. The microclimate of slopes with different orientations shows regular differences. The south-facing slopes have high sunlight exposure and receive ample precipitation from the southwest monsoon in May to September. The sunlit slope has higher temperature and precipitation, the physical and chemical weathering rate is high. Therefore, faster forming a thicker soil layer may ensure the material source of landslide formation.

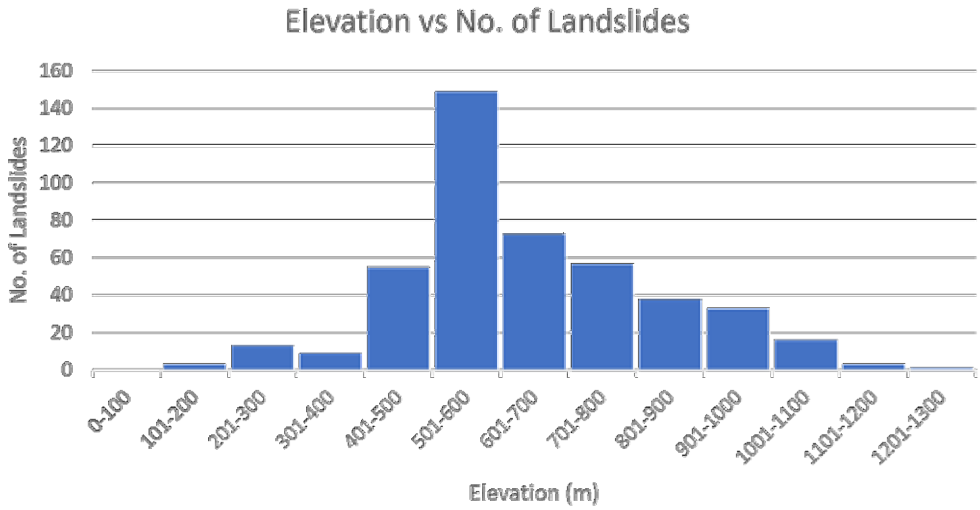


Figure 7: The elevation and landslide occurrence

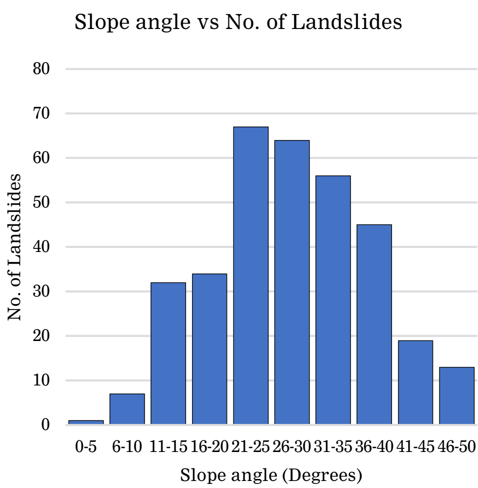


Figure 9: Number of landslides with slope angles

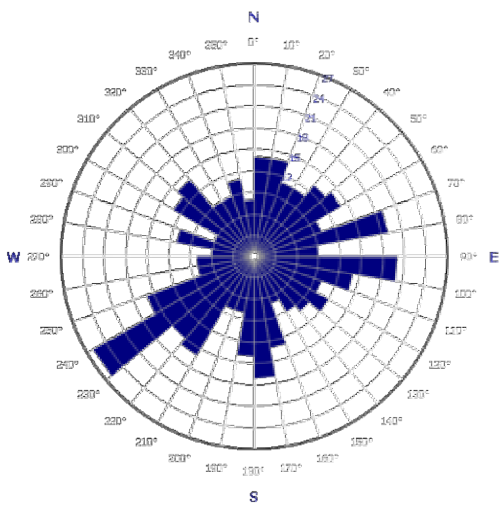


Figure 8: Landslides occurrence with slope aspect

Thus, south-facing slopes have a high tendency for landslide occurrence. Compared with the shaded slope, the vegetation coverage of the sunlit slope is low, and most of it consists of shrubs and herbs. The influence of shallow roots on the stability of the landslide on the sunlit slope is significantly weaker than that of the vertical roots of trees on the shaded slope. The influence of vegetation on slope stability is bidirectional, and it has adverse effects on the development of deep landslides, while vegetation can restrain the development of shallow landslides.

The slope aspect also influences carbon (C) uptake rates by altering soil moisture, temperature, and incoming light intensity (Eamus, 2003). The continuous alternation of wet and dry on a sunlit slope can easily form the macropore system in the unsaturated zones of the slopes, which is conducive to the rapid infiltration of precipitation, thus is unfavourable to slope stability. The dominant east-to-west direction of a slope aspect provides more affinity to landslide occurrence. The existence of more exposed weathered material is the basic reason for landslide formation in the east -west direction (Akgun *et al.*, 2010).

4.3.4. Curvature

Slope curvature exhibits two extreme values having positive and negative values. When considering the whole study area plan curvature ranges from -20.35 to 28.25 (Figure 10), profile curvature ranges from -30.30 to 35.00 (Figure 11) and total curvature ranges from -39.55 to 56.00 (Figure 10). The extracted values from previous landslide locations lie on ranges of plan curvature from -2.5 to +2.5 (Figure 10), while the profile curvature and the total curvature ranges from -4 to +4. Plan curvatures between -0.25 to 0.25 shows the highest number of landslide occurrences while next, the majority rest in more negative values. The results show that hillsides with relatively planar surfaces have the highest probability of landslides and that areas with concave curvature have a slightly higher probability than areas with convex curvatures. According to Anderson and Burt, 1978 groundwater flow does converge within an area of concave plan curvature and increasing pore water pressure and a subsequent lowering of shear strength may increase the probability of landslide initiation. Profile curvature between -0.25 to 0.25 also shows the highest number of landslide occurrences while positive values show relatively little more probability than negative values of profile curvature.

According to results planner surfaces are the most favourable to initiate landslides and further concave slopes are relatively more favourable than upwardly convex slopes. Profile curvature affects the driving and resisting stresses within a landslide in the direction of motion.

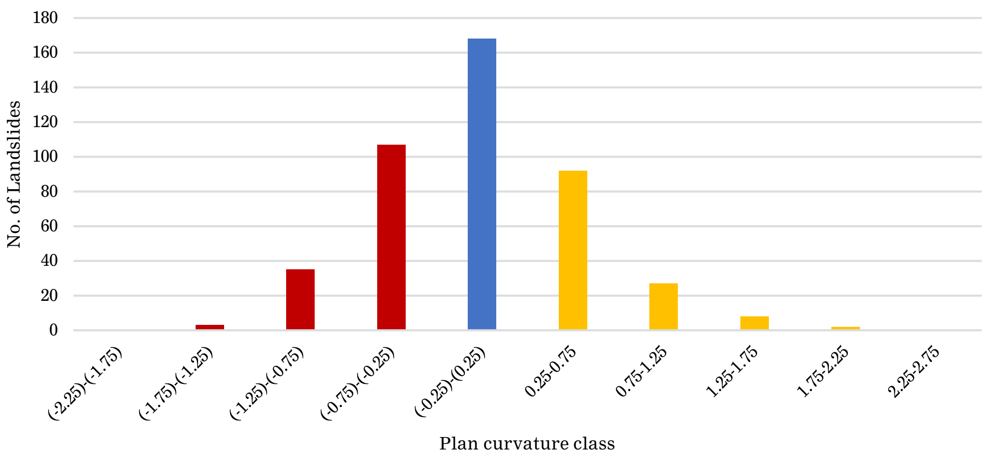


Figure 10: Occurrence of landslides with plan curvature classes

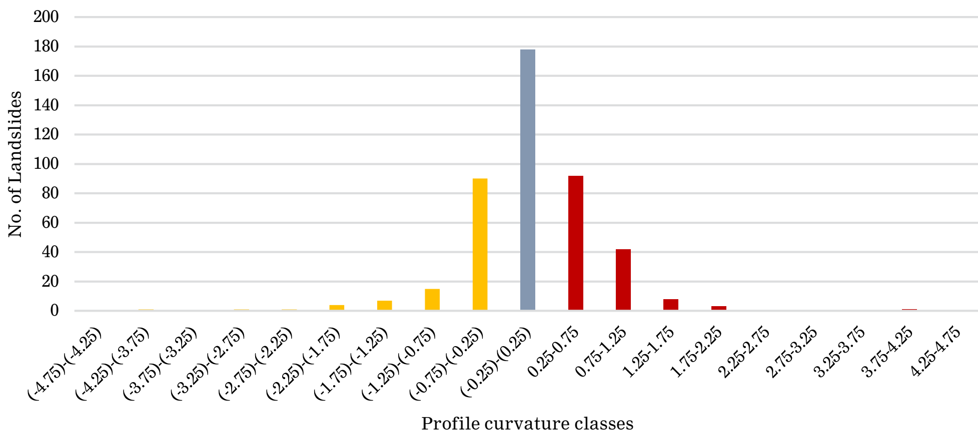


Figure 11: Occurrence of landslides with profile curvature classes

The highest percentage of recorded landslides were located on slopes with general curvature or total curvature of range -0.25 to 0.25. It means slopes with relatively flat surfaces are most favourable to initiate landslides. Negative values of total curvature are more dominant than positive values and it shows that concave surfaces (indicating valleys) are more favourable than convex surfaces (indicating peaks) to initiate a landslide.

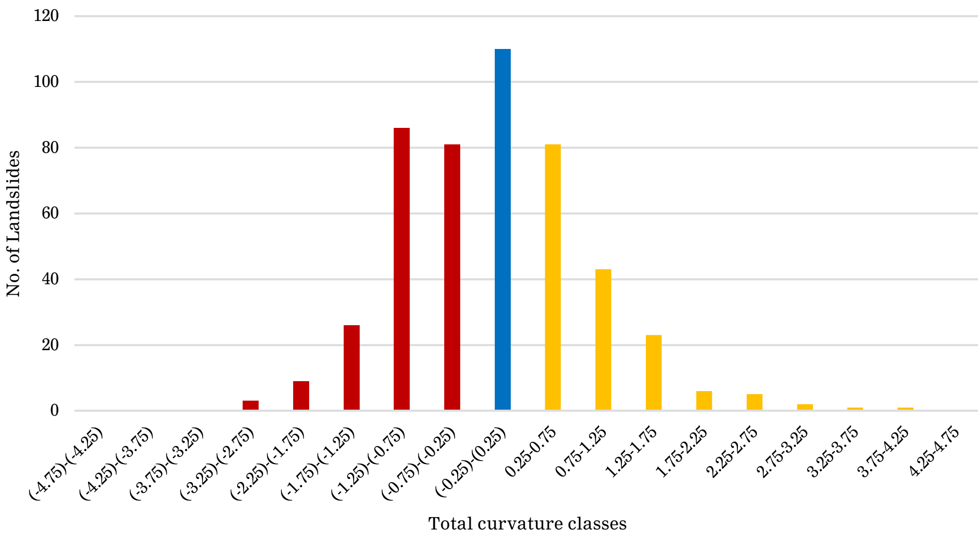


Figure 12: Occurrence of landslides with total curvature classes

5. Conclusion

This study confirmed that a strong correlation exists between the frequency of landslides with geographic factors of the Kandy region associated with the southwest monsoon period, especially in the month of May.

It was concluded that elevation, slope angle and slope aspect, have a significant relationship with the landslide distribution in Kandy District.

Landslide occurrence in Kandy District coincides mostly with an elevation of 500-600 m, with slope angles of 20^0 - 40^0, an east-to-west slope aspect, and a slope with flat and concave curvature.

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Building Resilience amidst
Economic Challenges

Kinematic analysis of rock cut slope failures and its progression to landslides - A case study from Durekkanda landslide

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Abstract

Ratnapura is identified as a critical district for landslide, slope failure, rock fall, and cut slope failure hazards due to inherent terrain factors and intense rainfall. Recent modifications made to natural slopes frequently cause dominant slope instabilities leading to landslides. Therefore, in every heavy rainfall event, over 80% of the cut-slope failure are reported. The stability of natural and man-made rock slopes (e.g., open pit benches, road cuts, dam abutments, rock quarry walls, and tunnel portals) has always been of great concern for engineering geological studies. Rocks as a natural engineering material in these slopes exhibit considerable variations in strength and deformability both spatially and inherently.

This case study was done to identify the impact of the Geological setting on the initiation and progression of cut slope failure in Durekkanda using kinematic analyses and use this method for future landscaping as a model to minimize other rock cut slope failures. The affected slope section is located between culverts 11/3 and 11/5 of Ratnapura Wewalwatta B391 Road at Durekkanda. Here, the first failure occurred in 2015 as a rock cut slope failure and in 2016 it further developed along its two flanks with dimensions of nearly 20-40 m in length. However, in 2017 it progressed as a massive landslide and fully obstructed the Ratnapura-Wewalwatta Road.

According to the analysis, there is a 25% possibility of planar sliding, 50% of wedge sliding, 33.33% of direct toppling (intersection) and 25% of direct toppling (base plane). However, flexural toppling was not obvious.

By kinematic analysis along the cut slope face, it was revealed that vulnerability for planar sliding, wedge sliding and direct toppling is comparatively higher than surrounding where the fault plane creates more intersections with other discontinuities. Also, development of the massive secondary landslide has also followed the axis of the fault as a result of critical structural geological settings.

Keywords: Kinematic analysis, Intersection, Cut-slope failure, Durekkanda landslide

1. Introduction

The stability of natural and man-made rock slopes such as open pit benches, road cuts, dam abutments, and tunnel portals has always been of great concern for geology studies. The majority of rock masses can be considered assemblages of intact rock blocks delineated in three dimensions by a system of discontinuities. These discontinuities can occur as unique randomly oriented features or as repeating members of a discontinuity set. This system of structural discontinuities is usually referred to as the structural fabric of the rock mass and can consist of bedding surfaces, joints, foliation, or any other natural break in the rock. The advancing of rock cutting failures into massive landslides or slope failures has a direct impact on critical intersections of geological discontinuities.

Figure 1: Drone image of Durekkanda landslide area

In that place, the first failure has occurred in 2015 as a rock cut slope failure. This failure has dimensions of nearly 8m in length and 4m in height. In 2016 it further developed along its two flanks with dimensions of nearly 20-40 m in length. However, in 2017 it progressed as a massive landslide and fully obstructed the Ratnapura-Wewalwatta Road (Figure 2).

Figure 2: Initial rock cut slope failure in 2015 (a) Progressed cut slope failure in 2016 (b) cut slope failure developed into a landslide in 2017 (c) in Durekkanda

Kinematic analysis is often used to investigate and determine the possibility of structurally controlled failures such as plane sliding, wedge sliding, and toppling. Kinematic analysis can be used as a tool to identify the most critical planes and intersections. Secondly, the most stable rock slope face direction as well as cut face angles can be determined to minimize the initiation of hazards.

The planar type of sliding failure in rock slopes usually occurs when a structural discontinuity plane dips toward the slope face at an angle smaller than the slope face angle and greater than the angle of friction of the discontinuity surface (Goodman 1989). The kinematical analysis of wedge sliding is based on the analysis of intersections. The intersection of two planes forms a line in a three-dimensional space. If an intersection point satisfies the frictional and kinematic conditions for sliding, then it represents a risk of wedge failure (Hoek and Bray, 1991).

Direct toppling occurs when individual blocks are formed by a set of discontinuities dipping steeply into the slope face, and the second set of widely spaced cross joints defines the block height (Goodman. 1989). The process of flexural toppling occurs at continuous columns of rock, separated by well-developed, steeply dipping discontinuities, breaking in flexure as they bend forward (Wyllie and Mah, 2004).

2. Objectives

The main objective of this case study is to identify the impact of the Geological setting on the initiation of cut slope failure and its progression into a landslide using kinematic analyses and use this method for future ground modifications as a model to minimize rock cut slope failures.

3. Study area

The studied site falls administratively under the Durekkanda Grama Niladhari (GN) division of Ratnapura Divisional Secretariat Division, Ratnapura District of Sabaragamuwa Province. The affected slope section is located between culverts 11/3 and 11/5 Ratnapura Wewalwatta B391 Road at Durekkanda. Coordinates 6. 712237°N / 80. 459257 °E) (Figure 3)

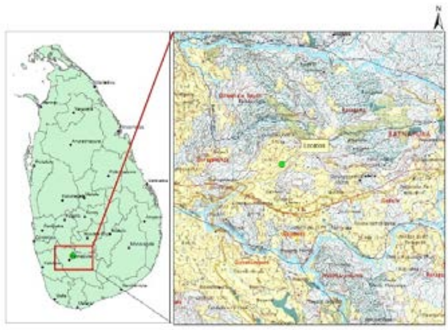

Figure 3: Topography map of area

Figure 4: Sectional view of a fault exposed in a cut slope face closer to the Durekkanda

The studied area consists of ductile as well as brittle deformational structural features such as folds, faults, shear zones, joints, and fractures. Furthermore, Ratnapura – Wewalwatta road (B391) is running through many shear zones, folds, faults, and highly jointed/ fractured bedrock (Figure 04). Thus, most locations were found to be geologically highly deformed areas. These geological structures probably supported most of the failures along this road cut.

With reference to the 1:100,000 geology map of the Geological survey and mines bureau, the location is situated close to the Bambarabotuwa shear zone where the lithology is undifferentiated charnockitic gneiss. Maximum elevation ranges between 800-900 m above mean sea level.

4. Methodology

Kinematic analysis

The kinematic analysis is purely a geometric evaluation of slope to identify the potential for different modes of structurally controlled sliding failures due to unfavorably oriented discontinuities within the rock mass (Hoek and Bray 1991).

Geological orientation of discontinuity such as foliation, joints, and faults was measured by dip direction/dip method using Brunton compass along the road cutting face and major scarp of the failed rock cut slope as well major scarp. Subsequently, kinematic analyses were done for identifying major failure types. After identifying the type of failure, further analysis was done for each phrase to find possible safe directions and angles. Kinematic analysis was performed by using "Rocscience Dips 6.008" software to recognize all the modes of failures with reference to pre-existed slope face dimensions.

In this analysis, clustering was done to minimize the overlapping and intersecting with the same planes. Calculation of the mean of a group of orientations was done using the following steps:

1. Convert all orientations from Dip/Dip Direction format to unit vectors $V_i=(x_i,y_i,z_i)$ using the relationships
   - x_i =sin(Dip)sin(Dip Direction)
   - y_i =sin(Dip)cos(Dip Direction)
   - z_i = cos(Dip)
2. Determine the mean of each component of the unit vectors. For example, the mean x component is calculated as

$$\bar{x}' = \frac{\sum_{i=1}^{N} xi}{N}$$

Where the N is the number of vectors.

3. Normalize the resulting vector so that it has a magnitude of one, i.e. it becomes a unit vector

$$\bar{x}'=\frac{\bar{x}}{\sqrt{(\bar{x})^2+(\bar{y})^2+(\bar{z})^2}},\ \bar{y}'=\frac{\bar{y}}{\sqrt{(\bar{x})^2+(\bar{y})^2+(\bar{z})^2}} \text{ and } \bar{z}'=\frac{\bar{z}}{\sqrt{(\bar{x})^2+(\bar{y})^2+(\bar{z})^2}}$$

4. Convert the normalized mean vector $(\bar{x}', \bar{y}', \bar{z}')$ into Dip/Dip Direction format using the relationships
   - Dip $=\cos^{-1}(\bar{z}')$
   - Dip Direction $=\cos^{-1}[\frac{\bar{y}'}{\sin(Dip)}]$

It was assumed that all discontinuity planes have a frictional angle of 30 degrees. However, the reality may slightly vary according to the interaction between surfaces. The friction angles were taken as 38^0 for fresh rock, 33^0 for slightly weathered rock and 24^0 for moderately weathered rock. (Premasiri et al., 2016) Once weathering conditions increase friction angles decrease.

5. Results and discussion

This area comprises moderately to highly weathered bedrock with two major sets of joint planes, foliation, and a normal fault. The fault plane has displaced nearly 12 cm relative to the other wall. This fault plane is going along the axis of the landslide. Along the fault plane, groundwater flowing can be observed. Foliation planes dip into the slope and the joint set 01 dipping towards the cut slope direction. Interfaces in joint set 01 contain a 10 to 20 mm yellowish-brown clay layer.

Table 1: Orientation of discontinuity planes (Clustered)

No	Intersection	Dip	Dip Direction
1	Joint 01	68	170
2	Foliation(F)	42	341
3	Joint 02	85	051
4	Fault	90	097

Table 2: Intersection of discontinuity planes

No	Intersection	Trend	Plunge
1	Fault-J2	005	80
2	Fault-F	010	38
3	F-J2	326	42
4	Fault-J1	189	66
5	J1-J2	130	62

Stereonet kinematic analysis was done to cluster data plane to identify which type of failures are to be possible in before the failure occurred. For this analysis cut rock slope angle was taken as 70^0 and rock slope direction was taken as 170^0.

According to the analysis, planar sliding, wedge sliding and Direct toppling were possible along the cut rock slope face but in given slope direction and slope angles flexural toppling were not occurring. The results indicate that 25% possibility of planar sliding, 50% of wedge sliding, 33.33% of direct toppling (intersection) and 25% of direct toppling (base plane).

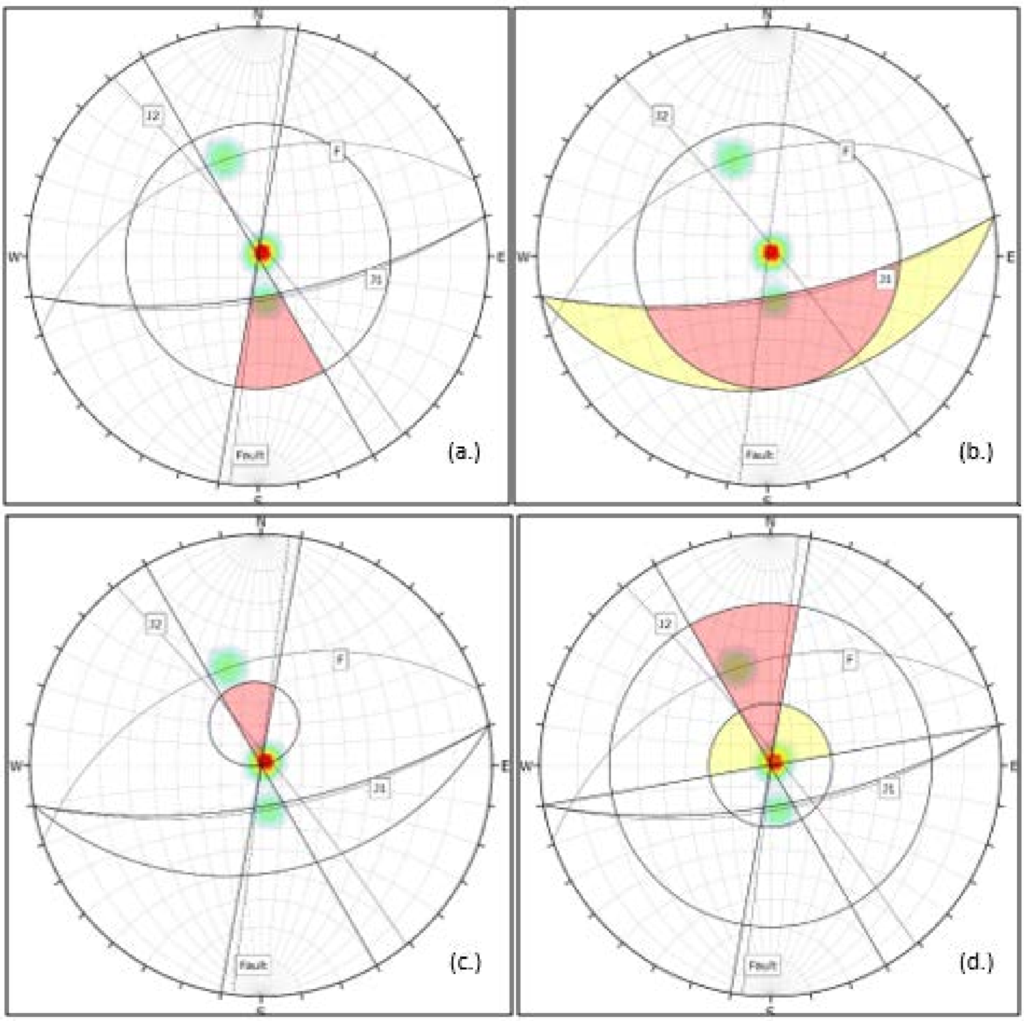

Figure 5: Possible failure (a)Planer sliding;(b) Wedge sliding;(c) Flexural toppling;(d) Direct toppling

Table 3: Stereographic Interpretation of critical planes and intersection for possible failures

Possible failure mode		Critical	Total	%
Planar Sliding (a)		1	4	25.00
Wedge Sliding (b)		3	6	50.00
Flexural Toppling (c)		0	4	0.00
Direct toppling (d)	Direct toppling (Intersection)	2	6	33.33
	Oblique toppling (Intersection)	0	6	0.00
	Base plane (All)	1	4	25.00

Same kinematic analysis was done to raw data for verify to above cluster data analysis in. In both type of analysis given same type of failures.

After identifying the main type of failures, the same kind of kinematic analysis were done in different slope angles and different slope directions to identify the critical and safe slope directions and slope angles.

6. Discussion and conclusion

Before the initiation of the landslide, a cut slope failure occurred in 2015 at the immediate intersection of the cut slope face and the fault plane. In 2016 this failure further developed and its dimensions extended besides and upward as a cutting failure. These intermittent cutting failures along the fault plane progressed into a massive scale landslide in 2017 making the fault plane as its axis. Coincident of cutting failure and landslide failure directions and their precise settings with geological discontinuities were obtained by observations and field data.

By kinematic analysis along the cut slope face, it was revealed that vulnerability for planar sliding, wedge sliding and direct toppling is comparatively high rather than surrounding where the fault plane creates more intersections with other discontinuities.

Further, the obtained data from the analysis show that every direction has a possibility for any kind of a failure. However, road cut directions in between 298°-317° (Trace direction 28°-47°) and 6°-143° (Trace direction 96°-233°) are safe for planer sliding and flexural toppling with respect to other directions (Table 4).

Table 4: Critical and safe direction for different slope directions (Slope angle as-70°)

No	Failure type	Critical Direction		Safe	
		Clockwise	Anti-clock wise	Clockwise	Anti-clock wise
1	Planer sliding	144^0-196^0(J1)	5^0-318^0(F)	197^0-317^0	6^0- 143^0
2	Wedge sliding	0^0-360^0(J1-J2, fault-j1)	360^0-0^0	-	-
3	Flexural toppling	210^0-298^0(j2/fault)	16^0-325^0(J1)	298^0-325^0	7^0- 210^0
4	Direct toppling	0^0-360^0	360^0-0^0	-	-

However, in general, roads are designed along contour lines and therefore it is very difficult to change road traces to prevent this kind of failure. Therefore, it is practically possible to change the slope face angle without changing the slope direction to minimize failures. With respect to the existing cut slope face direction, safe slope angles were attained by kinematic analysis. The analysis resulted that Cut slope angles smaller than 58^0 are safe for planar and wedge sliding and flexural toppling. Direct toppling by the intersection of the foliation plane and fault can be prevented by changing the slope angle but direct toppling by the intersection of the J2 plane and fault plane cannot be avoided (Table 5).

Table 5: Critical and safe cut rock slope angles (slope direction as-1700)

No	Failure type	Critical	Safe	Failure planes/intersections
1	Planer sliding	$>58^0$	$\leq58^0$	Joint set 01(Plane)
2	Wedge sliding	$>58^0$	$\leq58^0$	J1-Fault, J1-J2(Intersections)
3	Flexural toppling	$>75^0$	-	Foliation (Plane)
4	Direct toppling	$>0^0$		Fault-F,Fault-J2(Intersections)

According to above analysis, direct toppling is possible for each angle as well as each direction. Therefore, prevention of toppling is not possible without using structural measures. Thus, identifying the failure mechanism prior to design stages and applying suitable mitigation is necessary to prevent severe failures.

Additionally, cutting failure faces exposed by intermittent failures may have angles greater than optimum safe angles and they bear a risk to fail recurrently. Removal of toe-supporting soil mass has enhanced the exposure of vulnerable intersections of rock discontinuities including fault plane.

The landslide has been localized into the axis of the fault plane due to intensive geological weakness there as revealed by kinematic analysis.

The kinematic analysis discovers all the failure modes possible however, in some cases, all the failure types may not occur because of variations of interaction bonds and the friction values among the planes.

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Building Resilience amidst
Economic Challenges

Quantification of rainfall threshold limit for rain induced cutting failures - A case study at Nagoda, Galle, Sri Lanka

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Abstract

Cutting failures have been fetched as one of the major disasters along the southwestern slope of the central highlands of Sri Lanka during the South Western Monsoonal rain period, owing to inappropriate excavations, haphazard construction along slope areas due to land demand and a demographic boost. Although excessive rainfall is the most common cause of slope failures, the physical and chemical properties of soils, geological structures, land use patterns, and management practices, as well as drainage controls, all play a role in determining when a cutting failure occurs. Since rainfall plays a vital role as a triggering factor for cutting failures, finding the localized rainfall threshold limit at which a cutting failure will occur and helping to identify an evacuation moment is important for the safeguarding of lives. For this, it is paramount to study previous events and to define the local rainfall threshold limit for cutting failures. This case study focused on finding the rainfall threshold limit at which cutting failures occur when all other affected factors are known. Detailed field visits were done to identify the cutting failure events and locations. Hourly rainfall data, 24 and 72 - hour cumulative rainfall data for the area were analyzed. Contour maps and hydrology maps were used to identify the water management pattern of the area. According to the analysis, it is found that the range of rainfall thresholds for triggering cutting failure is 59 mm/24 hrs to 68.25 mm/ 24 hrs for the study area which is lower than the whole island alert warning rainfall limit of 75 mm day^{-1}. It is almost impossible to obtain hourly rainfall data from the specific location with the existing rainfall measurement procedure in the study area. However, further analysis with consideration of hydrogeological and geological factors will result in more accurate threshold limits.

Keywords: Cutting failure, Threshold rainfall, Nagoda

1. Introduction

Rainfall in Sri Lanka has multiple origins; Monsoonal, Convectional, and depressional rain account for a major share of the annual rainfall. Heavy rainfalls cause landslides and cut slope failures in central highlands and in the wet zone of the country, acting as the main trigger for such disasters. Except for the rainfall, the failure events could be triggered by the height and thickness of the soil cut, upper slope angle, upper slope type, soil type, cut angle, and water management of the area.

However, these disasters significantly affect socio-economic habits. To minimize the damage caused by landslides and mass movements, the prediction of landslides and precautions are important. Therefore, the requirement for an early warning system for landslide-prone areas has emerged. After studying several landslides in Sri Lanka and using rainfall data with the landslide Hazard Zonation Map, generalized threshold values for rainfall have been determined for the landslide-prone areas of Sri Lanka (Bandara 2008).

- Type 1 Alert: Rainfall exceeds 75 mm in 24 hours and continues.
- Type 2 Warning: Rainfall exceeds 100 mm within 24 hours and continues
- Type 3 evacuating warning: rainfall of more than 150 mm in 24 hours or 75 mm in an hour and continuing.

Galle district, which is in the wet zone, receives an annual rainfall of more than 2,500 mm and is also declared a landslide-prone area by NBRO. Even though the Galle district is declared a landslide-prone area, cut slope failures become the most prominent mass movement type in the region. The disturbances to the natural slopes by incautious soil cuts during construction, increase the occurrence of cut slope failures which leads to adverse disasters. As a result of land scarcity, people excavate the elevated areas without proper planning, which results in a series of cutting failures recorded in rainy seasons.

Over the past few years, cutting failures and slope failures have become more prominent in the "Nagoda" Divisional Secretariat than in the other parts of the Galle district. Though the investigations are carried out, and mitigation measures are proposed to reduce the potential of failures, socio-economic difficulties influence the implementation of the suggested recommendations. Even though, the terrain factors of the Galle district are completely different from those of the entire island, and the Galle district is known for cutting failures rather than landslides, so far, there is no system to define rainfall thresholds for cutting failures in the Galle district. The recent disaster analyses of the Galle district clearly state the necessity of having regional threshold values on the local scale. Currently using threshold values are not applicable for the Galle district, because most recorded events have occurred below the alert warning threshold, defined for the whole island (Weeranayake et.al 2021). Therefore, to safeguard lives and to reduce the disturbance to daily life by cut slope failures, it is important to have a localized threshold limit for the cut slope failures in the respective area.

2. Study area

Cutting failure is the most visible failure event in the Galle district. The highest number of cutting failures among Nagoda divisional secretariat division are due to high population density and people excavating elevated areas without proper planning. Also, people in developing countries don't have a tendency to mitigate those cuts. As a result, cutting failures are most prominent, and a series of cutting failures are recorded in every seasonal rainy period.

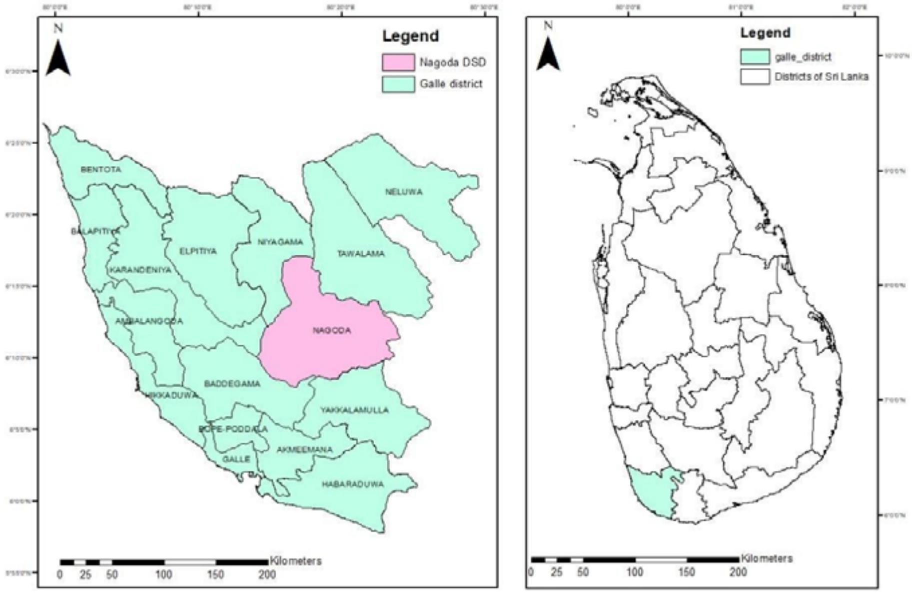

Figure 1: The study area

3. Methodology

In the relevant year, preliminary geological investigations were conducted for the reported cutting failure cases reported to the Divisional Secretariat. Hereafter, some selected locations were revisited from May to June 2022. Three rain gauges were considered nearby, of which two are in the Divisional Secretariat area, namely Udugama (L69) and Nagoda (R48). There is another automatic rain gauge near the investigated area, located at Baddegama DSD and called Baddegama (B47).

Available rainfall intensity data has been collected from the website www.rainfall.nbro.gov.lk from 2017 to 2021. 1 hour, 2 hours, 3 hours, 24 hours, and 72 hours of rainfall were analyzed accordingly using the available 30 minute rainfall data. Rain gauge readings were taken at 09.00 hrs every day at a fixed time.

This analysis took into account cutting failure events in 2017, 2018, 2020, and 2021.The year 2019 could not be used for analysis due to the loss of rainfall data due to equipment error. The rainfall threshold is suggested by considering the cumulative rainfall values.

Only reported cases were considered, and there may be other failure cases within the DSD area, especially on large-scale land without any building or development. However, all existing data were considered by referring to old records of the Nagoda Divisional Secretariat and the National Building Research Organization, Galle.

4. Results and discussion

4.1. Collecting cutting failure date

Difficulties faced in data collection are the exact hourly rainfall data at the specified failure location could not be obtained as it was not measured there. The rainfall data of the nearest rain gauge was obtained for analysis. Finding the exact time of failure is almost impossible due to the lack of proper records from affected people at a specific location in June 2022.

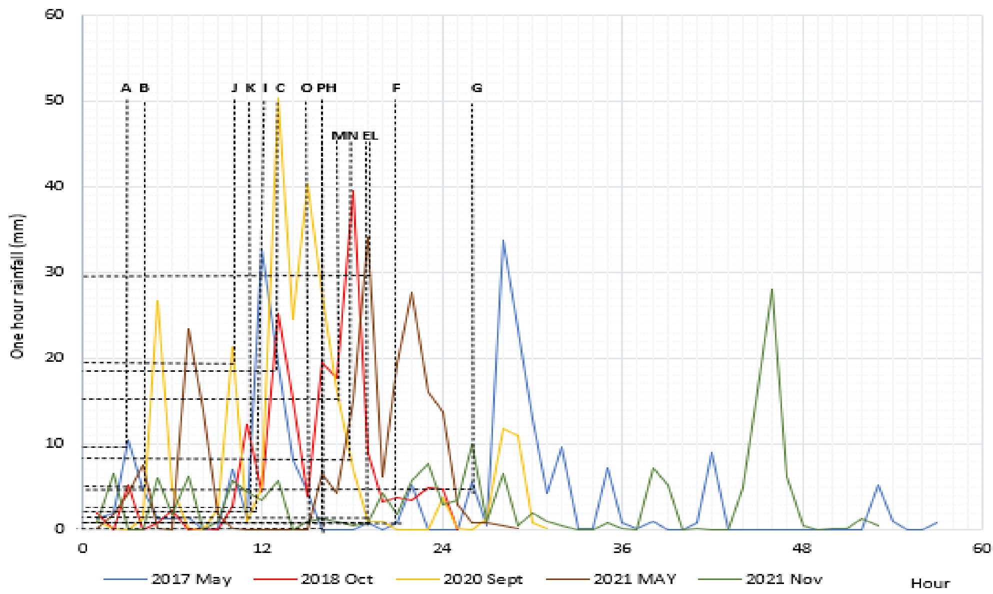

Figure 2: One-hour rainfall for cutting failures occurred in past few years

4.2. Rainfall analysis

Figure 2 shows the hourly rainfall of the event according to the year. Cutting failure events are named by the letters A to P, indicating an hourly rainfall range of 0 to 29 mm/hr. Therefore, rainfall an hour before the event is not influence on failure.

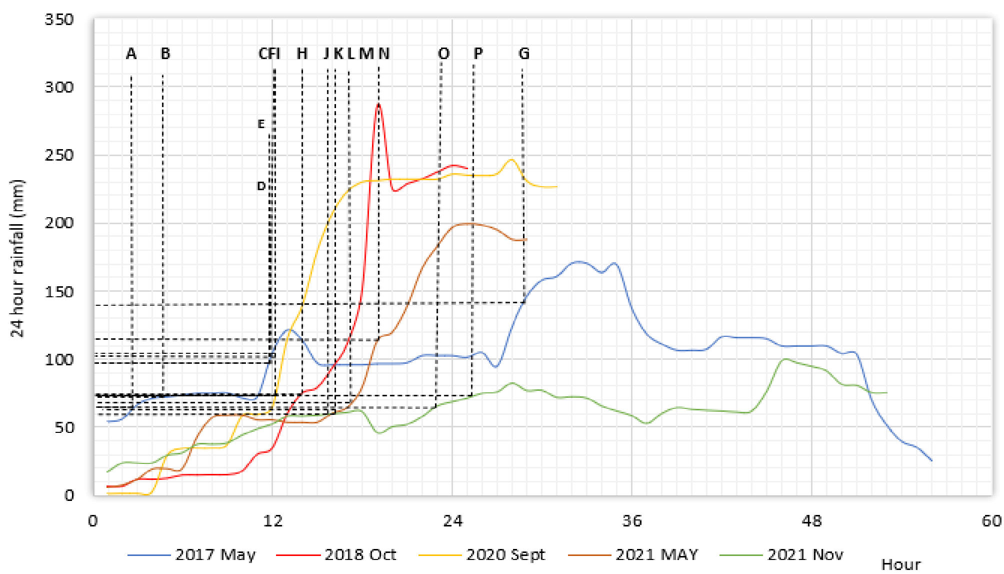

Figure 3: 24-hour rainfall for cutting failures occurred in past few years

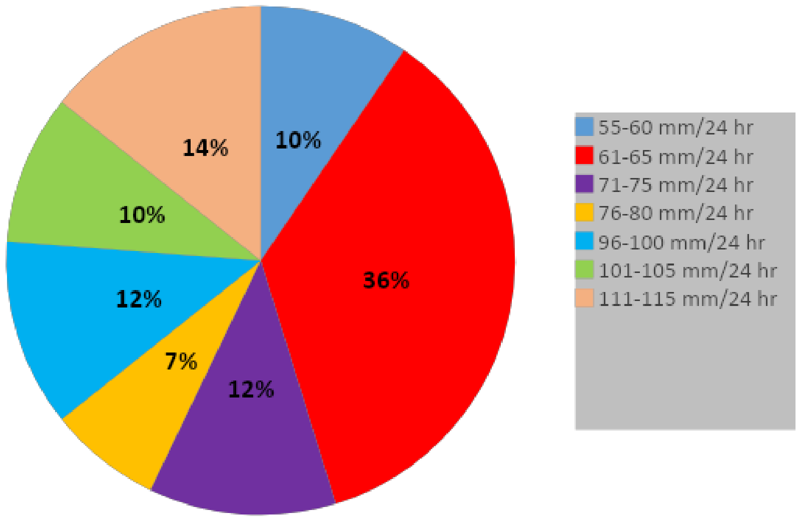

Figure 4: Representation of cutting failures triggered in several rainfall

Figure 3 shows the 24-h rainfall of the cutting failure events plotted. As a threshold, 24-hour rainfall to trigger cutting failure is 68.25 mm/24 hours in 2017, 60.25 mm/24 hours in 2018, 64.25 mm/24 hours in September 2020, 59 mm/24 hours in May 2021 and 60 mm/24 hours in 2025. 24 hours in November 2021. This variation may be due to land use management, morphological and geological identities and rain water management patterns in such places.

75 mm/hr is the NBRO decided landslide alert warning rainfall margin for Whole Island, which is higher than all the above considered events from year 2017 to 2021. Evacuation notice to the public in landslide potential areas is given after having 150mm rainfall per 24 hours of period.

Incident intensities were graphed against the relative rainfall as shown in Error! Reference source not found.. Highest intensity is recorded for 61-65 mm/hr rainfall which is 36%. In addition to that, a considerable amount of cutting failures occurred at high rainfall intensity, 111-115 mm/24 hr.

5. Conclusion and recommendations

Although the developed countries of the world use modern technology to reduce cutting failure, Sri Lanka, an underdeveloped country, cannot afford such costs. Therefore, it is important to predict an early evacuation. NBRO, Sri Lanka has finalized rainfall limits for the entire island's landslide-prone areas, with a warning limit of 75 mm per 24 hours and an evacuation warning limit of 150 mm per 24 hours. Furthermore, there is no specific threshold value for cutting failure cases in the Galle district.

Due to failure cases being observed even at 59 mm/24 hr rainfall intensity, the recommended rainfall threshold for cutting failures in Nagoda and Galle district should be 55 mm/24 hr. The failure event has no effect on rainfall intensity one hour before and 72 hours after it occurs. This study is only based on rainfall data. Further research needs to be carried out, considering hydro-geological and geological factors as well.

Acknowledgement

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Building Resilience amidst
Economic Challenges

Use of instrumentation to predict a slow-moving landslide in Nuwara Eliya District - Sri Lanka

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Abstract

Several kinds of natural disasters like landslides and land subsidence in Sri Lanka occur due to the geological conditions and the effect of climate change and the national development has been affected by these disasters. According to the historical records, many natural and manmade disasters has occurred due to the heavy rainfall. In the mountainous and hilly areas located in the central part of the country, which accounts for 20% of the total territory of the island and where 30% of the total population of the people live, landslides and steep slope failures frequently occur due to the geological and topographical conditions in such areas. Such type of landslides are mainly characterised by a sudden debris transition during heavy rainfall events. This feature makes them rather difficult to predict and therefore remains a major threat to nearby populated areas.

Presently, the landslide early warnings are issued based on the amount of observed rainfall. The improvement of landslide monitoring systems and methods will contribute to disaster risk reduction in Sri Lanka in the hill country, mainly for slow moving landslides.

Slow-moving landslides are triggered by intense rain leading to a catastrophe. Therefore, monitoring of slow-moving landslides by employing novel technology is essential to issue reliable early warnings for evacuation when living with landslides. The study shows that installing instruments throughout the unstable slopes with a sensors network, in order to achieve continuous monitoring of the overall shape deformation within slow moving landslides. Hence, this paper presents the methods used to install the Landslide Remote Monitoring System (LRMS) which enabled the transmission of data using a radio communication network to support the determination of the reference value of landslide early warning in Diyanilla landslide in Nuwara Eliya District.

Keywords: Colluvium soil, Landslide remote monitoring system, Slow moving landslide

1. Introduction

Landslide is a typical and frequent geological disaster, which causes great loss of life and injury to people and their properties as well as damage to infrastructure. Major landslide hazards, such as landslides in high mountain terrains have become important constraints to the development of urbanization and major infrastructures within the area.

In the most destructive and catastrophic landslide events, rocks, soil and debris can travel at speeds approaching several tens of meters per second (Hilley et al., 2004). However, few landslides, commonly referred to as slow-moving landslides, creep at rates ranging from millimeters to several centimeters per year and can persist for years to decades. Although slow-moving landslides rarely claim lives, they can cause major damage to infrastructure and sometimes fail catastrophically, transitioning into fast-moving landslides that can result in thousands of casualties. In addition, slow-moving landslides have highly erosive features that control the landscape morphology in many mountainous regions (Colesanti and Wasowski, 2006).

Most landslides in mountainous regions occur in the rainy seasons, as a result of the fluctuation of groundwater table within the terrain which consists of colluvial soil. Therefore, observation of groundwater is of primary importance in any instrumentation programme. As the main cause of landslides is severe rainfall, therefore, it is important to assess precipitation levels and correlate them to resulting landslides. Hence, there have been many cases of soil masses moving slowly and either surface or deep displacement measurements are very important in assessing the phenomena. Observations of earth-retaining structures and the load versus time behavior of soil and underlying bedrock in relation to the movements may also be considerable factors.

The persistent and long-term motion of slow-moving landslides provides an exceptional opportunity to investigate landslide processes and mechanisms. Presently, landslide early warnings in Sri Lanka are issued based on the amount of observed rainfall. But, due to the recent improvement of landslide monitoring systems by using advanced sensor-based technology, the NBRO is willing to contribute to disaster risk reduction procedures in the country.

This paper focuses on installing instruments in monitoring the movement of Diyanilla slow-moving landslide in the Walapane Divisional Secretariat in Nuwara Eliya District. This study introduces a reliable method for potential landslide hazard analysis by coupling monitoring data with installed sensor-based landslide monitoring instruments.

2. Study area

The affected area belongs to the Harasbedda and Palapathana Grama Niladhari Divisions of the Walapane Divisional Secretariat in the Nuwara Eliya District of the Central Province of Sri Lanka (Figure1). The area is accessible via the Nuwara Eliya – Walapane main road (B332, B413), and it is located between the 67^{th} and 68^{th} kilometer post of this main road, which serves as the main access to the Walapane, Nildandahinna, Adhikarrigama, and Keerthibandarapura areas.

The entire study area is spreads over about 1.5 km^2 spatial extent and consists of a thick colluvium deposit. The uppermost part of the study area has huge bedrock exposures, and the lowermost area has a colluvium soil deposit that has a depth of more than 4 meters. Spring and seepages are prominent, with a fluctuating groundwater table, and boulders ranging in size from 1-3 m were scattered throughout the area.

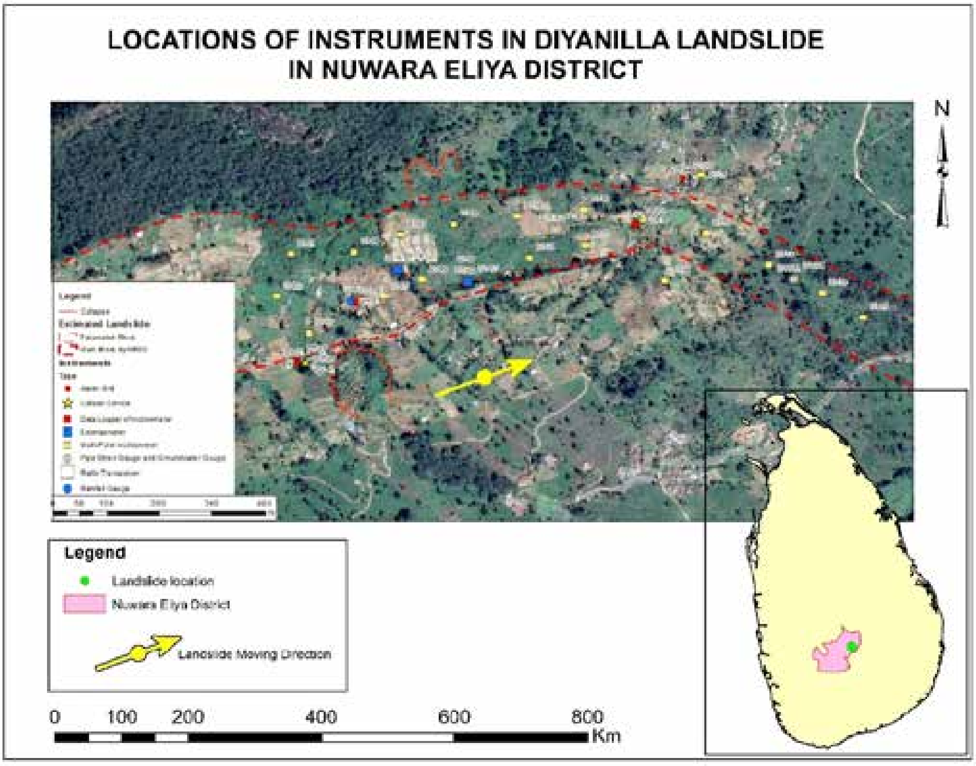

Figure 1: Location map and the location of instruments in Diyanilla landslide

The study area is located in the Central Highlands of Sri Lanka, which has a unique landscape and rainfall patterns. The average annual rainfall in the area varies between 2500 mm and 3000 mm. The average annual temperature of the area is between 16 ^{C} and 24 ^{o}C, whereas the temperature may drop in certain periods with the increase in elevation in mountainous terrain. The terrain is very rugged, with steep escarpments covering about 50% of the area on the upper slopes. The bedrock is often exposed, while in the upper sections of the escarpments, there is a thick cover of colluvium deposits with various sizes of boulders. Bedrock exposures in some areas have steep sides and often dome-shaped exposures of bedrock that cover over 5% of the area. The general slope angle of the area is 25 to 35 degrees.

The study location is having prominent bedrock outcrop situated in the direction of the intermediate slope of the foliation plane. Low to medium weathering conditions are present in the soil and bedrock in the study area. Mostly, the bedrock outcrops were identified above the crown area of the landslide. The studied landslide location consists of dry valleys and ridges, whereas the land use of the total area consists of vegetable cultivation, home gardens, and tea estates. The uppermost area of the landslide (initiation area) consists of vegetable cultivation with improper surface drainage systems with prominent erosional characteristics of the soil. Whereas, the lowermost area of the landslide (depositional area) consists of tea estates with proper drainage systems and minimum soil erosional activities. The middle area of the landslide (flow path) may have thick colluvium deposits used for vegetable cultivation and it consists of houses and home gardens of the villagers.

The GPS coordinates of the study area are N 7^0 02' 05.33", E 80^0 51' 49.12" and the elevation is 1516 m above the msl. The study area lies on the Hanguranketha sheet of 1:50,000 topographic map (sheet no. 62) published by the Survey Department of Sri Lanka and on the map no. 14 of 1:100,000 scale Geology Map published by the Geological Survey and Mines Bureau, Sri Lanka. According to the 1:50,000 Landslide Hazard Zonation Map published by National Building Research Organisation (NBRO), the affected area lies in the category indicated "Landslides that are to be expected".

3. Methodology

In order to conduct the topographic and geologic survey at the pilot site and formulate the installation plan for equipment, bore holes were conducted at the Diyanilla site. Instruments of the landslide remote monitoring system were received from Japan (OSASI company) and were installed prior to the bore hole investigations using an installation plan. Servers of these instruments were installed at the NBRO head office in Colombo.

Installation of observation and communication instruments is conducted for the development of Landslide Remote Monitoring System. Each instrument was connected to a mobile network, then the observed data would transmit to the NBRO head office. Table 1 shows the items of the instruments which were installed at the Diyanilla slow-moving landslide site. All of the installation work was done under the supervision of a project team of qualified professionals.

The drilling machine which was used a hydraulic-driven rotary type drill. It was used to drive a casing pipe of 90 mm in diameter to the depth of 30 m through the borehole. The bit was selected deliberately to meet the geological conditions for the best core recovery and efficiency. Water levels in boreholes were measured and recorded every morning before the commencement of the day's drilling work. This measurement was continued during the period when the hole was being drilled.

The recovered core samples were placed in order in core boxes and each core box had five grooves; each groove with adequate dimensions for containing one meter of core section. After the drilling was completed, the drilling for installing the pipe-strain gauge was carried out at the same borehole. The installation of a pipe strain gauge was required for the 100 mm borehole for safe installation. A checklist was prepared to install and operate the system at the pilot site and operation was confirmed by counterparts.

Core drilling was performed for the purpose of obtaining the sub-surface geological conditions in the pilot site and installation of pipe strain gauge and groundwater gauge. All the instruments such as ground surface extensometer, rain gauge, groundwater gauge, strain gauge, and multi-point inclinometer, and network equipment (radio transmitters, communication device, alarm device, and cloud service) were installed on the slope.

The inclinometer is a device for monitoring the onset and continuation of deformation normal to the axis of the borehole casing by passing a probe along the casing (Dunnicliff 1988). Thus, an inclinometer monitors deformation normal to the axis of the casing which provides a profile of subsurface horizontal deformation. The depth at which shear movement is detected by the inclinometer is the depth of the failure surface. The portions of the casing that have not sheared represent the areas above and below the failure surface if there is one failure plane impacting the casing.

A strain gauge is a sensor whose resistance varies with applied force. It converts force, pressure, tension, weight, etc., into a change in electrical resistance which can then be measured. When external forces are applied to a stationary object, stress and strain are the results. Extensometers are devices used to measure the changing distance between two points. They are commonly used in the monitoring of landslides.

This system transmits measurement data taken by observation instruments in landslide risk areas to a management office located at a distance, in real time. Although the installed system monitors the on-site conditions, evaluates the risk of landslide and informs local residents of the risk at an early stage and urges them to evacuate by using an alarm system.

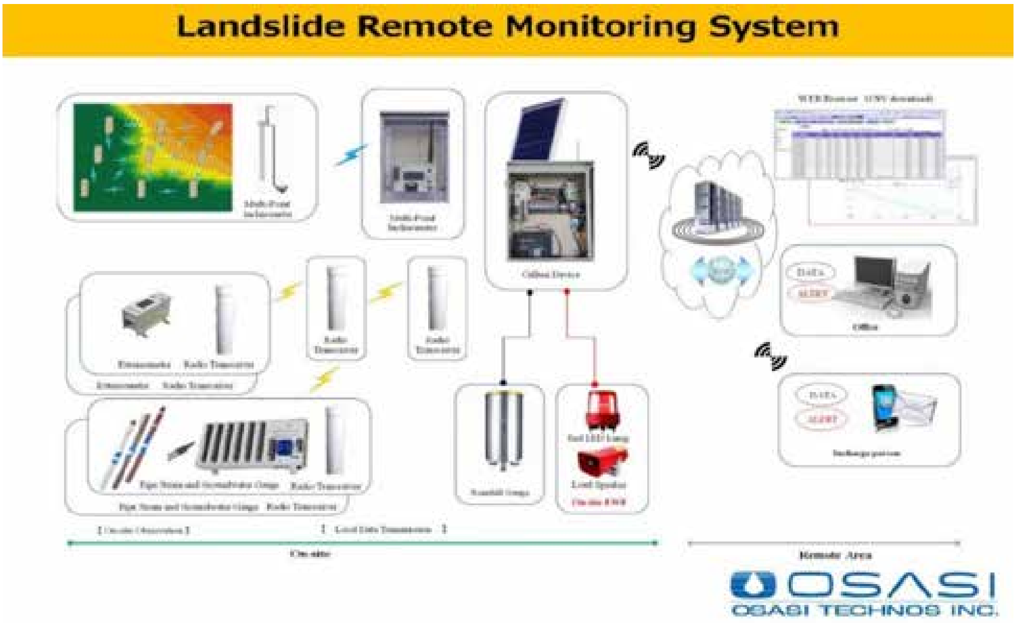

Figure 2: Monitoring system image

(a) (b)

Figure 3: Photographs showing (a) Extensimeter and data transceiver; (b) Data Logger of Multi-Point Inclinometer, Alert Unit, Cellular Device and Data Transceiver

(a) (b)

Figure 4: Figure 4: (a) Pipe Strain Gauge, Groundwater Gauge and Data Transceiver; (b) Alert Unit and Data Transceiver

(a) (b)

Figure 5: Photographs showing (a) Multi point inclinometer; (b) Rain Gauge and Data Transceiver

4. Discussion

Landslide monitoring and instrumentation are extremely crucial for the safety of the surrounding areas and people. The installed instruments within the slow-moving landslide in the Diyanilla area generate an alarm according to the threshold limits of the sensors, which can be changed as required.

Monitoring the slope for any pre-signs of instability can help to perform remedial measures even before alarm conditions are generated. Landslide monitoring involves the use of a durable prediction and forewarning system, coupled with effective efforts to curb slope movement. The destruction can be drastically reduced with the help of monitoring and instrumentation. A reliable plan for corrective and preventive measures in a landslide or landslide-prone area must be based on a detailed integrated geological and geotechnical investigation and monitoring. This monitoring programme can be carried out in a couple of years and prior to the data gathered from the instruments, slope stabilization techniques can be implemented to propose an effective mitigation plan for the landslide area. Qualified professionals in landslide and engineering geology are essential to evaluate the type of landslide and perform corrected measures based on the data collected during the monitoring period. The solution plan should take the cost and effectiveness into consideration.

5. Conclusion

The threshold limits of each and every sensor of the instrument should be set according to the acceleration of the landslide which can be expected more accurate evacuation alarm value according to the rainfall triggering factor which is helpful to the disaster-affected communities.

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Building Resilience amidst
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Influence of contributory terrain factors on spatial occurrence of landslides - A case study from Matara District, Sri Lanka

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Abstract

Catastrophic rainfall that fell across southern districts of Sri Lanka in May 2003, resulted in numerous landslides causing substantial life and property losses like never before in the history. This study was aimed at exploring the influence of several causative terrain factors on spatial distribution of 513 landslides that occur in Matara District during the rainfall event, to provide an insight into the origination of landslides within the locale. Landslide density of each factor class was used as the primary measure of its degree of impact on landslide initiations. Solid rational influences of bedrock type, overburden soil type, slope angle and proximity to springs, streams and joints on the generation of landslides were recognizable. inexplicable associated with results concerning overburden soil thickness, watershed order and slope aspect were concluded as consequences of complexities of the factor classes used in the analysis or independent evaluation of each factor overlooking the collective influence created by superimposition of other factors. Paired with additional detailed studies to address the mentioned gaps, findings of this study can be reasonably used to improve landslide susceptibility mapping in Sri Lanka to better assess landslide hazards in the future.

Keywords: Causative factors, Landslides, Susceptibility

1. Introduction

Landslides associated with intense rains are the most pressing natural hazard in the Central Highlands of Sri Lanka. According to the available records, major landslides occurred within last four decades alone have caused a loss of more than 1,500 human lives making over 200,000 homeless. Despite enormous risk reduction efforts taken by the Sri Lankan government in the recent past, considerable loss of lives and economic losses are still recorded due to landslides, with damages on the rise throughout the island, every year. Thus, it is essential to develop mechanisms to manage future landslide events successfully in such regions.

In this regard, landslide susceptibility mapping which has become a major tool for landslide hazard zone predictions in the world, is also applied by many scientists in Sri Lanka in various contexts. Landslide susceptibility mapping largely depends on understanding the nature of the factors that have direct influence on the slope instability. Hence, it is the relationships between past landslides and the various terrain factors associated with them that form a basis for predicting future landslides and assessing the landslide hazard. This study was intended to gain a better insight into our understanding about the onset of landslides in Sri Lanka, by exploring the influence of several causative terrain factors on spatial distribution of 513 rain induced landslides that occur Matara District in 2003.

2. Study area

The study area is located in the Matara District in Southern Province of Sri Lanka. It encompasses approximately 263km^2 area which falls within eight number of 1:10,000 scale base map sheets (40km^2 each) numbered 81/17, 81/18, 81/22, 81/23, 87/02, 87/03, 87/08 and 87/13 (Figure 1). Elevation of the study area ranges from 46 to 1138m from mean sea level. During the Southwest monsoon, the area receives heavy rains from May to September every year, which sometimes result in floods in Ginganga and Nilwala basins in Galle and Matara districts. The devastation caused by flash floods and landslides on 17th May, 2003 was triggered by the three-day cumulative rainfall that preceded the event was unprecedented and people in the Rathnapura, Matara, Hambantota, Galle and Kalutara districts were severely affected. The most significant fact is that Galle, Matara, and Hambantota districts which had not been considered earlier as landslide prone, were highly affected by the catastrophic landslides, killing 54 people in a single day. Landslides and floods resulted in over 190 deaths in total, leaving approximately 200,000 people displaced due to the events (Seneviratne et al., 2005). The recorded daily rainfall on 17th May, 2003 in the study area ranged from a minimum 155mm to maximum 730mm.

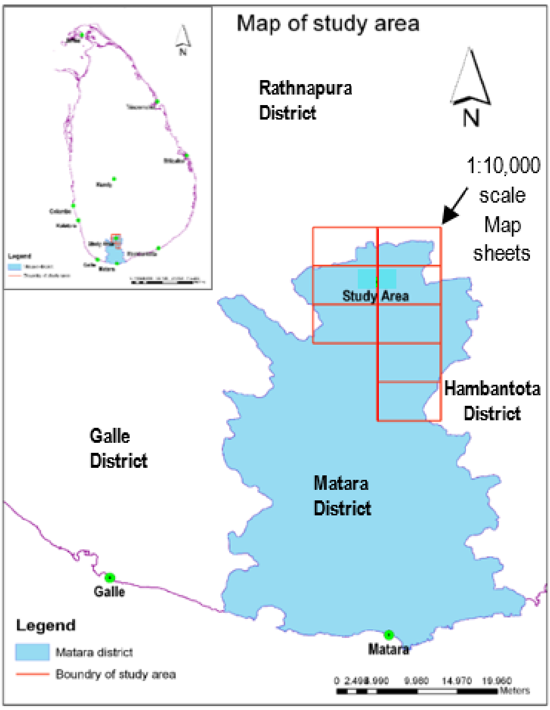

Figure 1: Map of the study area (encompasses 1:10,000 scale base map sheets 81/22, 81/23, 87/02, 87/03, 87/08, 87/13 wholly and sheets 81/17 and 81/18 partly)

3. Methodology

Field data used for this study were collected by National Building Research Organisation (NBRO) of Sri Lanka in July, 2004 with the aim of consulting local authorities and people for future disaster management activities, researching landslides problems, and preparing landslide hazard maps of the region. Priority areas were selected on the basis of density of past landslides and density of population under the landslide threat. Field data relevant to a selected high priority area of 263 km^2 were collected by a team of multidisciplinary specialists with landslide expertise from Landslide Studies and Services Division (LSSD) and the Human Settlements Division (HSD) of the NBRO. The data comprised of bedrock geology and structure, soil types and thicknesses, elevation data (contours), landform, land use, hydrology and drainage conditions associated with landslides occurred in May, 2003 in the study area. Digitization of field data was completed in 2008 by the Computer and GIS section of the LSSD.

Collected data were first organized according to the requirements of the study. This included data checking, correcting, editing and introduction of new features to the maps where necessary. By editing the landslide distribution map that shows zones of initiation, flow paths and zones of accumulation, a surface of rupture map was created as the analysis should only be focused on the area of rupture. Derived maps such as slope aspect, stream network and watershed were prepared using the Digital Elevation Model created from 1:10,000 scale contour data with 10 m contour intervals. In total, nine landslide causative factors were prepared for the analysis. These static factors included: bedrock type, geological structures and their orientation, soil type, soil thickness, slope angle, slope aspect, watershed order, distance to springs, streams and joints. For each factor, classes were defined. Determination of boundary values for classes was based on literature reviews, personal judgment and experience in the field of study. Using parameter data and landslide distribution map, extent of each factor class, number of landslides and area of landslides within each factor class were determined. Since neither the number of landslides nor the area of landslides within a parameter class is a satisfactory measurement of influence of various factors on slope instabilities, density of landslides (landslide area per unit area) within each parameter class was calculated and utilized as the main indicator. Relationships between the selected terrain factors and spatial distribution of landslides in the study area were analyzed and compared. ESRI ArcInfo 9.2 and 9.3 and statistical software were used in data preparation, geo-processing and information creation.

4. Results and discussion

The landslide inventory map consisted of 513 slides out of which 506 could be considered shallow translational landslides. Area of rupture surface of the landslides varied from 14.62 to 122053.9m^2 with a mean area of 4364.8 m^2. About 80% (403) of the studied landslides were found to be smaller than the mean area. Total area of rupture was 2.21 km^2 which accounted for 0.84% of the total study area. A 3 m grid resolution was selected as the common raster resolution considering that the smallest landslide with a rupture area of 14.62 m^2 as the smallest feature to be identified and to minimize the difference between vector area (actual area) and raster area.

4.1. Lithology of bedrock

Majority of the study area (about 49%) was found to be underlain by Charnockite type bedrock. It also recorded the highest landslide area (61.6%) and the highest landslide density. Hence, solely based upon the bedrock type, regions underlain by Charnockite can be considered most susceptible to landslides. This is reasonable as the presence of higher joint density associated with the rock type offers weak zones and facilitates infiltration of rainwater aiding weathering and rise of hydrostatic pressure within the subsurface. As the area of the factor class decreases from Garnet-Biotite-Charnockitic Gneiss to Hornblend-Biotite Gneiss, the landslide area and the landslide density also decreased. However, Quartzo Feldspathic Gneiss, the least occurring rock type, which covers less than 1% of the study area, accounts for more than double the landslide density of comparatively more abundant rock type, Meta Gabbros.

4.2. Type of soil overburden

Residual soil is the most widespread soil type covering 88.43% of the study area. Although the highest landslide area of 1.4122 km^2 (63.97%) was recorded for this soil type, it accounted for the least landslide density amidst all soil types. Highest landslide density was observed in colluvial soils while the second highest in colluvium mixed residual soils.

4.3. Overburden soil thickness

Concerning overburden slides, depth to soil-bedrock boundary (overburden thickness) is an important factor. However, with regard to soil profile factor, any logical pattern of landslide density could not be observed within the study area (Table 3 and Figure 4). For instance, weak soil classes such as Coll=3-4 exhibited a lower landslide density than class RS=3, even though theoretically residual soil is considered comparatively more stable than colluvial soils.

4.4. Slope angle

As per the results obtained for the study area, landslide density increases gradually with slope angle until the category of 45^0-48^0 (Table 1). A marginal yet noteworthy rise in landslide density is observed in the category of 6^0-9^0. Slopes with 0^0-6^0 slope angle can be regarded as gentle slopes where landslides are unlikely. Landslide density continues to increase with the slope angle (except the anomalies at the categories of 54^0-57^0 and 57^0-60^0) until it reaches a peak at the 63^0-66^0 category. This gradual increase of landslide density with the slope angle is in line with the increase of driving force generated by the soil weight as the slope gets steeper.

However, as the slopes get much steeper, there is more tendency for soil erosion and consequently, exposed bedrock. Therefore, slopes that are too steep to form substantial overburden soil, rarely experience landslides involving soil (Walker et al., 2013). The results for the study area seem to confirm this fact, since landslide density starts decreasing for slopes above 66^0 and drops substantially once the slope angle exceeds 69^0.

In general, significantly high landslide densities have been recorded for slopes with angles ranging from 6^0 to 69^0 which involves just 0.022% of the total study area and 0.185% of total landslide area (Table 1). In addition, a vast majority (99.54%) of the study area comprises of slopes ranging from 6^0 to 48^0 which contains 98.36% of the total landslide area but demonstrates only low to moderate landslide densities. Overall, the results clearly demonstrate the theoretical understanding of influence of the slope angle towards the occurrence of landslides.

Table 1: Slope angle factor classes used in the study with landslide area and landslide density contained by each class

Slope angle (degrees)	Area of the factor class (km^2)	Area of landslides within the factor class (km^2)	Landslide density within the factor class	Slope angle (degrees)	Area of the factor class (km^2)	Area of landslides within the factor class (km^2)	Landslide density within the factor class
0-3	21.4584	0.00576	0.00027	39-42	4.3464	0.08159	0.01877
3-6	27.1997	0.03675	0.00135	42-45	2.8063	0.05789	0.02063
6-9	25.8458	0.10055	0.00389	45-48	1.5053	0.03318	0.02204
9-12	26.8527	0.16414	0.00611	48-51	0.6831	0.01859	0.02722
12-15	27.1283	0.20501	0.00756	51-54	0.2955	0.00916	0.03101
15-18	25.8370	0.22395	0.00867	54-57	0.1286	0.00278	0.02163
18-21	23.4798	0.23295	0.00992	57-60	0.0583	0.00147	0.02515
21-24	20.3729	0.22775	0.01118	60-63	0.0323	0.00185	0.05746
24-27	16.9474	0.20925	0.01235	63-66	0.0184	0.00159	0.08638
27-30	13.6006	0.19050	0.01401	66-69	0.0086	0.00065	0.07500
30-33	10.5509	0.16372	0.01552	69-73	0.0014	0.00001	0.00633
33-36	8.2345	0.13403	0.01628	Total	263.4367	2.20748	-
36-39	6.0445	0.10436	0.01726	Mean	10.9765	0.09198	0.02150

4.5. Slope aspect

Aspect is the direction that a slope faces and defined as the compass bearing in the downhill direction of the steepest slope. In the study area, comparatively higher landslide densities were demonstrated by two major directions of aspects, 80^0 -150^0 (E to SE) and 320^0 -360^0 (NW to N). The highest landslide density was recorded in the slope aspect category of 120^0-130^0. The second highest landslide density wasrecorded in category 130^0-140^0, which is also the class with highest landslide area.

Slopes with the aspect of 150^0 to 160^0 were found to be the most common within the study area, comprising 3.67% of total land area and of 4.03% of the total landslide area. The study area is usually exposed to the Southwest monsoonal rains from May to September, yearly. Although it is considered that the slopes facing the direction of major rainfalls are more susceptible to failures, the highest landslide densities within the study area were observed in the slopes facing almost orthogonal to the direction of major monsoon.

4.6. Association with major joints

Throughout the study area, a strong influence of joints on the occurrence of landslides was recognizable. Joints refer to fractures in rock occurring in parallel sets in one or more directions. This is a common feature in all the rocks within the study area and presence of this property imparts a degree of permeability to non-porous, crystalline rocks by providing continuous or dissected structural planes beneath the slope material which in many instances can act as slip surfaces or weak zones. As these weak planes are pervasive throughout the in situ weathered residual soils, landslides in them may in fact, be partly controlled by joints in the solid rock at depth. Also, joints facilitate groundwater infiltration and movement resulting in excess pore water pressures, internal erosion and deep weathering. Therefore, it is evident that proximity to discontinuities such as lineaments, faults or major joints increases the risk of slope instability. In the study results, an overwhelmingly high landslide density is observed in regions within 0 to 50 m range distance from major joints (Figure 7 and Table 6). A considerably higher influence up to 200 m is apparent. Thereafter, landslide density gradually decreases with the distance.

4.7. Order of watershed

When analyzing hydrological and drainage features of the study area, it was observed that 1st order watersheds recorded the second highest landslide density. From 3rd order watersheds, which accounted for the highest landslide density, a steady decrease of landslide density up to 6th order is observed. However, 3rd order watersheds only make up 8.76% of the study area, whereas first order watersheds make up 61.16% of the study area with 69.75% of the total landslide area. As a general rule, lesser landslides are expected to occur as the order of the watershed goes up. This is because lower order watersheds are associated with steep hilly terrains with V-shaped valleys and strong denudation activities, which are all more favorable conditions for slope instabilities. Yet, due to the anomaly at the 2nd order, where landslide density is very much lower than that of 3rd and 4th orders, a smooth relationship in landslide density of watersheds can only be observed from 3rd to 6th order.

4.8. Association with water springs

Landslide density depicts a solid relationship with the proximity to water springs up to a limit of 300 m. Springs represent regions of groundwater convergence, where high hydrostatic pressures can be expected within the subsurface and yield a considerable amount of subsurface erosion, which are strong causes of slope instabilities. As per the study results, locations within 0 to 50 m distance from the springs can be considered the most landslide-prone. The effect seems to diminish rapidly with the increase of distance, demonstrating a good relationship between landslide occurrences and distance from the springs.

4.9. Association with streams

Similar to the distance from springs, landslide density was found to be less frequent in locations far from the streams. Streams are surface water bodies flowing along the valleys, where groundwater table alight on the slopes and runoff water is collected. Hence, closer to the streams, slope materials are almost saturated with groundwater with high hydrostatic pressure. At the same time, mostly valleys are the cutting edges of slopes (toe of the slopes), where high erosion activities take place due to runoff. The bank erosion reduces the toe support enhancing the instabilities in slopes. Therefore, high landslide density is generally associated with close proximity to streams and the study results which indicate the smooth curve conform to this concept. While the areas within the distance of 0-50 m from streams have the highest landslide density, influence seems to continue up to 150 m from the streams. From 150 m onwards, landslide density continues to be more or less the same.

5. Conclusion and recommendations

Results generated by the analysis of the landslide density in the study area in relation to the selected nine terrain factors were used to visualize their quantitative influence as individual causative factors of landslides.

In terms of some factors, results exhibited sensible correlations. For instance, regions underlain by Charnockite type bedrock can be considered the most susceptible, since it has recorded the highest landslide density complying with the higher joint density associated with the specific rock type, which facilitates the infiltration of rainwater aiding rise of hydrostatic pressure within the subsurface and also weathering. The results related to soil types indicated that, conforming to their low resistance to shear, colluvium soils and mixed colluvium/residual soils are more prone to landslides. Also, the theoretical understanding of influence of the slope angle towards slope instabilities, i.e. increase of driving forces due to weight of the slope material with the rise of slope angle is acknowledged by the obtained results. Moreover, proximity of a location to springs and streams in the study area demonstrates fairly positive relationship with landslide occurrences, in accordance with the fact that springs and streams being regions almost saturated with groundwater causing considerable amounts of surface and subsurface erosion, which are all reasons for slope instabilities. A strong positive relationship between the presence of joints and the occurrence of landslides is exhibited as the proximity of a location to major joints is associated with higher landslide density. The joints are weak structural planes beneath the slope material, which facilitates groundwater infiltration, excess pore water pressure, internal erosion and deep weathering, which in many instances supplement as reasons for them to act as slip surfaces.

However, results obtained for some of the studied factors did not adhere with any rational explanation. For instance, any logical pattern of landslide density within the study area could not be observed in relation to the soil thickness. This might be mainly due to the large number and the complexity of the soil thickness classes that were used in the study. Therefore, a more acceptable classification scheme for soil thickness in line with soil type needs to be implemented for field data collection in the future studies. Similarly, higher landslide densities were observed in the slopes facing almost orthogonal to the major monsoon direction, opposing the general view that the slopes facing the major rainfall direction are more susceptible to failures. Absence of logical explanation in both these cases, might be a consequence of independently evaluating each terrain factor for the study which might have overlooked the superimposition of other highly favorable slope instability elements.

Considering the watershed order, the obtained results did not exhibit strong positive relationship. Although, in general, more landslides are expected in lower order watersheds with a decline towards the higher order watersheds, this was only true for 3rd to 6th order watersheds of the study area, due to the anomalies amongst landslide densities of 1st, 2nd and 3rd order watersheds. The reason behind this might be once again, the other terrain factors at play in determination of the stability of slopes in these watersheds with anomalous landslide densities. In addition, it is possible that the slightest anomalies observed in results related to some factors, which are otherwise quite logical could be due to errors associated with the field data and the scale of the study.

Overall, the findings of this research study is a contribution towards better understanding the nature of the factors that have direct influence on the initiation of landslides in Sri Lanka. Nonetheless, it should also be noted that the above results are greatly dependent upon the quality of the input data used in this study. Besides, additional and more in-depth studies are needed to address the inadequate logical conformities in results of this study, and to understand collective influence of the above factors on occurrence of landslide rather than individually assessing each factor. Meanwhile, usability of results and findings of this study for further development of the landslide susceptibility models in Sri Lanka seems to be promising, and higher accuracy predictions of spatial occurrences of slope instabilities through susceptibility models can eventually lead to identification of critical areas of the country to which special attention on landslide risk reduction measures should be engaged.

Acknowledgement

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Building Resilience amidst
Economic Challenges

Landslide risk identification in Kegalle District - landslide event; November 2021

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Abstract

Landslides have been identified as one of the most frequent and widespread natural disasters that can lead to huge damage to life and property in the mountainous terrain of Sri Lanka. Landslide Risk Management (LRM) can be viewed as a series of events leading to Landslide Risk Reduction (LRR), including risk identification, communication and mitigation. National Building Research Organisation (NBRO) is the designated national focal point for LRM in Sri Lanka. Preliminary landslide investigation is an effective grass root level risk identification method applied by NBRO. LRR measures are applied for only prioritized landslide locations. Hence, it is very important to study the spatial and statistical distribution of landslides within the area, site-specific vulnerabilities, elements at risk (houses, community structures, facilities and services *(buildings, access roads, schools, and hospitals and etc.*), landslide risk *(high, medium and low)* and types of landslide in the application of LRR activities.

The study was based on landslides that occurred in the Kegalle District with the adverse landslide event "November 2021" to identify the spatial distribution of incidents within the area, type of ground failures, and site-specific elements at risk. A total of 382 preliminary landslide investigation reports were studied. It revealed 15% of the ground instabilities were natural landslides whereas 85% were manmade ground instabilities and they are densely accumulated into the northern part of the Kegalle District. A total of 117 houses were at high risk and proposed for resettlement in safer locations, while 523 elements were at medium risk and proposed for living with landslides adopting other applications of LRR activities.

Keywords: Landslide, Landslide risk reduction, Spatial distribution

1. Introduction

Kegalle, one of the top fourteen landslide-prone districts in Sri Lanka, has experienced a number of ground instabilities because of its dense population, rapid urbanization, unauthorized constructions, and encroaching slope lands due to prolonged torrential rainfall triggered landslides. The Central Highlands is primarily covered by metamorphic rock formations that are strongly foliated, banded, and highly jointed. These terrains are prone to collapse along their inherent weak points. Deep-seated rotational-type landslides can easily occur on scarp slopes where there are frequently thick accumulations of colluvium. In steeper slopes and where the bedrock is exposed at cliffs and escarpments, rock falls are prevalent. Large rocks and dirt chunks can frequently slide when slopes are cut since the support is removed.

As the National Building Research Organisation (NBRO) is the focal point for landslides in Sri Lanka, its mission and vision are to implement Landslide Risk Reduction (LRR) activities in the country. Risk identification (susceptibility/ hazard/ risk mapping, site-specific landslide investigation), risk communication (early warning, education/ training/ awareness, preparedness) and risk mitigation (structural countermeasures, resettlement, resilient constructions, land use planning) are the steps of the LRR process. Priority is given to selected areas in the application of LRR activities.

Many landslides hit the Kegalle District due to torrential and prolonged rainfall from 9th to 11th November, 2021. It has brought significant economic and social impact causing severe damage to life and property, the environment, and the socio-economic life of the society. As per requests made by the District Secretariat and Divisional Secretariats of the Kegalle District regarding reported sites, NBRO conducted preliminary geological investigations and issued reports proposing LRR measures to minimize the landslide risk. Hence, it is necessary to identify the spatial distribution of landslides, the statistical distribution of types of landslides and the risk of the elements in the area to prioritize the sites for effective LRR activities. Subsequently, geological, geomorphological and hydrogeological factors of affected areas of the Kegalle District were dramatically altered by the landslide disaster. Furthermore, Landslide Hazard Zonation Maps prepared by NBRO should incorporate these new landslide records.

Objectives of the study are (i.) to study the spatial distribution of the ground instabilities that occurred in the Kegalle District with the adverse rainfall event "9th to 11th of November 2021", (ii.) to study the statistical distribution of the type of ground instabilities and the risk level of elements in the area and, (iii.) to prioritize the areas/sites LRR activities to be applied.

2. Study area

The study area was concentrated mainly on 382 locations of instabilities occurred in the Kegalle District during the rainfall events from the 9th to 11th of November 2021.

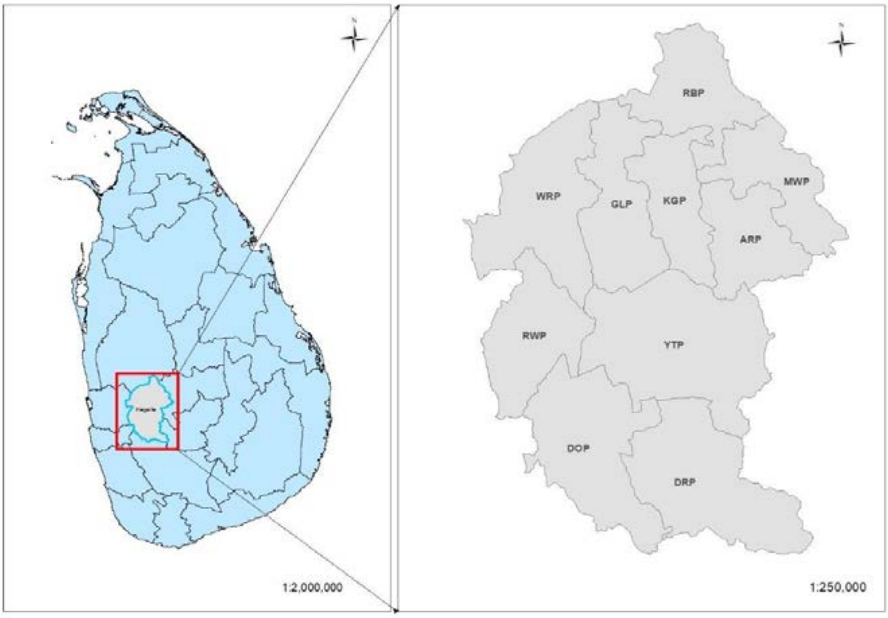

Figure 1: Studied area

3. Methodology

The information needed for the study and analysis were obtained from the preliminary landslide investigation reports issued by the Kegalle District Office of NBRO regarding this incident.

3.1 Identification of site-specific landslide risk

Disaster Risk (DR) is the likelihood or probability of a hazard striking a vulnerable community, causing injury, damage and loss (Figure 1) *(DR = Hazard x Exposure x Vulnerability /Capacity)*. Identification of hazards and vulnerability, monitoring and management of risk are integral to sustainable resilient developments. Elements at risk are people, household and community structures, community facilities and services (*buildings, access roads, bridges, schools, and hospitals*), livelihood and economic activities (*jobs, crops, livestock, and equipment*) and the environment. For that reason, it is very important to understand site-specific landslide risk in DRR.

Site-specific levels of risk were determined for post-failure locations based on the decision-making criteria such as field observations (geological, hydrological and geomorphological features and landslide symbols), and collaboration with expert opinions. The risk level of each site has been classified as high, medium and low risk in preliminary landslide investigations according to the NBRO manual of landslide hazard zonation (NBRO, 1995).

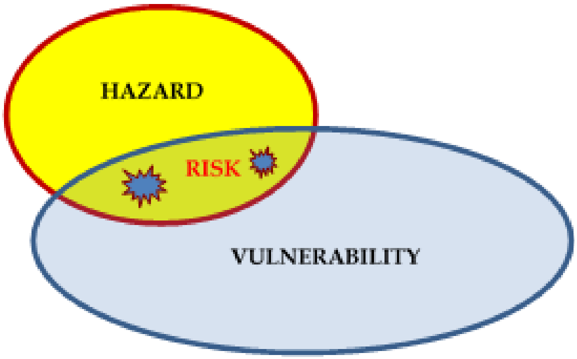

Figure 2: Risk is the overlay of hazard and vulnerability

3.2 Spatial and statistical distribution of landslides in Kegalle district

The spatial distribution of incidents will highlight the trend of occurrence with respect to the area. Analysis data on both spatial and statistical distribution of landslides in the district is used to identify the areas needing implementation of preparedness, preventive and mitigation actions and procedures.

Incident locations were mapped using ESRI ArcMAP 10.8 software. Using the plotted map, the number of incidents in the respective DSDs was determined.

3.3 Types of failures

Types of failures were summarized as Landslides (L), Slope Failures (SF), Cutting Failures (CF) and Rock Falls (RF). Landslides are defined as the mass movement of rock, debris or earth down a slope and have come to include a broad range of motions whereby falling, sliding and flowing under the influence of gravity dislodges earth material. Slope failure is a small-scale rapid movement of a weathered top soil layer (with or without rock) on a steep slope. Rockfall is defined as the free or bounding downslope movement of loose rock material under the influence of gravity. Cutting failures are the collapse of cut slopes due to loss of toe support and direct involvement of manmade activities.

4. Results and discussion

The landslide inventory map consisted of 513 slides out of which 506 could be considered shallow translational landslides. Area of rupture surface of the landslides varied from 14.62 to 122053.9m^2 with a mean area of 4364.8 m^2. About 80% (403) of the studied landslides were found to be smaller than the mean area. Total area of rupture was 2.21 km^2 which accounted for 0.84% of the total study area. A 3 m grid resolution was selected as the common raster resolution considering that the smallest landslide with a rupture area of 14.62 m^2 as the smallest feature to be identified and to minimize the difference between vector area (actual area) and raster area.

4.1. Identification of site-specific landslide risk

As shown in Table 1, 382 numbers of ground instabilities were studied. A total of 117 number of elements (houses/buildings/other infrastructures and etc.) were at High

Risk (HR) whereas 523 number were at Medium Risk (MR). High risk houses have been proposed to resettle in safer locations whereas other LRR measures have been proposed for MR elements to minimize the landslide risk.

To reduce the landslide risk, projects such as community-based landslide early warning projects, non-structural mitigation projects and etc. can be implemented for selected communities at medium risk practising living with landslides.

Table 1: Statistical data extracted from landslide investigation reports (Risk level of the elements and Types of failure)

Divisional Secretariat Division (DSD)	Risk Level			Types of Failure			
	High	Medium	Low	L	SF	CF	RF
Rambukkana (RBP)	80	297	40	3	16	222	11
Kegalle (KGP)	6	76	-	2	1	39	2
Mawanella (MWP)	15	27	-	2	4	11	1
Galigamuwa(GLP)	11	79	1	-	8	41	5
Aranayaka(ARP)	1	18	-	-	-	1	-
Bulathkohupitiya(BLP)	-	-	-	-	-	-	-
Dehiovita (DOP)	-	-	-	-	-	-	-
Deraniyagala (DRP)	-	8		-	1	-	-
Ruwanwella (RWP)	-	2	1	-	-	1	-
Warakapola (WRP)	-	6	-	-	-	3	-
Yatiyanthota (YTP)	4	10	-	1	-	7	-
Total	117	523	42	8	30	325	19

Note: L – Landslide, SF- Slope Failure, CF- Cutting Failure, RF - Rockfall

4.2. Spatial and statistical distribution of landslides in Kegalle district

According to Figure 3, incidents are densely accumulated in the northern part of the district. As per Table 1, 252 incidents (L, SF, CF, RF) occurred in Rambukkana DSDs. Figure 4 shows that ground failures are significantly higher in the Rambukkana DSD whereas they are noticeably lower in Bulathkohupitiya, Dehiovita, Deraniyagala, and Ruwanwella DSDs than in other DSDs.

4.3. Different types of failures

Figure 5 indicates a map with the recorded incidents, 85% are cutting failures whereas only 8% and 5% are slope failures and rock falls, respectively. Moreover, 2% per cent of them are landslides.

With the increasing trend of development and expansion of human settlements in the study area, CF has become a major concern. According to the reported data, almost all of the CFs that occurred during the studied period were caused by ground modification for constructions/developments which were carried out without NBRO recommendations.

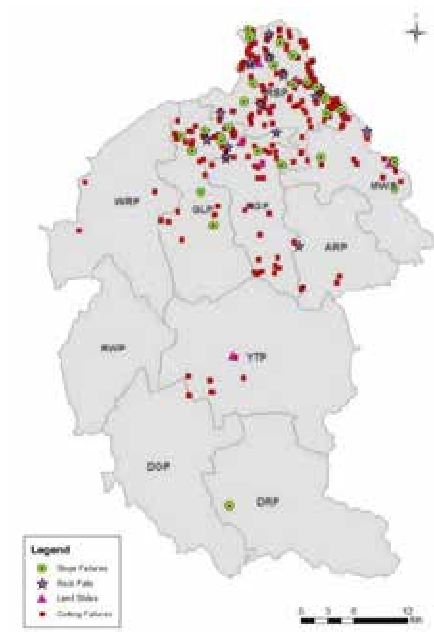

Figure 3: Spatial distribution of the landslides

Ground instabilities such as Ls, SFs, and RFs are natural instabilities but CFs are man-made ground instabilities.

Hence, 15% were natural landslides whereas 85% of the incidents were induced by the human activities. Among the Divisional Secretariat Divisions, Rambukkana Division is the most landslide-prone division due to human activities.

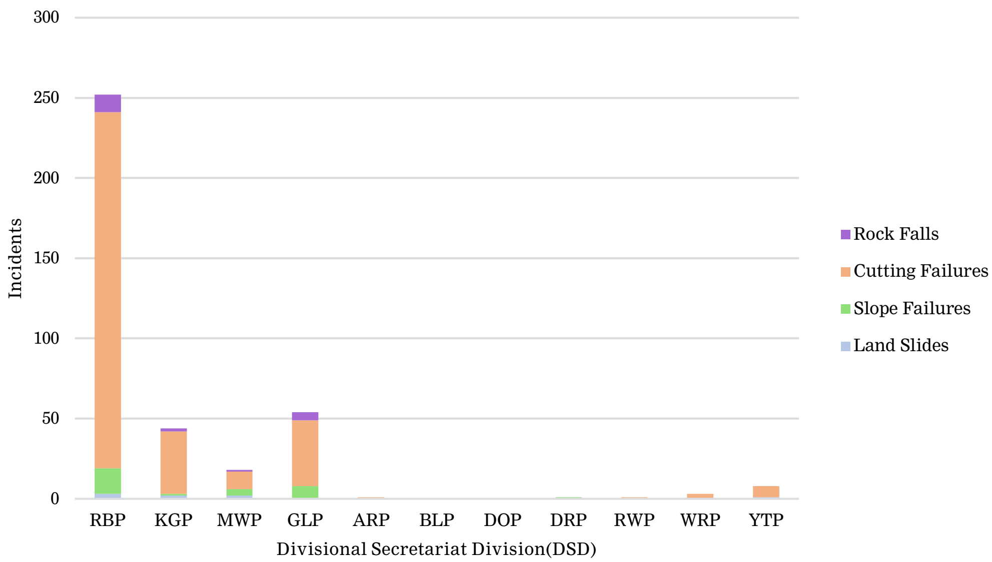

Figure 4: Statistical distribution of landslide incidents in Kegalle district

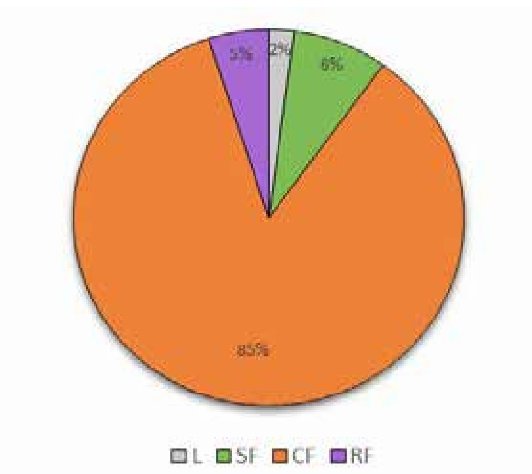

Figure 5: Distribution of different types of ground

Cutting failures are encountered with unplanned constructions/ developments on slope lands without adopting suitable mitigation measures to reduce potential ground failures. Long-term loss of toe supports of vertical cuts forming in development activities easily loose their stability with the prolonged intense rainfall. Encouraging to obtain the NBRO clearance certificate prior to the constructions and developments leads to promote landslide-resilient constructions on slope lands with proper LRR countermeasures.

5. Conclusion

Based on the results of the present study, the following conclusions can be made about the ground instabilities in the Kegalle District induced by adverse rainfall events during 9th -11th November 2021. Incidents are scattered in the northern part of the district and 15% of the incidents reported were natural landslides whereas 85%

were manmade ground instabilities. Among all DSDs, Rambukkana DSD is the division most prone to manmade incidents.

6. Recommendations

When LRR activities such as community-based landslide early warning projects, structural and non-structural mitigation projects are implemented, priority should be given to the northern part of the district.

It is proposed to consider the landslide data in updating landslide hazard zonation maps including possible landslide debris flow and rockfall paths.

Local variation of geological structures and lithology, geomorphological, hydrological and hydrogeological factors, overburden and soil characteristics can be affected by incidents densely accumulated in the northern part of the district. Hence, further studies should be carried out to identify the influence of such factors on ground instabilities in the study area.

Acknowledgement

We extend our appreciation to the members of the staff, Kegalle District Office, Landslide Research and Risk Management Division of National Building Research Organisation, who assisted in data collection.

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Building Resilience amidst
Economic Challenges

Precipitation influence on landslides - A case study for a landslide event in November 2021 in Kegalle District, Sri Lanka

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Abstract

Landslides have been identified as one of the most frequent and widespread natural disasters that can lead to huge damage to life and property in the mountainous terrain of Sri Lanka. Issuing landslide Early Warning (EW) is an effective non-structural landslide risk reduction activity. It is crucial to get the landslide records and rainfall data for deciding the threshold limits for issuing an EW for a disaster-causing rainfall event. The majority of incidents were recorded in Rambukkana, Kegalle and Mawanella Divisional Secretariat Divisions (DSDs) around 3.30 a.m. on 9th of November 2021.

The study was based on rainfall data extracted from automated rain gauges installed by National Building Research Organisation (NBRO), at Anwarama, Kotawella and Kegalu Maha Vidyalaya (MV) Rain Gauge Stations (RGSs) in three DSDs during the event to identify the influence of rainfall on landslides in the DSDs. Rainfall data before the disaster time was studied. The study area was subdivided into drainage basins using Arc-GIS software and LiDAR data. Then, utilizing the basin map and the spatial distribution of the incidents during the event, applicable rain gauges were identified. In this study, incidents within the 9 km diameter buffer zone from the RGSs were considered.

1-hour rainfall values were 41 mm, 19.5 mm, and 17 mm and 72-hour rainfall values were 301 mm, 208.5 mm, and 233 mm at Kotawella, Anwarama, and Kegalu MV RGSs for the event. Incidents occurred even if 1-hour rainfall is less than 75 mm *(75mm is the present 1-hour threshold limit of NBRO)* and 72-hour cumulative rainfall was higher than 200mm. It was concluded that the influence of both cumulative and 1-hour rainfall was the main factor in triggering most of the incidents in Rambukkana DSD. It is recommended to consider both cumulative and 1-hour rainfall threshold limits when issuing a landslide EW. It is more appropriate to develop an EW process based on both cumulative and 1hr rainfall threshold limits for each drainage basin in high-risk areas.

Keywords: Landslide, LiDAR data, Cumulative rainfall, Early warning

1. Introduction

Landslides have been identified as one of the most frequent and widespread natural disasters that can lead to huge damage to life and property in the mountainous terrains of Sri Lanka. Despite the meteorological factors that trigger these events, the anthropogenic factors, like increasing population, urbanization in hazardous areas, deforestation, and land use change, amplify the negative consequences, therefore increasing the exposure of people and infrastructures to disaster risk (Tavares et al. 2012; Promper et al. 2015; Gariano et al. 2017).

After the catastrophic landslide event that occurred in 2016 with 147 losses of lives in the Kegalle district, recently a higher number of deaths which was 12, were recorded in 2021. Three landslide events were reported in May, June and November of 2021. The majority of incidents were recorded in Rambukkana, Kegalle and Mawanella Divisional Secretariat Divisions (DSDs) around 3.30 a.m. on 9th of November 2021. According to reports data for this event, 3 deaths were recorded in the DSDs. 101 numbers of buildings/ infrastructures were at high risk whereas 400 numbers of them were at moderate risk.

NBRO, being the focal point for landslides in Sri Lanka, implements structural and non-structural landslide risk reduction measures to reduce risk at the local and regional level. Issuing landslide Early Warning (EW) is an effective non-structural landslide risk reduction activity. EW is issued when the rain in a certain area exceeds the threshold limit. In general, NBRO is using 75 mm and 150 mm of rainfall as threshold values for 1-hour and 24-hour rainfall respectively in the EW process. During the November 2021 event, a significant number of incidents occurred even if 1-hour rainfall was less than 75 mm.

This work aims to evaluate the effect of long-term and short-term rainfall on ground instabilities in drainage basins of Rambukkana, Kegalle and Mawanella DSDs in the Kegalle District.

2. Relationship between rainfall and landslide

Rainfall is considered the most important natural physical process for landslide triggering in Sri Lanka. Landslide events can occur whether there is intense rainfall over a short period or prolonged rainfall. Most of the landslides can be regarded as rain-induced. Therefore, these occurred when the slopes were highly saturated. This analysis gives only a general idea about the extent to which rainfall is responsible for the failure of the hill slope. However, the actual rain-induced failure mechanism varies from case to case.

Rainfall has both direct and indirect effects on a landslide in an area. The indirect effect includes facilitating weathering, both physical and chemical and the gradual removal of fine particles by the subsurface flow. The direct effect includes saturation of the soil and rock mass, generation of excess pore pressure and erosion of surface soil.

3. Study area

This study was carried out for the 9th of November 2021 landslide event in Rambukkana, Kegalle and Mawanella Divisional Secretariat Divisions (DSDs) due to the majority of the incidents occurring in these DSDs.

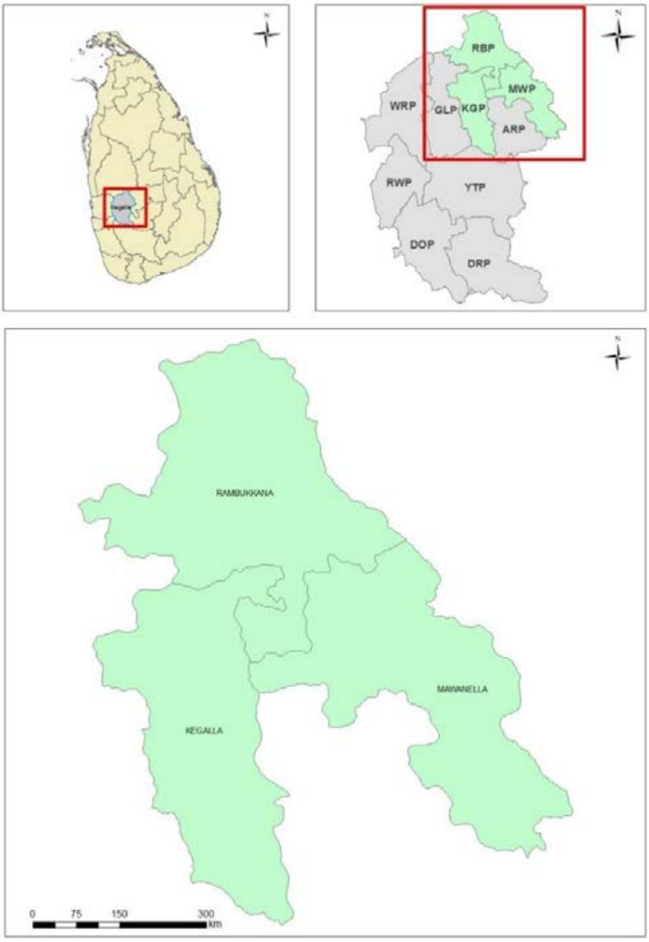

Figure 1: Study area (Rambukkana, Kegalle and Mawanella DSDs area)

4. Methods study

4.1. Landslide event: Disaster database analysis

A total number of 382 preliminary landslide investigation reports issued by the Kegalle District Office of the NBRO for the event were studied and data was collected.

4.2. Rainfall data adjustment

The study area was subdivided into drainage basins using Arc-GIS software and LiDAR data. Then, applicable rain gauges were identified utilizing the drainage basin map and the special distribution of incidents that occurred during the event. The spatial distribution of rainfall is highly unpredictable at a large scale, and to predict the area trend of rainfall, spatial analysis techniques are used. The Inverse Distance Weighted (IDW) interpolation is one of the most commonly used deterministic methods and explicitly implements the assumption that points closest to a point will have more influence on its predicted value than those farther away (Issaks, 1989). Many researchers have used this method for the interpolation of different data in different regions (Price et al. 1999) and thus it can be applied to precipitation/rainfall distribution (Hussain et al., 2021). Based on both fundamental geographic principles and IDW, it is assumed that the same amount of rain is received within a 9 km diameter from the rain gauge located in the same basin. Hence, incidents that satisfied both conditions were considered.

Available rainfall data was collected for the period from 3.30 a.m. on the 06th to 3.30 a.m. 09th of November 2021 covering the disaster period. The raw data available for calculations are the daily accumulation of rainfall. Therefore, the raw data was returned to observation data from the available 30 minutes rainfall, because the 1-hour, 24-hour, 48-hour and 72-hour rainfall data were used to analyse the rain characteristics.

5. Results and discussion

According to the report data, the majority of incidents were recorded around 3.30 a.m. on the 9th of November 2021. Based on the map produced by using ArcGIS and LiDAR data, Kotawella, Anwarama, and Kegalu MV rain gauges were identified in three different sub-basins (Figure 2). Henceforward, the three basins will be referred to by the names of the rain gauges associated with them in the paper for convenience.

According to Figure 2, it is clearly shown that the DSD area and the basin area are not spatially overlapped on the ground. Hence, areas, where a warning should be issued, can be avoided by the NBRO landslide early warning system which is based on administrative boundary areas. For that reason, in order to issue warnings for a potential hazard area, it is important to consider both factors: (1) the basin area where the potential hazard site lies, and (2) the distance between the potential site and rain gauges.

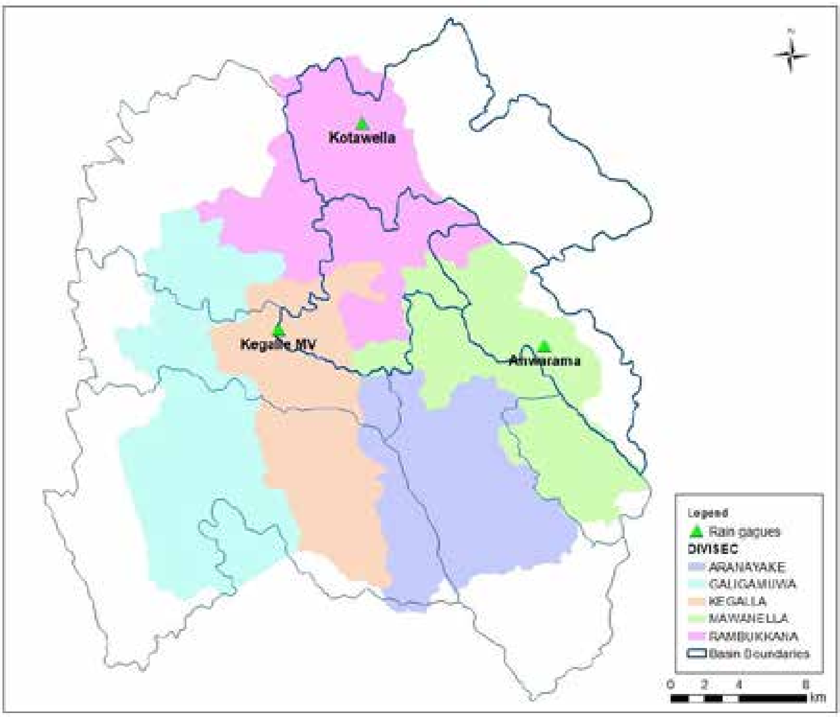

Figure 2: Related and adjacent DSDs to studied sub-basins

Table 1: No. of incidents observed within each basin

Basin	No. of incidents within the basin and 9 km diameter of the buffer
Kotawella	135
Anwarama	35
Kegalle MV	35

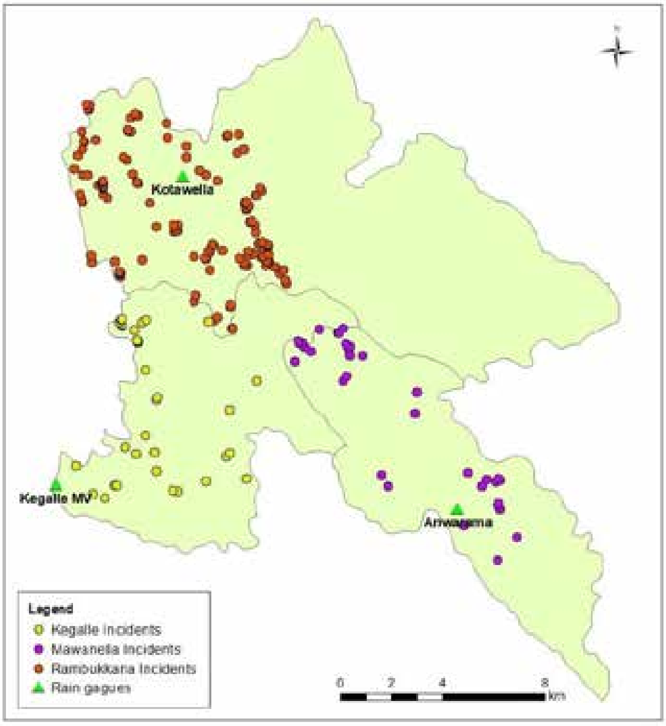

Figure 3: : Incidents in landslide event; November 2021 at a distance of less than 9 km from Kotawella, Anwarama and Kegalle rain gauges and within the same basins as rain gauges

According to Figure 3 and Table 1, 135 incidents were recorded in the Kotawella basin whereas the same number of incidents (35) was reported in both Anwarama and Kegalu Maha Vidyalaya basins. Hence, the number of ground instabilities is dramatically higher in the Kotawella basin than in the others.

Table 2: Rainfall value for sub-basins

Sub-Basin	1hr/mm	24hr/mm	48hr/mm	72hr/mm
Kotawella	41.00	181.00	235.50	301.00
Kegalle MV	17.00	131.75	181.75	208.50
Anvawarama	19.50	109.50	157.00	233.00

According to Figure 4 and Error! Reference source not found., at the incident time, 1-hour rainfall intensities for the event were 41 mm, 19.5 mm, and 17 mm at Kotawella, Anwarama, and Kegalu MV RGSs, respectively. Hence, Kotawella RGS had a higher peak than others. However, rainfall at the event does not exceed the current NBRO 1-hour threshold values. Before the incident, there was more intense 1-hour rainfall in the Kegalle MV and Anvawarama basins.

According to Error! Reference source not found., Kotawella exceeded the 24-hour threshold value, whereas Anwarama and Kegalle MV did not exceed the 1-hour or 24-hour rainfall threshold limits. But considerable incidents were reported in the Anwarama and Kegalle MV basins. In general, the results show that landslides can occur even with low, intense rainfall if it falls for an extended period of time. Hence, it is important to consider 48-hour and 72-hour threshold limits in EW.

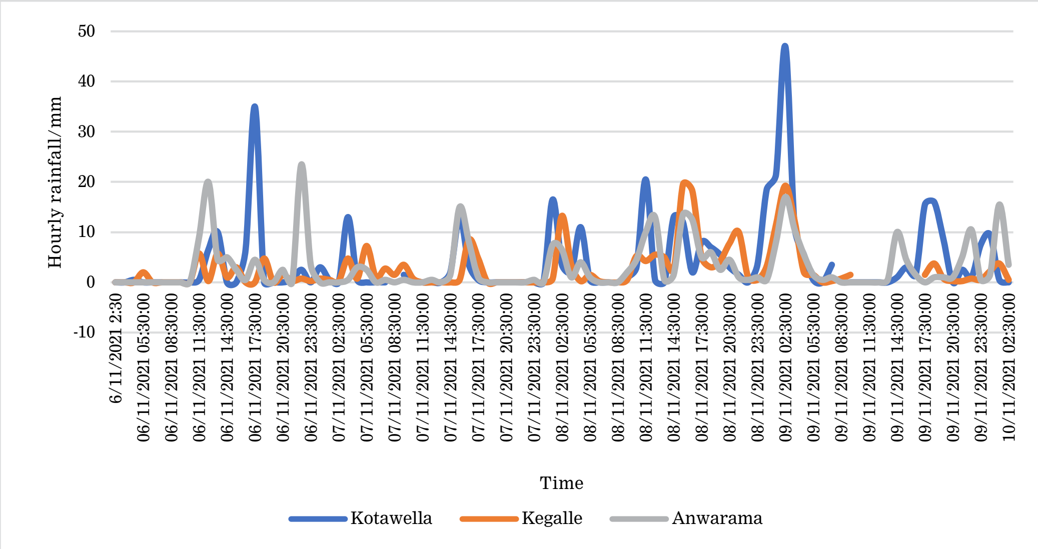

Figure 4: 1-hour rainfall values for each hour from 06/11/2021 02:30:00 to 10/11/2021 02

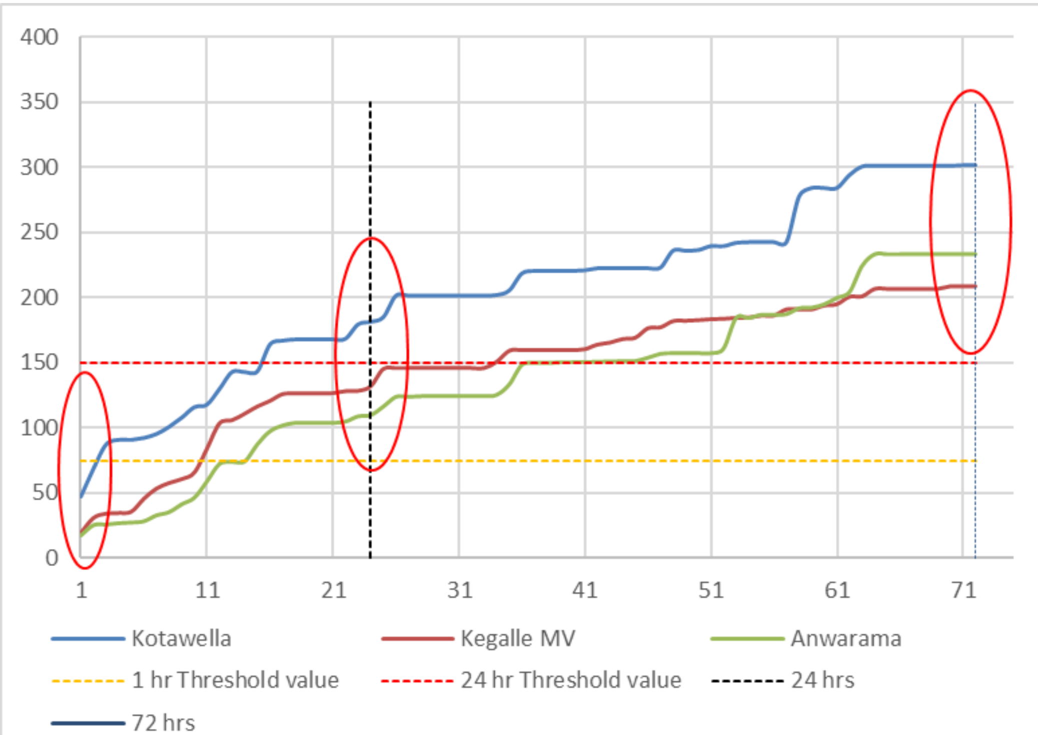

Figure 5: Cumulative rainfall for the last 72-hour from the incident time

6. Conclusion and Recommendations

It is concluded that the influence of cumulative rainfall was the dominant driver in triggering the majority of incidents in this event. Hence, even though the effect of 1-hour of rainfall is not significant, when combined with higher cumulative rainfall values, land failures can occur.

Considering cumulative rainfall, 24-hour of rain alone is not enough to issue an early warning if it rains continuously. It is important to introduce 48-hour and 72-hour rainfall threshold limits.

Issuing an EW based on DSDs isn't accurate enough if the site is located far away from the considered rain gauge and not in the same basin of the rain gauge. The study suggests that it is more appropriate to develop the EW process based on the drainage basin and distance from the rain gauge. For ease of notification, it is preferable to use Grama Niladhari Divisions.

Acknowledgement

We would like to express our appreciation to the staff of the Kegalle District Office, Landslide Research and Risk Management Division of the National Building Research Organisation, who assisted us in collecting data for this project.

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Building Resilience amidst
Economic Challenges

Assessment of vapour concentration and estimation of pollutant load for chemical disasters - A case study on worst maritime disaster in Sri Lanka

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Abstract

In recent years, world has experienced a wide range of chemical related incidents which ended up with disasters. These incidents occur due to natural events, accidental or intentional events. The final result of such disasters caused number of fatalities, economic losses, public health issues, and environmental damages. The most recent disaster is X-Press Pearl ship accident which had taken place at the west coast of Sri Lanka. The ship contained large quantities of chemicals (liquid and solids), materials, oils and toxic substances. Once the ship caught fire accidentally, there was a high possibility to release chemicals as vapours and combustion products to the surrounding atmosphere. These chemical vapours and combustion products could be significantly hazardous to human beings, aquatic life and the environment. Therefore, our study was focused to assess the risk of vapour concentration and pollutant load considering possible worst-case scenarios.

In this regard, potentially high-risk chemicals and their quantities that can be released to the environment and maximum amount of material damage due to the fire, were taken from the Dangerous Goods (DG) manifest of the ship. The vulnerable areas due to the incident affected by vapour concentration were estimated by using Areal Locations of Hazardous Atmospheres (ALOHA) software. The affected vulnerable areas were divided into three levels of concerns namely red zone, orange zone, and yellow zone based on the Emergency Response Planning Guidelines (ERPG's) with respect to each hazardous chemical. Then potential risk areas for human health were identified for emergency response.

The load of pollutants due to the burning of chemical and other materials at the ship were estimated based on the mass balance analysis using respective emission factors. While selecting emission factors, the combustion goods were considered as chemicals, considering the composition of ship cargos and finally it was found that total emitted pollutant load due to the accidental fire was 14,682 Metric Tons (MT) and

load emission respect to CO_2 (843 MT) is more than the annual average CO_2 levels emitted by the transport sector (9 MT) in 2021, Sri Lanka.

Keywords: Vapour concentration assessment, X-Press Pearl, ALOHA, ERPG's, Emission loads

1. Introduction

Chemical incidents in the immediate vicinity of populated areas may result catastrophic consequences with large number of fatalities. During last few years, world has experienced wide range of chemical related incidents. The recent deadly explosion of 2,730 MT ammonium nitrate stockpiled in Beirut's port killed at least 181 with 6,000 injured. Two other noticeable chemical accidents that resulted in catastrophe are Bhopal, India and San Juanico, Mexico in 1984. The Bhopal incident released more than 40 MT of toxic Methyl Isocyanate (MIC) gas killing close to 3,800 people immediately and thousands more in the aftermath [Beckett, 1998; Broughton, 2005; Hood, 2004; Mishra et al., 2009]. The analysis of chemical-related disasters in Sri Lanka shows that 132 chemical accidents leading to some degree of disasters have occurred in industries and related facilities throughout the country during 2006 – 2019 [Kaushalya, 2016]. Also, as an island nation that situated in a major navel route, Sri Lanka is more vulnerable to maritime disasters. As a very recent example, MV X-Press Pearl ship incident can be considered.

MV X-Press Pearl was a container ship that carried 1,486 containers of chemicals and materials [Partow, 2021]. The ship was anchored in outer harbour of Colombo, about 18 km off the west coast of Sri Lanka. Unexpectedly, there was an accidental fire reported on-board of the ship involving containerised chemicals and products. The ship contained highly volatile liquid chemicals that can be directly released as vapour to the atmosphere, and also contained other substances such as (epoxy resins, fabrics, metal, papers, etc.) that undergo fire and produce toxic gases which disperse into surrounding areas depending on the prevailing meteorological conditions. These combustion products can be SO_2, NO_2, CO_2, PM, Dioxin and Furan, etc. which are harmful and toxic to human and environment depending on the exposure time, exposure concentration etc. Due to high temperature in fire, metallic materials could also be released with the combustion products. As a result of that vapour and combustion products can be deposited around the water bodies and some can travel significant distance depending on their atmospheric behavior. Therefore, the situation presented the risk of pollution of the waterways and air with hazardous and noxious materials, with the potential for environmental impact and threat to the health of responders, crews on surrounding vessels and persons onshore.

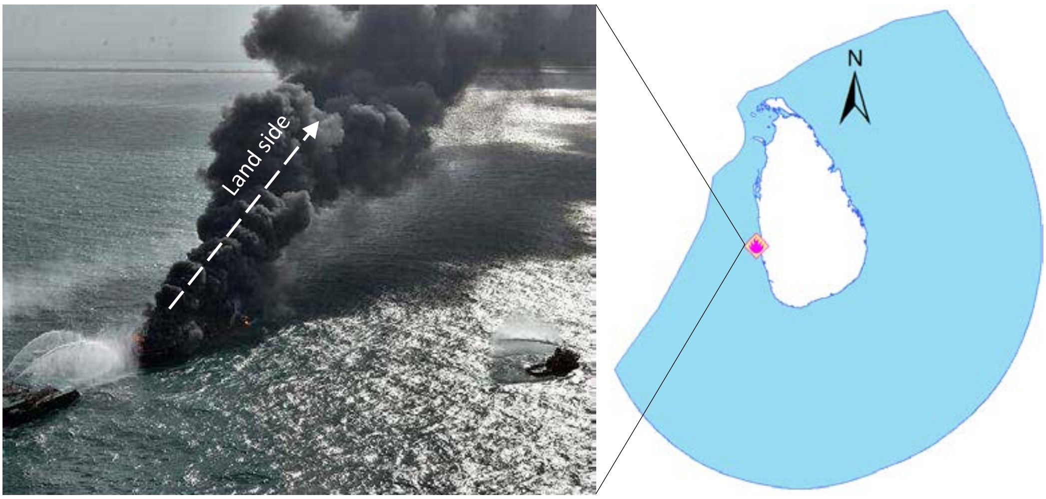

Figure 1: Wind induced smoke rises from X-Press Pearl ship

In such incidents, behavior of chemicals released to atmosphere can be assessed using modelling software. Therefore, this paper discusses the identification of potential risk areas due to the ship incident by using ALOHA modelling software and estimation of pollutant loads, to help in emergency response activities and to assess the damage caused by the incident respectively. Correspondingly, the technique applied in this study can be used to develop emergency response plans, post disaster assessments and risk assessment in chemical industries, etc.

2. Methodology

2.1. Software selection

There are two types of numerical models: first, as operational models applied by decision makers in which results should be clear and instantly available. Other models in which simulation time is less important, and special consideration is given to the accuracy of results [Predrag, 2018]. So, public safety responders and emergency management personnel use operational models for emergency planning of accidental chemical releases. There are various commercial codes for operational models including Gaussian distribution for consequence analysis of risk, such as SLAB, ALOHA, PHAST, etc. [Hosseini, 2016]. Among them, ALOHA (Arial Location Hazardous Atmosphere) is a hazard modelling program which is used widely to plan for and respond to chemical emergencies. Therefore, ALOHA (Version 5.4.7) program was used for identifying vulnerable areas due to chemicals released from the MV X-Press Pearl ship.

2.2. Data collection

Chemical details

Upon receipt of the DG manifest, National Building Research Organisation (NBRO) conducted a review of the hazards presented by DG substances carried by the ship. As a result of that 15 substances on-board the vessels were identified as DG and were distributed throughout the ship in 81 containers. These DG carries number of risks to both human health and the environment. Among them three key products (Nitric acid, Vinyl acetate and Methanol) were selected for the vapour concentration assessment based on the fact its release vapours into the air through volatilization and are found on board the ship in notable quantities (Table 1).

Table 1: Chemicals assessed for air exposure levels and their quantities

Chemical	Volume reported in the inventory
Nitric acid	25 MT
Vinyl acetate	43 MT
Methanol	182 MT

Meteorological details

Meteorological data within the firing period was taken from the Katunayake International Airport meteorological station. The data used were wind speed, wind direction, air temperature and atmosphere stability class.

2.3. Model application

Although the fire remained within an isolated location on-board, individual substance modelling has been conducted to account for a worst-case scenario release of these hazardous substances. Details assumed to be common to all chemicals are listed in Table 2.

Table 2: Common input details for ALOHA software

Variable	Detail
Location of release	7°04'17.6" N, 79°45'27.6" E
Wind speed	8 – 10 ms^{-1}
Wind direction	SW
Depth of release	Water surface
Discharge rate of chemical	10 MT/hr.
Initial area of release	3m diameter pool
Water temperature	30^0C
Air temperature	29^0C
Air stability class	Slightly stable
Surface air was passing over	Open water

2.4. Selection of toxic level of concerns (LOC's)

The forecasts were compared with level of concern (concentration over distance) that have been established for the products to advice on safety exclusion zones considering worst-case scenarios and comparisons were made to the American Industrial Hygiene Association's Emergency Response Planning Guidelines (ERPGs), for short term exposure. ERPGs estimate the concentrations at which most people will begin to experience health effects if they are exposed to a hazardous airborne chemical for 1 hour. A chemical may have up to three ERPG values, each of which corresponds to a specific tier of health effects. The three ERPG tiers are defined in following Table 3.

Table 3: Potential health hazards of the ERPG tiers

ERPG Tiers	Potential Health Effects
ERPG 1	The maximum airborne chemical concentration which an individual can be exposed to for a period of 1 hr without experiencing or developing more than mild, temporary health effects without perceiving a clearly defined objectionable odor.
ERPG 2	The maximum airborne chemical concentration which an individual can be exposed to for a period of 1 hr without experiencing or developing irreversible or other serious health effects or symptoms which could affect an individual's ability to take protective actions.
ERPG 3	The maximum airborne chemical concentration which an individual can be exposed to for a period of 1 hr without experiencing or developing fatal health effects.

2.5. Pollutant load estimation

The pollutants such as SO_2, NO_2, PM, and CO_2, are the prominent gases that generate due to the fire which disperse in the atmosphere depending on the meteorological conditions and reach to ground level away from the source and depreciate the quality of ambient air. The levels of deterioration are based on the emission rate of the pollutant, pollution load (the time and process efficiency), meteorological condition of the atmosphere and the distance from the source etc. As per the evaluation conducted by NBRO for the load fire of the ship, 43% out of the total load was susceptible to be burned. Based on that value, emission loads were calculated for SO_2, NO_2, CO, PM, and CO_2 by using emission factors that are summarized in following Table 4. [Review of emission factors for incident fires, 2009]

Table 4: Emission factors for chemical burning

Pollutant	SO_2	NO_2	CO	PM	CO_2
Emission Factor (mg/g)	175	25	68	8	843

3. Results and discussion

3.1. Nitric acid (HNO_3)

Predictions were developed for the dispersion of HNO_3 vapour in the surrounded air space due to the release of nitric acid onto the decks of the ship, assuming direct release within 2.5-hour time period. The result shows that red and orange tiers of ERPGs are within the sea area and the yellow tier represent some areas in the ground (Figure 2). Accordingly, it was identified that the area of about 120 km^2 can be considered as a vulnerable area in accordance to yellow tier of ERPGs based on the prevailed wind speed and wind direction. The identified area is relatively highly populated area and therefore, the health and environmental damage due to air emission would be significant. Also, the result indicates potential for exposure to personnel working around the ship without appropriate safety measures.

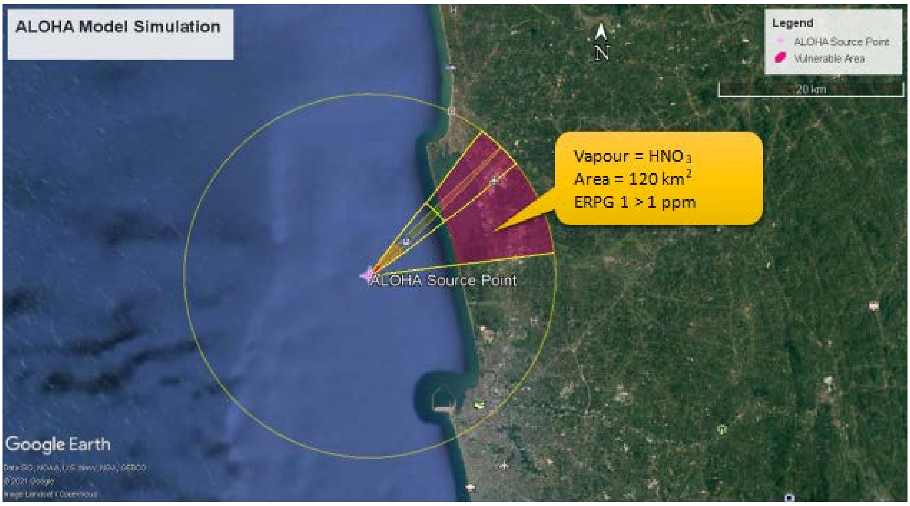

Figure 2: Identified vulnerable area in according to ERPGs for Nitric Acid

3.2. Methanol

The simulation for the potential short-term exposure limits indicate that lowest limits (ERPG 1) should not be exceeded beyond 3.5 km downwind but that ERPG 2 could be exceeded within 0.6-1.5 km downwind and that ERPG 3 is likely to be exceeded within 0.1-0.6 km downwind. The vapor concentrations calculated for the methanol was dispersed below safety thresholds before reaching to the land as shown in the following Figure 3. Nevertheless, all the critical exposure levels are within the sea area closure to the location of the ship and it will generate a risk of sea water contamination.

Figure 3: Identified vulnerable area in according to ERPGs for Methanol

3.3. Vinyl acetate

Vinyl acetate is highly volatile and rapidly evaporate on exposure to the atmosphere and would generate heavier than air vapour if evaporating on the deck. Calculations for short term exposure, indicate a high danger zone, exceeding red tier of ERPGs, would exist within 0.1 km to 0.6 km downwind of the vessel and orange tier of ERPGs might be exceeded at distances of up to 1.5 km. Yellow tier of ERPGs was exceeded at distance up to 7 km. The vapor concentrations calculated for the Vinyl acetate was dispersed below safety thresholds before reaching to the land as shown in the Figure 4. Nevertheless, all the critical exposure levels are within the sea area closure to the location of the ship and it will generate a risk of sea water contamination.

Figure 4: Identified vulnerable area in according to ERPGs for Vinyl acetate

3.4. Pollutant load

Based on the collected information, the total load of air emissions released to atmosphere as chemical fire can be estimated. As highlighted in Table 5, total of 14,682 MT of air pollutants were added to the atmosphere by the fire at MV X-Press Pearl ship. The calculated SO_2, NO_2, CO, CO_2, and PM productions are 2,296 MT, 328 MT, 892 MT, 11,061 MT, and 105 MT respectively.

Table 5: Estimated amount of pollutant load released to atmosphere

Total Weight (MT)	Amount Combustion	Emission Load (MT)					Total (MT)
		SO_2	NO_2	CO	PM	CO_2	
30,514	43%	2,296	328	892	105	11,061	14,682

4. Conclusion

Dispersion modelling for released gases from X -Press Pearl ship was carried out using ALOHA software and results suggest less risk to terrestrial communities based on the ship position and the exposure thresholds used (Table 6). But chemical vapor and pollutant concentrations are very high around the ship area and have potential for high exposure to personnel working around the ship without appropriate safety measures. As a result of that, there is high possibility of deposition and acid rains with rain around the 10 km area from the ship. Modelling considered a worst-case scenario, whereby significant releases of the most dangerous substances occur, though actual releases at-site may be considerably less. The vessel was at a significant distance offshore and modelling suggests terrestrial populations are considered safe from the effects of individual substance vapours, however diligence must remain for those working at site for more localised effects and for the possibility that substance combinations could produce additional threats.

Table 6: Maximum distances for chemical vapours at LOC's

Chemical	LOC's	Maximum Distance to LOC's (km)
Nitric acid	ERPG 3 / (78 ppm)	1.5 (dispersed within the sea)
	ERPG 2 / (10 ppm)	4.4 (dispersed within the sea)
	ERPG 1 / (1 ppm)	21.5 (dispersed into land)
Vinyl acetate	ERPG 3 / (500 ppm)	0.6 (dispersed within the sea)
	ERPG 2 / (75 ppm)	1.7 (dispersed within the sea)
	ERPG 1 / (5 ppm)	7.1 (dispersed within the sea)
Methanol	ERPG 3 / (5000 ppm)	0.6 (dispersed within the sea)
	ERPG 2 / (1000 ppm)	1.5 (dispersed within the sea)
	ERPG 1 / (200 ppm)	3.6 (dispersed within the sea)

Air quality monitoring programs that were conducted at ship and land area by the NBRO also proved the results of ALOHA model. Hence, application of such modelling approach for assessing chemical release incidents can be recommended.

The pollutant load emission was estimated by assuming burning of 43% of cargo in the ship as chemicals and estimations indicate that total of 2,296 MT of SO_2, 328 MT of NO_2, 892 MT of CO, 105 MT of PM, 11,061 MT of CO_2 were added to the atmosphere by the fire incident of Xpress Pearl ship.

Acknowledgement

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Building Resilience amidst
Economic Challenges

Study on exposure to domestic indoor air quality in Colombo, Sri Lanka

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Abstract

Indoor Air Quality (IAQ) has a significant impact on health and quality of life as people spend about 90% of their time in indoor environments than outdoor. In particular, poor indoor air quality is caused by many indoor and outdoor sources and exacerbated by inadequate ventilation. This can affect occupant's health and finally the human productivity. Hence, identification of pollutants, levels & causes are highly important in IAQ management.

Our study was aimed to investigate the IAQ in selected households in different utility areas, dependence on the cooking fuels and stove conditions of households in Colombo district, Sri Lanka. The measurements were taken continuously for the period of five days including weekdays and weekends by using real time monitoring equipment with data loggers. During the monitoring period, the activities of households were recorded.

The results indicate relatively high pollutant levels during the cooking time of the day in all households. The average concentrations of CO_2 and Particulate Matter (PM_{10}) in kitchen areas are higher than those measured in the bed rooms. Whereas, the levels in bedrooms are higher than in living rooms. The measured parameters of CO_2 and Particulate Matters ($PM_{2.5}$ and PM_{10}) levels are significantly high in houses, which use firewood without chimney than the houses with chimney. The pollutant levels are high in the houses, which use firewood as cooking fuel than Liquefied Petroleum Gas (LPG). Further, the results indicate that the average concentration of PM_{10} levels in household with firewood stoves exceeds the World Health Organisation (WHO) guideline levels for 24 hours. The PM_{10} levels in households with chimney have significantly low values compared to stove without chimney despite of using LPG as cooking fuel.

Keywords: Carbon dioxide, Carbon monoxide, Respirable particulate matters

1. Introduction

Air pollution, both indoors and outdoors, is a major environmental health concern, affecting people especially in developing countries. This is a critical issue in all countries as people typically spend 90% or more of their time indoors. The condition is worst when the most susceptible individuals such as the elderly and those with pre-existing medical conditions[1].

It is known that approximately 11,000 liters per day of air is inhaled by a healthy elderly person. This amount is higher for children and different for susceptible individuals such as the elderly or having pre-existing medical conditions. When air is contaminated with toxic pollutants they migrate into human body and get absorbed, then retain & cause damage to different organs. Studies have shown that even short-term exposure to unsatisfactory indoor air adversely influence human productivity. In addition, the long-term exposure to polluted air may increase symptoms of allergies and asthma, finally which may leads to development of chronic illnesses like cardiovascular disease or lung cancer. The exposure to high toxic air pollutants even at relatively small concentrations may cause a variety of health effects such as headache, allergy, or mucus membrane irritation[2]. The extent of the effect of a particular pollutant on human health depends on its concentration, toxicity & the duration of exposure. Therefore, quality of air especially in indoors is highly recognised as important in improving occupant health, comfort, physical & mental wellbeing and the human productivity[3].

IAQ in domestic households depends on sources of pollution, environmental conditions, housing characteristics and behavioural factors etc. In addition, IAQ levels highly depend on factors such as the physical & chemical properties of pollutants (gaseous or particulate, reactivity, deposition, size for particulates), use of household products such as detergents, cosmetics and insecticides, construction and furnishing materials such as chemical flame retardants and occupant behaviour & activities. However, the major pollutant sources of residential households are the emissions from cooking activities.

Poor indoor air quality is usually the result of sources that release and accumulate pollutants (gases or particles) into indoor spaces. The ventilation is the phenomena that exchange indoor air with outdoor atmosphere generally considered as fresh air. Once the ventilation is inadequate due to the construction and design failure in buildings that causes indoor air quality problems. In addition, temperature and humidity levels can also control the air dispersion and result in poor indoor air quality. All internally generated airborne pollutants ultimately can be classified into three groups; (1) those related to human activity or presence (2) those formed in combustion processes (heating and cooking) and (3) those released from construction material and furnishings. Concentration of contaminants coming from the first two categories tends to vary with time and in the third, is more likely to be constant. In addition, if the outdoor air is polluted it can contribute to poor indoor air quality as well.

The most common indoor pollutants are Carbon Monoxide, Carbon Dioxide, Ozone, Volatile Organic Compounds (VOCs), Particulate Matter with different aerodynamic diameter (PM_{10}, $PM_{2.5}$, PM_1, etc.), Total Suspended Particles (TSPs), Organic and Inorganic contaminants, Biological particles such as bacteria, fungi, pollen; and Asbestos which has been used as a building construction material.

Globally, biomass fuel is considered as the main source of indoor air pollution in households[4]. In Sri Lanka, 78.5% of the households use wood; 16.7% use LPG and 2.8% use Kerosene as the cooking fuel. Among the households using wood as the primary cooking fuel, 65.3% of households cooked in kitchens within the same building; 9.5% of these households had an outdoor kitchen area[5, 6].

The main objective of this study is to collect the IAQ data in different utility areas within the house such as living room, bedroom & kitchen area to assess the residential IAQ in selected urban/sub urban areas.

2. Study area

The sampling sites were selected by considering the urban and suburban areas of the Colombo district having different environmental conditions. Special consideration was given in selecting households based on the cooking fuel (LPG & firewood). The houses were selected that use Liquefied Petroleum Gas (LPG) and firewood as cooking fuels and with & without chimney for ventilation purposes.

IAQ data were collected from the bedroom, living room and kitchen area to represent different indoor conditions. The sampling locations in urban/sub urban areas of Colombo district are given in Figure 1.

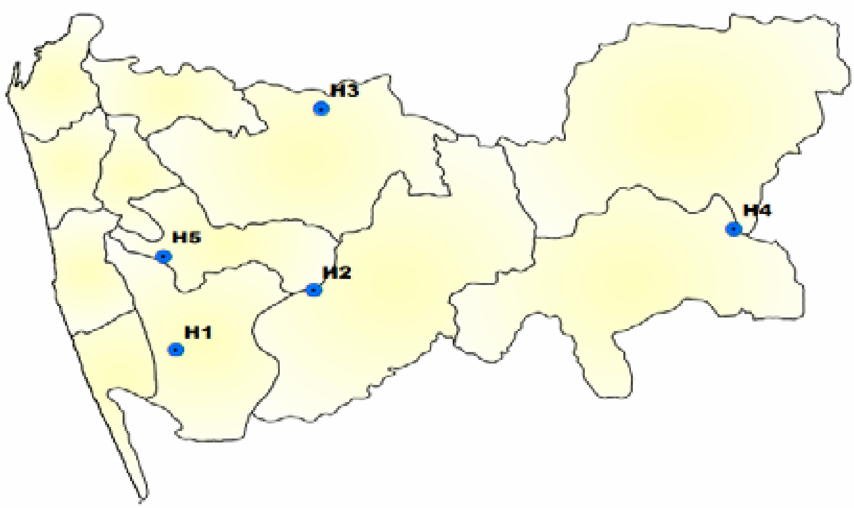

Figure 1: The selected locations in Colombo district

3. Methodology

The measuring parameters were Carbon Dioxide (CO_2), Carbon Monoxide (CO), Particulate Matter levels (PM_1, $PM_{2.5}$ PM_{10}), Total Volatile Compound (TVOC), Nitrogen Dioxide (NO_2), temperature and humidity.

The equipment used for the measurements were sensor-based air quality monitoring devices with data loggers (Real-time air quality monitoring sensors) with different technologies. Both Beta (β) attenuation technology and Light scattering technique were used for the measurement of Particulate Matter concentration. The Non-Dispersive Infrared (NDIR) absorption technique was used to measure CO_2 levels. Whereas, Chemiluminescence (CLD) technique was used to measure the NO_2 levels.

The sensor units were installed in each utility area of each household simultaneously. The measurements were done in five consecutive days including week days and weekends to cover the times of preparation of breakfast, lunch & dinner and all indoor housing activities as well. The sensor units were positioned to the center of the living room & bedroom and 1m from the stove in kitchen area.

The raw data were transferred to the computer from a data logger and the data were analysed by using statistical software by using MINITAB 16.

During the sampling period, the socio-economic parameters such as divisional area, number of occupants, respiratory problems, ventilation conditions, and the use of mosquito coils and incense sticks were recorded in each household by using a detailed questionnaire. The collected data were useful to analyse the variation of the parameters with respect to the daily activities in each household. The brief information gathered related to cooking activities in each household is given in Table 1.

Table 1: General description of cooking activities in selected houses

House No	Cooking Schedule	Type of cooking fuel	Use of chimney at kitchen area
H1	Morning- 3.30-5.30am Night - 6.30-7.30pm	Fire wood & LPG	No
H2	Morning- 4.30-5.30am Night - 6.30-7.30pm Only weekends-12.30-1.00pm	LPG	No
H3	Morning- 4.30-6.15am Night - 7.00-8.30pm	Fire wood	No
H4	Morning- 5.30-7.00 am Night - 7.30-9.00 pm	Fire wood	Yes
H5	Morning- 4.00-6.00 am Day- 12.15 -1.15 pm Night - 6.00-8.00 pm	Fire wood & LPG	Yes

4. Results and discussion

The measured average indoor air pollutants in each utility area of all households are given in Table 2.

Table 2: The 24-hrs average indoor air pollutants in each utility area of all households

House No.	Utility area	$PM_{2.5}$ (ug/m^3)	PM_{10} (ug/m^3)	CO_2 (ppm)	VOC (ppm)	Temp. (^{0}C)	Humidity (%)	NO_2 (ppm)	CO (ppm)
H1	Living	52	62	520	1	34	57	7	3
	Bedroom	53	60	532	0	35	58	7	4
	Kitchen	63	75	504	1	34	57	6	4
H2	Living	44	48	455	0	37	52	7	3
	Bedroom	38	42	435	0	38	56	8	2
	Kitchen	62	69	483	0	37	51	8	3
H3	Living	84	102	458	0	36	58	8	3
	Bedroom	51	57	439	0	36	57	9	2
	Kitchen	114	129	570	0	36	59	8	4
H4	Living	34	38	449	0	36	53	7	2
	Bedroom	26	30	436	0	36	56	8	2
	Kitchen	38	53	486	0	35	56	6	3

H5	Living	26	36	435	0	36	53	6	1
	Bedroom	31	32	448	0	37	53	7	1
	Kitchen	33	40	488	0	36	56	8	2
Guideline Levels	WHO	25	50					3	10
	ASHRAE			1000					
	ACGIH								
	LEED				0.15				

Among those parameters, the most predominant and variable parameters were Particulate Matter, CO_2 & CO and those parameters were analysed and compared with relevant indoor air quality guidelines recommended by the World Health Organisation (WHO) for indoor air quality.

The measured 24-hr average concentrations of PM_{10} levels in kitchen areas of each house with respect to 5 consecutive days are shown in Figure 2, 3, 4, 5 & 6. High peaks were observed in cooking times in all houses. As shown in figures the pattern is similar in all houses. However, in house no. H3, the evening cooking time shows only two peaks for two days. This is due to in other days they have not prepared their meals as indicated in socio-economic data base. In addition, the house no. H5 shows three predominant peaks as they have prepared meals three times per day as indicated in socio-economic data base.

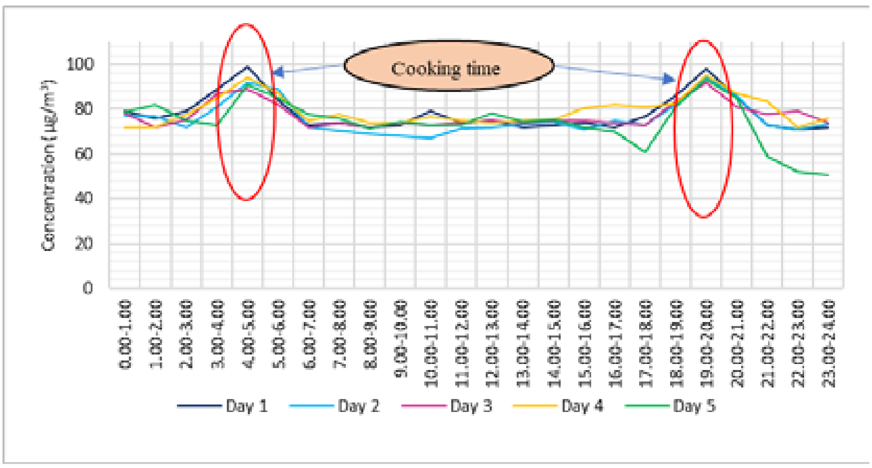

Figure 2: Variation of average PM levels during cooking/non-cooking intervals at H1

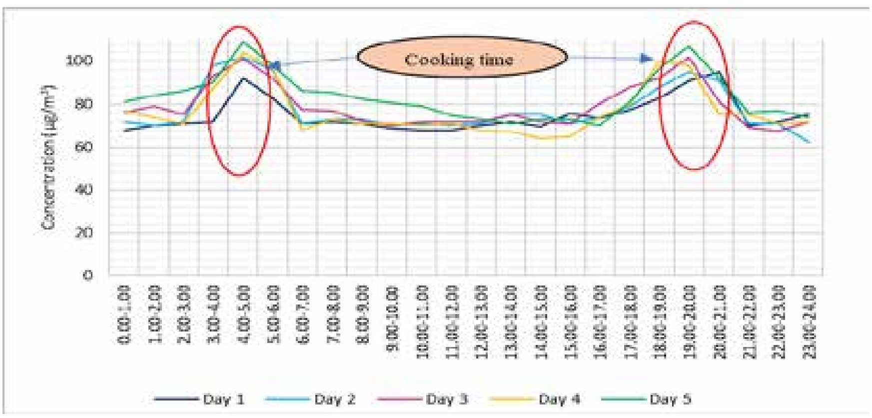

Figure 3: Variation of average PM levels during cooking/non-cooking intervals at H2

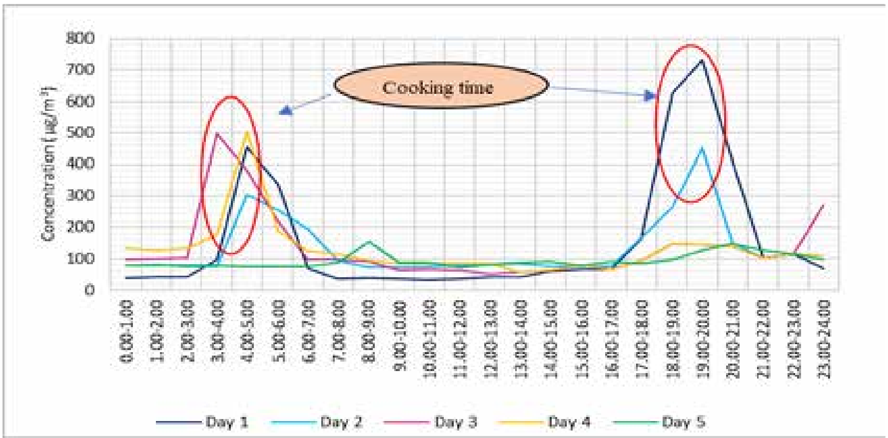

Figure 4: Variation of average PM levels during cooking/non-cooking intervals at H3

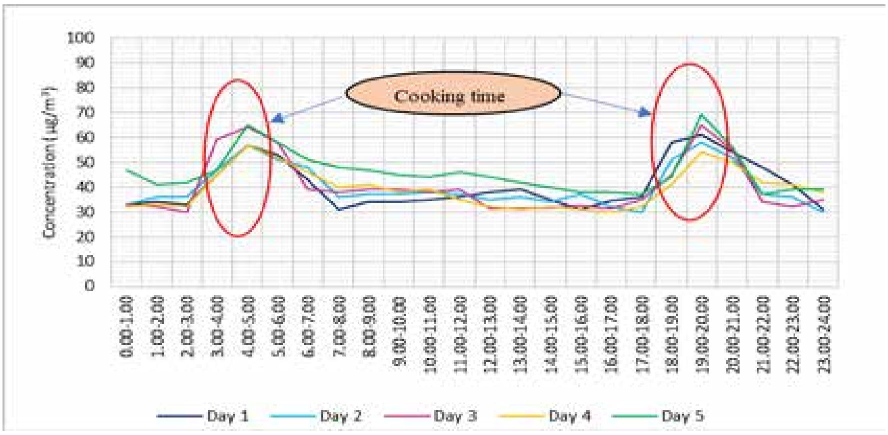

Figure 5: Variation of average PM levels during cooking/non-cooking intervals at H4

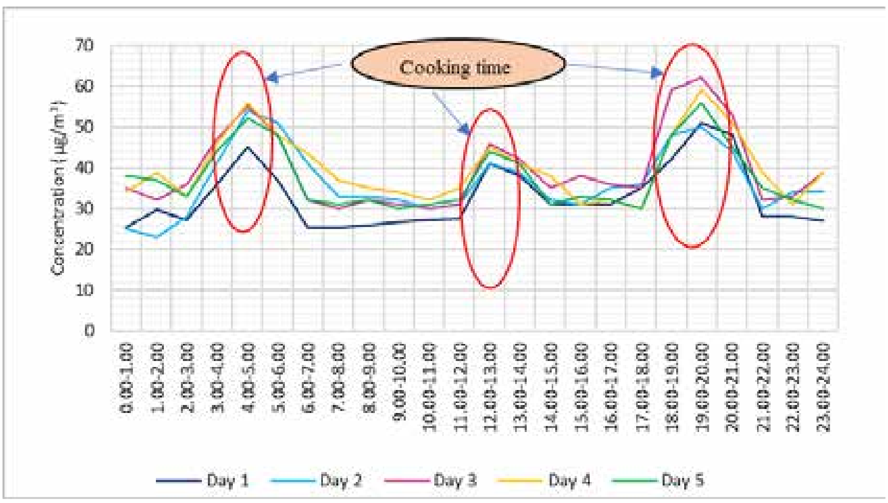

Figure 6: Variation of average PM levels during cooking/non-cooking intervals at H5

The measured 24-hr average indoor air pollutant concentrations with respect to $PM_{2.5}$, PM_{10}, CO and CO_2 in different utility areas (living areas, bedroom area and kitchen area) in each household are represented in Figure 7, 8, 9, & 10 respectively.

The average pollutant levels of PM ($PM_{2.5}$ & PM_{10}), CO_2 and CO in all utility areas in houses, which use firewood as cooking fuel (without chimney) were significantly higher than the other. This is because, LPG is considered as a cleaner fuel and stove with chimney has a proper path to emit pollutants generated by stoves. Whereas, even with the use of LPG, pollutants levels are high in houses that use combination of cooking fuels. Among $PM_{2.5}$ particle portion, higher percentage consists with particles less than 1 micrometers (fine particles), which poses the greatest risk to health. The average concentrations of $PM_{2.5}$ levels in all houses exceeded WHO guideline levels and PM_{10} levels also exceeded in most of utility areas in houses. The average CO_2 and CO levels did not exceed the relevant guideline levels. The recorded other parameters were in very low concentrations when compared to the guideline levels.

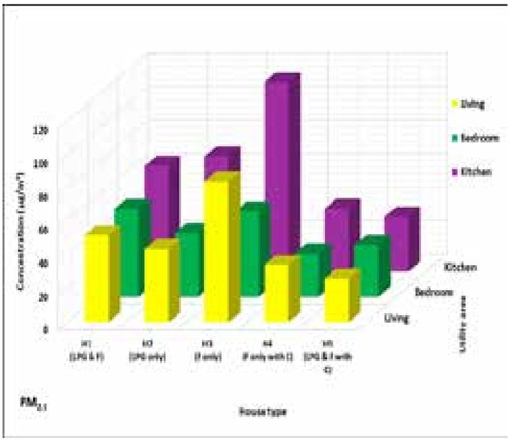

Figure 7: Variation of average $PM_{2.5}$ levels with fuel type and utility area

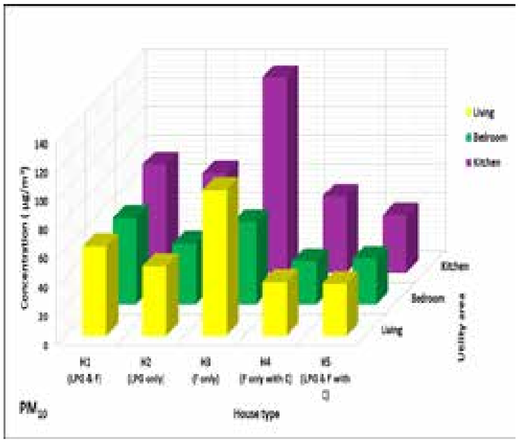

Figure 8: Variation of average PM_{10} levels with fuel type and utility area

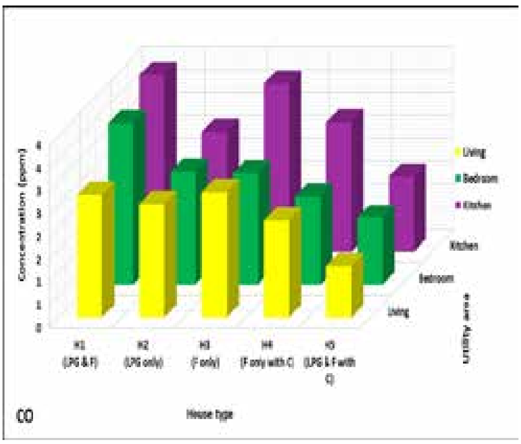

Figure 9: Variation of average CO levels with fuel type and utility area

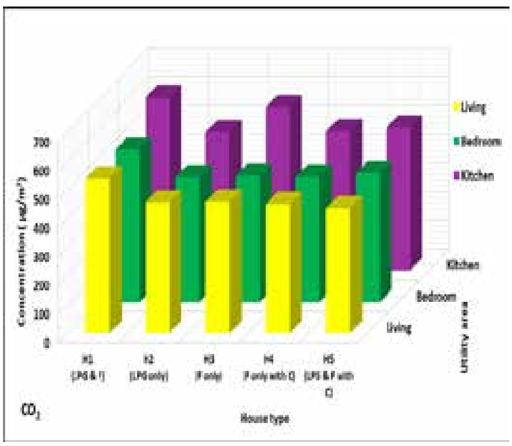

Figure 10: Variation of average CO_2 levels with fuel type and utility area

The data clearly indicate that the measured pollutant levels are low in houses with chimney and stoves using LPG as cooking fuel. In Sri Lanka, about 78% of the households use firewood for cooking often in congested poorly ventilated kitchens indicating that the exposure levels are relatively high, which could affect health of occupants[5]. Further this may also affect air quality in other utility areas such as living room and bedroom.

It has been clearly shown that the Particulate Matter levels were significantly higher in households using firewood compared to where LPG is used for cooking. The representative levels were significantly higher in households using firewood when compared with the houses which use LPG for cooking. In addition, it is evident that, this pollution levels can be reduced or controlled by using proper ventilation mechanism such as the use of a chimney and allowing open areas for well dispersion of pollutants. According to Figure 10, the average CO_2 levels in all utility areas were significantly much higher in the households, which use both LPG & firewood compared to where only LPG is using for cooking. According to the socio-economic data, it was observed that this variation is due to the high frequency of use of firewood cooking stove than LPG cooking stove during the measuring period. In addition, poorly ventilated kitchen within the same building without chimney could affect air quality in the living room and bedroom in the particular household. During the cooking time, there will be high temperature above the stove and a temperature gradient will be created within the chimney resulting in high dispersion of pollutants through the chimney to outside. Therefore, having a chimney will minimize the dispersing of hot air to other utility areas in a house and can be used as a tool to reduce the indoor air pollution significantly.

5. Conclusion

Among measured parameters, the most dominating parameters in the selected sampling sites were found to be CO_2 and PM_{10}. Therefore, more concern should be given to investigate these parameters in future studies to achieve better conclusions. The pollutant levels were higher in domestic kitchens than in bedrooms and living rooms. In all households the pollutants levels are significantly high during the cooking time than in other times of the day. The pollutant concentration levels are remarkably low in kitchen areas when using proper ventilation systems such as chimney or when kitchens are in open areas irrespective of whatever the cooking fuel is used. Therefore, by providing a chimney or a fume hood above stoves is a valuable tool to reduce the indoor air pollution significantly.

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Building Resilience amidst
Economic Challenges

Study on factors contributing to the vulnerabilities of communities living in landslide high hazard areas - A case study on Kegalle District

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Abstract

Landslide is identified as one of the major disaster events in Sri Lanka as posing a severe threat to human lives. This extreme natural event is unpredictable, but their risk can be managed by taking appropriate countermeasures. Therefore, it is vital to understand, that disasters require tracing the connections that link the impact of a hazard on people. Accordingly, this paper aimed to analyze factors and processes of vulnerability that generate landslide risks. This study utilized 7,223 building survey data from the Kegalle District, collected from a questionnaire survey conducted under the Landslide Risk Profile Development Project (LRPDP) of the National Building Research Organisation (NBRO). The survey data extracted 15 factors from the questionnaire which was used for the LRPDP as per the Vulnerability categories – root causes, dynamic pressure unsafe condition. The findings revealed that majority of the factors are biased on the risk posing side; Approval obtained for house construction, type of terrain of the surrounding area of the house, and membership in a village level society/organization are the highly vulnerable factors; and each factor is interconnected for a certain level.

Keywords: Communities, Hazard, Landslide, Vulnerability factors

1. Introduction

Landslides are a common geological hazard that occurs because of various reasons. It happens when massive amounts of soil, rocks, or debris slide down a slope as a result of a natural occurrence or human activity (Nadim, et.al, 2006). The World Health Organization (WHO) reported that 4.8 million people were affected and more than 18,000 people deaths were from landslides during the 1998 - 2017 period.

These extreme natural disasters are triggered by climate changes, high intensity of rainfall, deforestation and unplanned (haphazard) urbanization (Schuster, 1996; Yin, et al., 2021) and it is unpredictable, but the risk can be managed by taking precautionary measures and installing early warning system. To do so, it is important to identify and understand the factors of trigger landslide risk (Arrogante-Funes. Et.al, 2021).

The United Nations Office for Disaster Risk Reduction (UNDRR) define risk as “the potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity”. It simply indicates the integration of the hazard and vulnerability. The literature concerning landslide hazard assessment is extensive (Miccadei, et.al, 2022; Wani, et.al, 2022; Souisa, et.al, 2016). Meanwhile, Lin, et.al, (2017) & Arrogante-Fune et al. (2021) stated that there are very limited research done on the factors contributing to landslide vulnerability. Because, vulnerability is a complex phenomenon to explain (Lin, et.al, 2017), Glade (2003) noted that the periodic probability of humans exposed to the disaster and the element at risk differs from a similar hazard event. So, it is emphasized that understanding the vulnerability of the particular context is vital to reduce the associated risk. To fill this gap, the study aims to identify the vulnerability factors to support the authorities to take appropriate countermeasures.

Accordingly, this paper is organized as follows: Section 2 explains the importance of understanding the vulnerability factors in disaster management. In section 3, the study presents the methodology and materials of the study. Results and discussion of the study are presented in section 4. Finally, the conclusion and future research interests are presented in section 5

2. Literature review

Vulnerability is defined in the natural hazard nomenclature as “the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard”. It is a widely talked about key topic among researchers, in order to reduce the risk and assist the vulnerable communities to achieve a safer living environment (Nor Diana, et. al., 2021). The vulnerability factors can be categorized into three, and those are – underlying causes (Root causes), dynamic pressures and unsafe conditions.

Root causes are an interconnected set of extensive and general processes that occur within a society and the global economy. They are 'distant' in at least one of the following ways: chronologically remote (occurring in a distant center of economic or political power), geographically distant (in history). Dynamic pressures are processes and activities that 'translate' the impacts of underlying causes into dangerous conditions both temporally and spatially. These are more recent or immediate manifestations of underlying economic, social, and political tendencies. Unsafe conditions are the exact ways in which a population's susceptibility manifests itself in time and space in connection with a hazard (Wisner et.al., 2003).

Accordingly, the authors tried to incorporate several factors into vulnerability assessment. Arrogante-Funes et.al (2021) considered factors such as socioeconomic - marginality, population, state of buildings and income; ecological – biodiversity, state of conversation, habitat fragmentation and ecological regeneration delay. Nor Diana and others (2021) analyzed 18 social factors – age, gender, ethnicity, built environment, income, family structure, education, employment, urban/rural, special need population, migration, health and population. Ketelaar (2018) categorized the landslide vulnerability as individual vulnerability and collective vulnerability: Individual vulnerability – poverty indices, the proportion of income dependent on risky resources, dependency and stability; collective vulnerability – Gross Domestic Product per capita, relative inequality, qualitative indicators of institutional arrangements.

Pollock & Wartman (2020) emphasized that vulnerability depends on human behavior factors, including challenging elements such as prior hazard awareness, situational awareness, and decision-making skills. Most of the time the finding of the human behavioral factors depends on expert judgment. The reason behind this is, the investigation of the vulnerability should be assessed aftermath of a disaster but the people who have been involved in the incident could relocate, be hospitalized, or be dead. Finally, it has to go through ethical approval to conduct research (Pollock & Wartman, 2022) and it will be a huge time-consuming process. To sum up, vulnerability is a critical phenomenon to define due to the changing attribute; still, the authors tried to analyse the vulnerability through several factors. Still, it is also essential that disasters require tracing the connections that link the impact of a hazard on people with a series of factors and processes that generate vulnerability.

3. Research design

3.1. Methodology

The methodology for this study followed the NBRO initiated project called "Landslide Hazard Zonation Mapping Project (LHMP)" to identify the landslide susceptibility location in the upcountry areas in the early 1990s. Under the LHMP, landslide hazard maps were developed on two scales such as 1: 50,000 and 1: 10,000. 1:50,000 scale maps were developed decision-making national and regional level development endeavors while 1: 10,000 scale maps were aimed to use as a tool for more localized decision-making. The 1:10,000 scale maps were developed for identified regions of the landslide-prone districts. The NBRO initiated a landslide risk profile development programme for the areas covered by the 1:10,000 scale LHMP maps in the year 2016. The project surveyed all the buildings located in landslide high-risk category areas of the LHMPs.

Further, the survey question includes (i) demographic profile of the households (ii) land use and characteristics of the buildings (iii) guidelines followed in construction (iv) impacts caused by disasters (v) availability of disaster preparedness measures (vi) disaster risk reduction measures practiced by the occupants. Initially, the study tried to extract 15 vulnerability factors from the questionnaire survey as shown in Table 1.

Table 1: The factors taken to analyze the vulnerability

Vulnerability catagory	Vulnerability factor
Root causes	R1: Possibility of access road to house affecct by disaster
	R2: Preference in the event of disaster induced relocation
Dynamic pressures	D1: Professional Support obtained to build house
	D2: Designer of the house
	D3: Approval obtained for house construction
	D4: Type of terrain of the surrounding area of the house located
	D5: Change of land morphology

	D6: Action taken to discharge water
	D7: Level of education
	D8: Engage in disaster management activities
	D9: Take precautionary measures to face landslide during last three years
	D10: Availability of disaster management committee in the village
	D11: Receive instruction on disaster prepardness
Un-safe condition	U1: Employment
	U2: Membership in a village level society/organization

Secondly, in order to understand the most vulnerable level, the weighted overlay method was applied for each factor to normalize the data, and the high vulnerability score was taken for the analysis.

In addition to the vulnerability calculation, we used the IBM SPSS Statistics package to perform a correlation analysis to evaluate the importance levels of the factors that have a significant impact on the total vulnerability levels.

3.2. Case study area

A case study approach was used in this study to assess the landslide vulnerability of the community. Kegalle District was selected as the case study area (Error! Reference source not found.). It is one of the major disaster-prone areas in Sri Lanka. Considering this the LRPDP also initiated the survey in this district. From the entire spatial extent of the Kegalle District, 1,693 Km2, land area of 776.99 Km2 has been mapped under 1:10,000 Landslide Hazard Zonation Map. It covers 10 Divisional Secretariat Divisions (DSD) such as Aranayake, Bulathkohupitiya, Dehiowita, Deraniyagala, Galigamuwa, Kegalle, Mawanwella, Ruwanwella, Warakapola and Yatiyanthota. Among these 10 districts, nearly 7,223 houses have been surveyed (6,459 landslides are to be expected, 194 landslides are most likely to occur, 417 landslides have occurred in the past and 153 rock falls and subsidence).

Figure 1: Location of Kegalle District

4. Results

4.1. The root causes

The survey finding indicates only 24% of the housing units have alternative roads to access their houses and the majority (76%) of the housing units have no alternative roads to access their houses during a disaster (Figure 2).

In the event of relocation induced by a disaster, most (46%) families prefer to relocate within the current Grama Niladari Division and 24% of families prefer to relocate within the current DSD, while another 15% of families prefer to relocate within the current district. The survey revealed, 13% of families have no specific preference for relocation. While 2% prefer to relocate to other places in the event of relocation induced by the disaster (Figure 3).

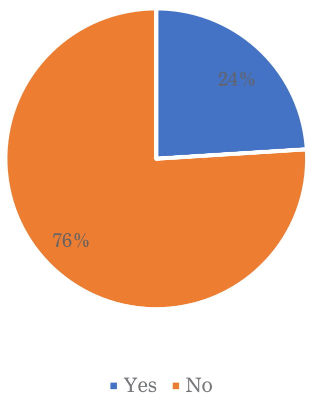

Figure 2: Possibility of access road to house affect by disaster

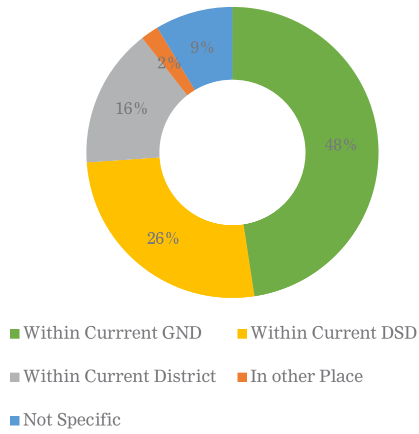

Figure 3: Preference in the event of disaster induced relocation

4.2. The dynamic pressure

Among the surveyed housing units only 20% of the houses obtained the support of professionals, whereas 59% haven't obtained the support (Figure 4). Most importantly, the majority 37% of the houses are designed by the house owners themselves. Meanwhile, about 21% of the houses have been designed by architects/draftsmen, 28% of houses have been designed by Mason and another 4% of the houses have been designed by private & government organizations (Figure 5).

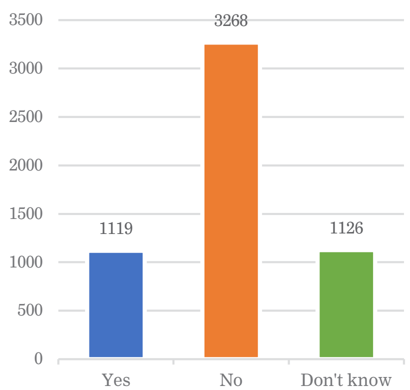

Figure 4: Professional Support obtained to build house

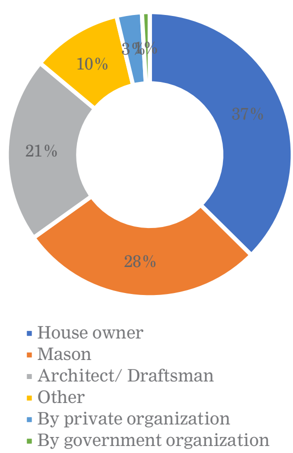

Figure 5: Designer of the house

For the purpose of assessment of potential landslides, the type of terrain is classified namely; steep slope, rolling terrain, gentle slope and flat terrain. Of these categories of type of terrain, about 29% of the surveyed houses are located within the gentle slope (50-110) terrain, while 54% of the houses are located on steep slope (>310) terrain and minor share (7%) of houses are located on rolling terrain.

As per the current legal system, it is essential to obtain clearances from relevant authorities to become a legally constructed house. In 2011, the ministry of disaster management issued a circular concerning NBRO clearance for building construction in landslide-prone areas. As per the circular (NBRO 2011/1), obtaining clearance from NBRO for construction in ten landslides prone districts, such as Badulla, Galle, Hambantota, Kalutara, Kandy, Kegalle, Matale, Matara, Nuwara Eliya, and Ratnapura is a mandatory requirement. Accordingly, Figure 7 indicates that 90% of the houses haven't obtained approval for house construction, while 4% of the houses have obtained approval from the local authority, and 2% from NBRO.

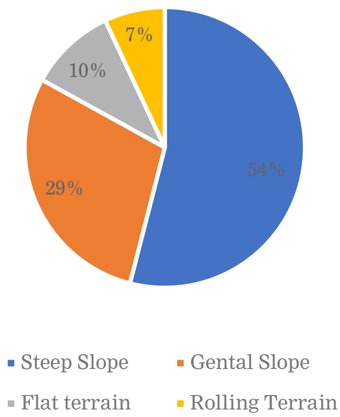

Figure 6: Type of terrain of the surrounding area, the house is located

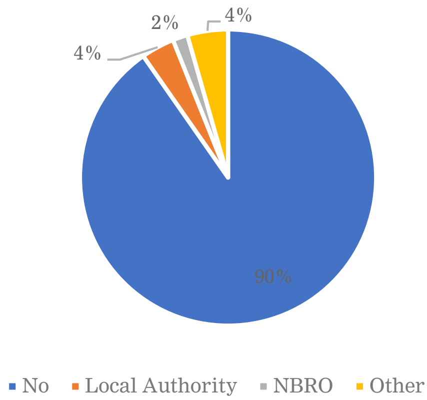

Figure 7: Approval obtained for house construction

As per the findings 46% of the people have changed their terrain shape, 43% haven't done any changes and 11% of the people were not aware of the changes (Figure 9). Most of the landslides in Sri Lanka have occurred during heavy storms and prolonged rainfall events. There will be a reduction in the strength of soil as a result of surface erosion of the soil on a slope due to heavy storms and prolonged rainfall. Channels and other drainage systems can divert water out and away from the slope and decrease the oversaturation of the soil that triggers mud and debris flows. Therefore, it is extremely important to manage both surface and subsurface drainage of a slope. Accordingly, only 23% of the people have a systematic drainage system, 36% of the people have a drainage system but not sufficient and 41% don't have a proper drainage system (Figure 8).

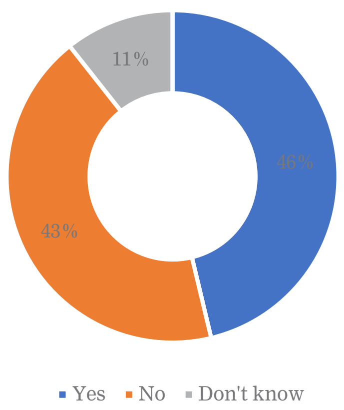

Figure 8: Change of land morphology

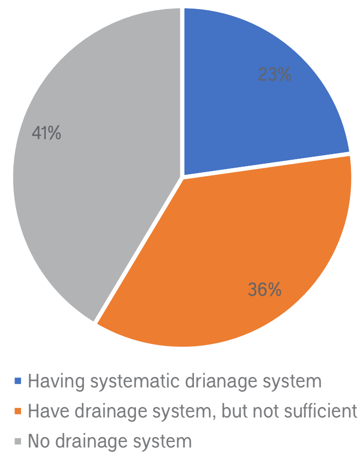

Figure 9: Action taken to discharge water

As per the Disaster Management Act No.13 of 2005, the formation of a village Disaster Management (DM) committee is essential. The committee is composed of 5 sub-committees; 1) Early warning dissemination, 2) Evacuation support, 3) Health and first aid, 4) Evacuation shelter management, and 5) Patrolling and vigilance. However, survey finding shows only 44% of the residents know the existence of a DM committee, 16% of the residents say there is no DM committee and 41% don't know whether a DM committee exsits or not in their village.

It becomes evident that the majority (27%) of the households have completed Ordinary Level exams, while nearly 25% of the household members have passed Grade 8. Nearly 26% have completed their primary education. It is worth to noting that, 4% of heads of households haven't received any formal education and 0.8% have completed a Degree.

Even though about 44% of houses know that there is a DM committee in their village but only 17% engage in disaster-related activities while 83% are not involved in DM-related works. Early warnings are prime preparedness measures that can minimize the impact of the disaster(United Nations, 2010). But the finding indicates that only 26% of the residents have received instruction on disaster preparedness.

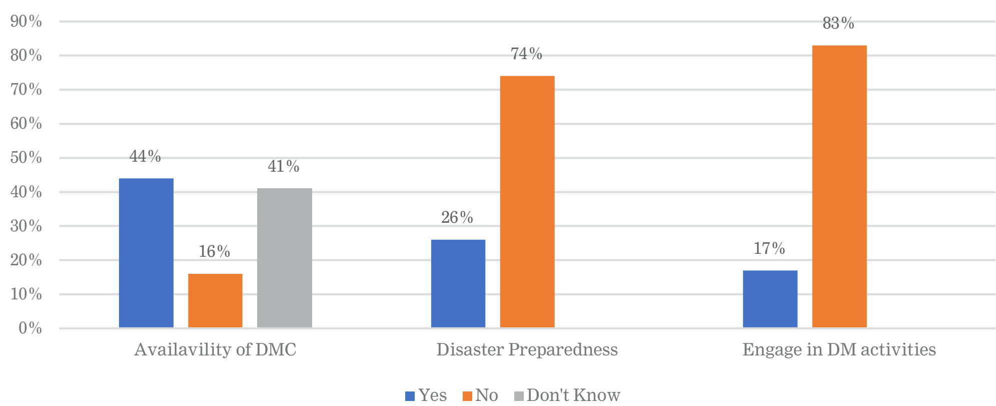

Figure 10: Availability of DM committee, Preparedness and Engage in DM activities

Within the last 3 years, only 8% of the houses have taken precautionary measures to face landslides, whereas 92% of the houses haven't taken any precautionary measures.

4.3. The unsafe conditions

In terms of employment, about 10% of heads of household are employed in the government sector, while another 18% are employed in the private sector. The unemployment rate of the surveyed head of households is 21%. The head of household engaged in work for daily wage accounted for 20%.

It is also important to note that more than half of the people (57%) don't have membership in a village level society/organization.

4.4. Vulnerability level

In addition to the above findings, it is also important to understand the most vulnerable factor to provide an appropriate strategy for Kegalle District.

It is evident that "R2-Preference in the event of disaster-induced relocation, D3-Approval obtained for house construction, D4-Type of the terrain of the surrounding area, the house is located, and U2-Membership in a village-level society/organization" are the factors contributing more than 80% of the vulnerability of the community.

Meanwhile, "R1-Possibility of the access road to house affected by disaster, D2-Designer of the house, D5-Change of land morphology, D6-Action taken to discharge water, D7-Level of education, D9-Take precautionary measures to face landslide during last, D10-Availability of the disaster management committee in the village, and D11-Receive instruction on disaster preparedness" are contributing more than 50% of the vulnerability of the community. D1-Professional Support obtained to build the house, D8-Engage in disaster management activities, and U1-Employment are the least contributing factors. (Figure 11).

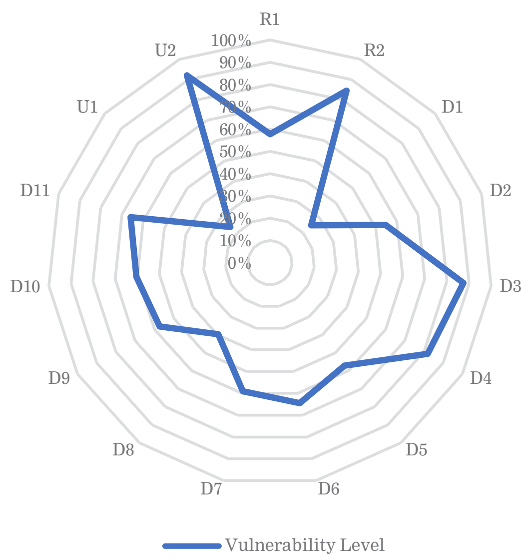

Figure 11: Vulnerability level of the factors

4.5. Factors correlations

In addition to the index calculation, the study also evaluated the correlation of the 15 factors by using the Pearson Correlation analysis. Table 2 indicates the 15 vulnerability factors which were taken for the analysis horizontally and vertically. Each factors has been defined by a number; e.g. 6 means the type of terrain of the surrounding area.

The results indicate a statistically significant correlation among several variables. One of the important relationships observed is the very high correlation between (3) Professional Support obtained to build the house with (4) Designer of the house (correlation .544); (10) Engage in disaster management activities with (13) Receive instruction on disaster preparedness (correlation .539); (12) Availability of disaster management committee in the village (13) Receive instruction on disaster preparedness (correlation .248); (11) Take precautionary measures to face landslide during last three years with (13) Receive instruction on disaster preparedness (correlation .359); and (10) Engage in disaster management activities (12) Availability of disaster management committee in the village (correlation .350). It is clear that the elements such as (10) Engage in disaster management activities (11) Take precautionary measures to face landslides during the last three years (12) Availability of a disaster management committee in the village (13) Receive instruction on disaster preparedness are some interconnected factors.

Table 2: Correlation of the vulnerability factors

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	-.031	.152	.127	.017	.010	.077	.100	.001	-.003	.008	.040	.022	-.017	-.020
2		1	.222	.224	.102	.059	.193	.101	-.025	.164	.081	.234	.187	.006	.013
3			1	.544	.132	.046	.240	.131	-.041	.080	.066	.119	.064	-.050	-.051
4				1	.278	.092	.216	.191	-.093	.077	.062	.144	.085	.012	-.044
5					1	.059	.111	-.019	-.124	.014	.056	.087	.057	-.058	-.093
6						1	.295	-.005	-.030	.097	.105	.057	.125	-.051	-.014
7							1	.047	-.001	.109	.121	.162	.148	-.031	-.074
8								1	-.013	.051	.049	.098	.079	.029	.000
9									1	.050	.007	-.039	.005	.003	.023
10										1	.297	.350	.539	-.107	-.009
11											1	.189	.359	-.295	-.015
12												1	.428	-.022	.008
13													1	.035	-.040
14														1	-.016
15															1

(1) Employment (2) Membership in a village level society/organization (3) Professional Support obtained to build house (4) Designer of the house (5) Approval obtained for house construction (6) Type of terrain of the surrounding area (7) Change of land morphology (8) Action taken to discharge water (9) Possibility of access road to house affect by disaster (10) Engage in disaster management activities (11) Take precautionary measures to face landslide during last three years (12) Availability of disaster management committee in the village (13) Receive instruction on disaster preparedness (14) Level of education (15) Preference in the event of disaster induced relocation

5. Conclusions

Landslide is identified as one of the major disaster events in the world as poses a severe threat to human lives. These extreme natural events are unpredictable, but their risk can be decreased by taking appropriate mitigation measures. Therefore, it is vital to understand the causes of the event.

Accordingly, the study has identified 15 vulnerability factors under 3 vulnerable categories such as root causes, dynamic pressure and unsafe condition. The findings indicate that the majority percentage of each indicator is biased on the risk-posing side; such as 76% of the houses don't have access to the house during the disaster, 48% of the people would like to have the relocation site within their GN division, 80% of the houses are built without the professional support, 37% of the houses are built by the house owners, 54% of the houses are located in a steep slope, 90% of the houses do not get the approval during the construction, 43% of the residents changed their land morphology, 41% don't have a proper drainage system, 16% stated that they don't have DMC and 41% they don't know about the DMC, 74% not taken any precaution measures, 83% not engage in any of the DM activities and 57% don't have membership in a village level society/organization. Exceptionally, 81% have greater than primary education.

As per the vulnerability level, among those factors, (R2) Preference in the event of disaster-induced relocation (D3) approval obtained for house construction, (D4) type of terrain of the surrounding area of the house located and (U2) membership in a village level society/organization are the factors contributing more than 80% of the vulnerability of the community.

Finally, the correlation analysis indicates that each factor is interconnected for a certain level and among them, engaging in disaster management activities, taking precautionary measures to face landslides during the last three years, availability of a disaster management committee in the village and receive instruction on disaster preparedness are highly interconnected. Even though the vulnerability level of these factors is moderate, still, the effect of one factor could accelerate the vulnerability of other factors.

Considering the above findings, this study could be directing the practitioners and the policymakers to specify the policy recommendation and countermeasures of the highly vulnerable factor to reduce the associated landslide risk of the particular study area.

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Building Resilience amidst Economic Challenges

Landslide hazard zonation map and its implications on land use planning - A case based on 2020/2021 mapping area

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Abstract

In 1986, Sri Lankan Government decided to launch the Landslide Hazard Zonation Mapping Project (LHMP) to study and identify the distribution of landslide potential in hazard-prone areas. As a result, NBRO is conducting landslide hazard mapping on 1:50,000 and 1:10,000 in scale. Annually NBRO releases hazard maps for approximately 800km² areas in the country. Those maps and associated guidelines can be used as a tool for development planning in the country. But increasing landslide impacts emphasized that the usage of these tools is limited among stakeholder agencies. Therefore, this study focuses on hazard zone distribution based on the landslide hazard zonation map of NBRO and the latest land use pattern to identify the most vulnerable land use categories to include in the land-use planning and management sector, to reduce landslide risk impacts in landslide hazard-prone areas.

Keywords: LHMP, Land use, Development, Landslide hazard

1. Introduction

Landslides are one of the catastrophic disasters that frequently occur in Sri Lanka. In recent years, landslides caused by heavy rainfall, particularly during monsoon periods. Fragile topography and steep slope together with ad-hoc development and improper land-use management have contributed to major impacts of landslide disasters, in the Central highland of Sri Lanka. Due to the disastrous landslides that occurred in the mid-1980s, the Government of Sri Lanka (GOSL) took the initiative of studying the landslide phenomena in the country.

National Building Research Organisation (NBRO) has been designated as the National Focal Point for landslide risk management in Sri Lanka by GOSL. The Landslide Research and Risk Management Division of NBRO has been conducting Landslide Hazard Zonation Mapping Programme (LHMP) since 1989. In August 1990 Sri Lankan government decided to launch the Landslide Hazard Mapping Project

(LHMP) implemented by the NBRO with the financial and technical assistance of UNDP and UNCHS. Mapping is carried out at a global scale at 1:50000 scale and at 1:10000 scale.

Currently, the 1: 10,000 scale mapping program is conducting in 10 landslides prone districts of Kalutara, Galle, Hambantota, Nuwara Eliya, Matale, Kandy, Kegalle, Ratnapura, Matara, and Badulla, and in addition to that mapping has been implemented within Monaragala, Gampaha, and Kurunegala districts with the main objective of identifying the areas which are prone to landslide in the country and manage the human settlements planning.

Landslide Hazard Zonation Maps are prepared by considering six (06) major factors and thirteen (13) sub-factors as follows;

Table 1: Factors considering in Landslide Hazard (Landslide Hazard Mapping Project Manual, NBRO)

Major Factor	Sub Factors
Bedrock Geology and Geological Structure	Lithology
	Amount & Direction of Dip in degrees
	Deviation Angle in degrees
	Discontinuities Linéaments, Faults & Mater Joints
Surface Deposits	Distribution of Soil Cover in meters
Slope Angle Range	Slope Angle Range
Hydrology	Relative Relief in meters
	Basin Area
	Basin Shape
	Drainage Density
	Proximity to water bodies
Land Use	Land Use Management
Land Form	Land Form Type

The main purpose of preparing the Landslide Hazard Zonation map is to utilize them in future planning activities. The maps indicate safe areas and the areas which can be utilized with corrective measures. (Table 2) Once the sites are selected with the guidance of these Landslide Hazard Zonation Maps, it is always advisable to carry out a location-specific subsurface investigation to assess the risk on the intended purpose since these maps are based only on the surface data. (Table 1)

The landslide hazard zonation map has seven major hazard categories according to their level of hazard. A detailed description of these hazard classes is listed below. The first four categories (1, 2, 3 & 4) are classified as high-risk hazard categories. The fifth category is considered as the modest level of hazard and the sixth category is identified as safe zones in terms of landslide hazard.

Table 2: Landslide Hazard Zonation Categories (Landslide Hazard Mapping Project Manual, NBRO)

S/N	Category	Description
1	Landslides have occurred in the Past	The known danger of landslide and therefore, the perennial threat to life and property exists in the area. All new constructions should be prohibited and land use &

2	Rock falls and Subsidence	management practices should be studied, & improved to halt and reverse the process of slop degradation. Landslide remediation should be undertaken and early warning systems should be established at all problematic sites.
3	Landslides are most likely to occur	Danger and potential threats to life & property exist. No new construction should therefore be permitted. Essential additions to the existing structures may be allowed only after a thorough site investigation and adequate precautions to be certified by a specialist(s). Early warning systems should be established if symptoms of landslides are clear and risk levels are high.
4	Landslides are to be expected	Moderate levels of landslide danger exist. New construction should be discouraged, and improved land use planning practices should be introduced to halt and reverse the process of slope degradation. All essential construction and remediation, & new projects are subjected to landslide hazard assessment.
5	A modest level of landslide hazard exists	A slight danger of landslides exists. Engineered and regulated new construction and well-planned cultivation are permitted. Plans for construction should be technically vetted and certified.
6	Landslides not likely to occur	No visible signs of slope instability or danger exist based on the present state of knowledge. No blanket limitations need to be imposed particularly on well-managed lands and engineered construction. Location-specific limitations may become necessary, particularly for areas prone to flooding and erosion.
7	Inaccessible Slopes	Inaccessible areas about which no direct information is yet available.

At present total mapped area covered in 1: 50,000 scale is about 32,593 km2 in the landslide hazard-prone districts. These maps could be used in evaluating the distribution of landslide potential at the national level and the maps could be utilized in disaster management activities that may occur due to landslides. Currently, the 1:10,000 mapping program covered 8,800 km2 in landslide-prone districts. These maps serve as a tool to guide investments in the development and utilization of lands susceptible to landslides at the local level.

Even though NBRO prepared and published the landslide hazard zonation maps annually in the online web portal of NBRO *(www.lrip.nbro.gov.lk)*, the users are limited and the awareness about the maps is less. Therefore, this study focuses to emphasizes the importance of understanding the landslide hazard situation in central hilly areas, enhancing awareness among different stakeholders, and identifying the spatial pattern of hazard distribution and its implication on land uses.

2. Literature review

Land use management plays a critical role in increasing or accelerating landslide hazards and vulnerability in hilly areas. Recent studies focusing on the effect of human-induced land use changes on slope stability have shown that in populated regions, the impact of humans on the environment contributes significantly to the initiation and reactivation of landslides. (Vanacker et al. 2003). Therefore, land use management and human-induced development activities should be monitored and guided by relevant authorities to minimize landslide-related hazard events. In Parallel, these scientific maps can be used as a planning tool in guiding investments in the landslide hazard-prone areas of Sri Lanka.

3. Research methodology and study area

This study used two types of inputs: land use and landslide hazard zones in identifying their pattern on the ground. The land use layer was prepared by NBRO using QGIS software at a 1: 2,500 mapping scale. Land use is categorized into four types; settlements, sensitive vegetation covers such as dense & degraded forests, forest plantations, grasslands, rocky lands, paddy & water bodies, market gardens, and bare lands. The market gardens mainly consist of market crop types such as tea, coconut, rubber, and vegetables. All these categories are identified in the land use map prepared under the LHMP program.

The settlements are further categorized into three categories; urban, rural, and estate settlements as identified in the land use map. Then, the spatial layers of settlements are intersected with landslide hazard zones to investigate the composition of settlement types on each level of landslide hazard. At the same time, the sensitive vegetation layer also intersected with landslide hazard zones to understand its spatial distribution on each hazard level. The area and percentage values are derived from the analysis and it supports the conclusion of this study.

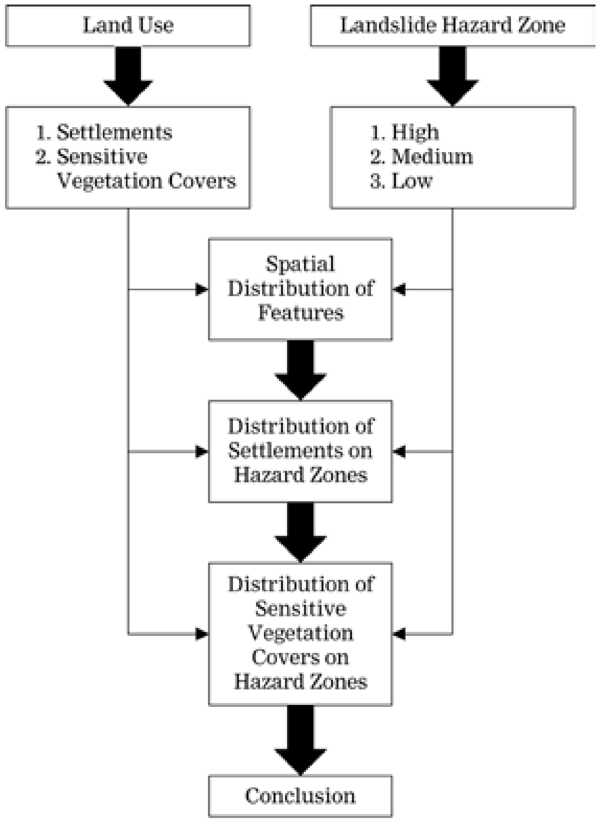


figure 1: Research Methodology

Annually NBRO carries out the hazard zonation mapping program for a selected area in hazard-prone districts. It is approximately covered of 500km2 in the 1:10,000 mapping sheets. Each 1: 10, 000 map sheet is to cover an area of 8 km x 5 km covering 40 km2. For this research, it is used the latest available mapping data in years 2020/2021 and it covers 840 km2 in Nuwara Eliya and Kandy districts in Sri Lanka.

3. Analysis & results

4.1. Hazard distribution

The mapping area of 2020/2021 covered 840 km2 in Nuwara Eliya and Kandy districts. Out of the total mapped area, 19.34% of the land is identified as a high level of landslide hazard. The moderate level of hazard is 57.14% of the mapped area and the low hazard is derived as 13.76%. The high landslide hazards potential areas emphasize the potential risk to both lives and properties. According to the LHMP guideline, it mentioned that new construction will take place in a landslide high-hazard area is prohibited. Further, it mentioned that all essential construction and remediation, & new projects are subjected to landslide hazard assessment.

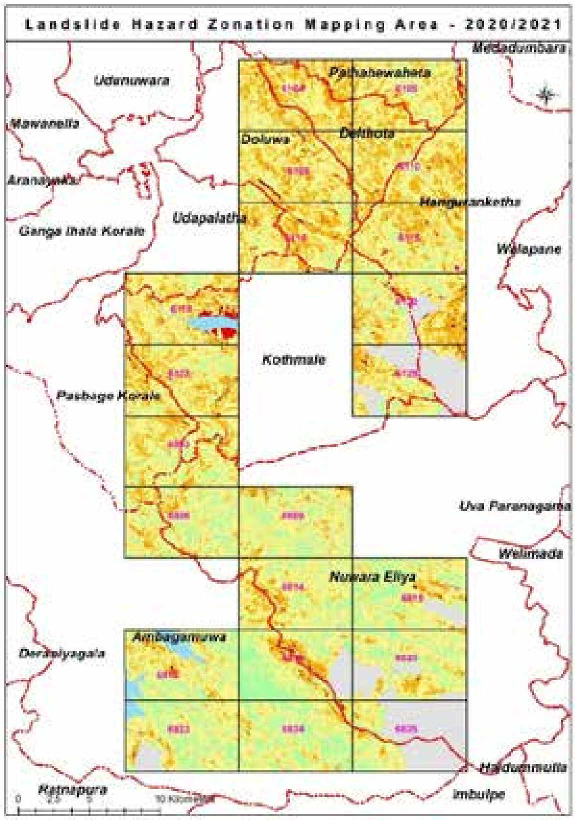


Figure 2: Landslide Hazard Zonation Map prepared in 2020 and 2021

76% of the mapped area is particularly declared as having high and medium levels of susceptibility to the landslide hazard. This is a crucial factor when any kind of development activities are taken place in this area. Since the map area has famous tourist destinations in the hillside of Sri Lanka together with main town centers such as Galaha, Hewaheta, Pussellawa, Kotagala, Thalawakelle, Norwood, Dayagama, and Bogawanthalawa, it is important to have awareness about the hazard level in this area.

4.2. Settlements distribution

In this mapping area, around 1% belongs to urban settlements that cover major town centers, and non-agricultural uses. The rural settlements are 6% and estate settlements are 3%. The distribution of settlements in this area doesn't have a specific spatial pattern and settlements are dispersed and couldn't identify the exact demarcations with other land cover patterns. Most of the rural settlements are located in the northern part of the map area which covers part of Kandy district and estate settlements are dominated in the southern part of the map area which covers part of the Nuwara Eliya district as shown in Figure 3.

Further, the Nearest Neighbor Index is calculated to understand the pattern of settlement distribution in the study area. The Average Nearest Neighbor tool measures the distance between each feature centroid and its nearest neighbor's centroid location. It then averages all these nearest-neighbor distances. If the average distance is less than the average for a hypothetical random distribution, the distribution of the features being analyzed is considered clustered. If the average distance is greater than a hypothetical random distribution, the features are considered dispersed. (ESRI explanation about the tool) The result expressed the dispersed pattern of settlements in this area as shown in the satellite image and the graph generated. (Figure 4 (a) & (b).

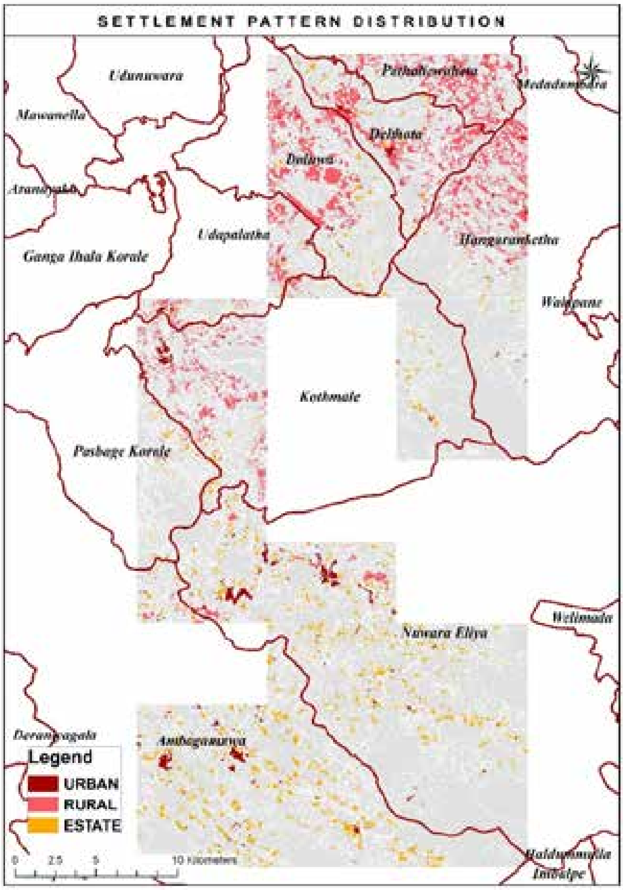
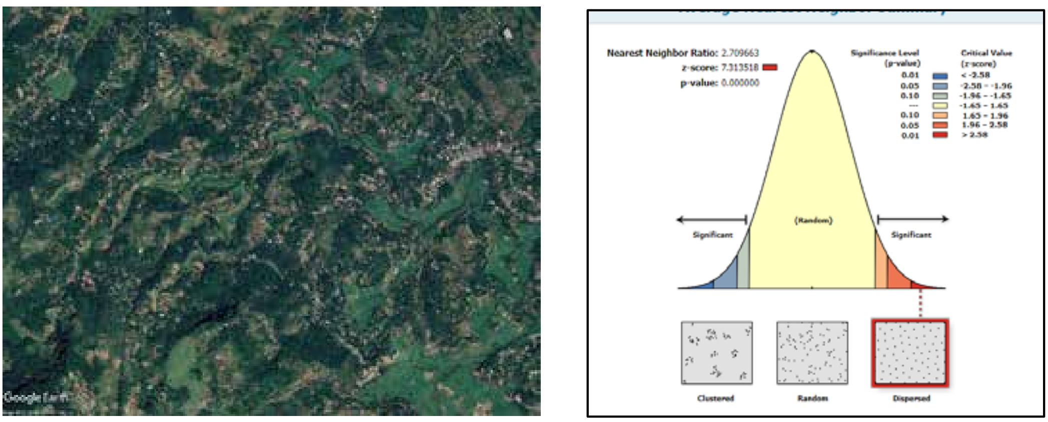


Figure 3: Distribution of Settlements Pattern in the Study Area



(a) (b)

Figure 4: (a) Satellite Image of Settlement Distribution; (b) Nearest Neighbor Index

4.3. Sensitive feature distribution

This study considered hazard distribution on sensitive land use types of the mapped area. The land use map has several categories that can be identified as environmentally sensitive features. Those are water bodies, dense forest areas, paddy fields, and protective vegetation covers. In the mapping area of 2020/2021, it is identified 34% of the area is forestry-type land covers, 1% belongs to water bodies, and paddy, rocky lands are 3% & other protective vegetation covers 2% of the mapped area. Together sensitive feature distribution covers 40% of the mapped area.

4.4. Overall land use distribution

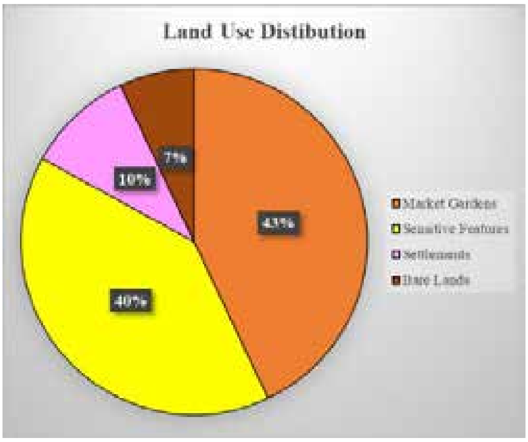


Figure 5: Percentage of Landuse Distribution

According to the overall land use distribution of the mapped area, 43% of the land belongs to market gardens such as tea, rubber, coconut, vegetables, and other commercial plants. 40% of the area covers sensitive features such as dense and degraded forests, forest plantations (e.g., Pinus) paddy fields, protective vegetation, and water bodies. 10% and 7% of the area respectively cover settlements and bare lands.

The main focus of this study is to identify the land cover distribution on hazard zonation categories. For that, both layers of hazard zone and land use are overlayed and intersected to emphasize its pattern.

4.5. Distribution pattern of overall land use types with vulnerability to landslide

Landslide high hazard zone has 49% of sensitive features and 18% of bare land areas. 27% of the market gardens also locate in the high-hazard area. The critical point is 20% of the settlements are located in these high and medium-risk areas. These areas are more fragile due to human interactions and improper development activities. Meanwhile, the potential landslide high and medium threats can be augmented and lead to damage to lives and properties. The main issue is that people don't consider the existing threat of landslides as well as they don't have proper awareness about the consequences of disasters.

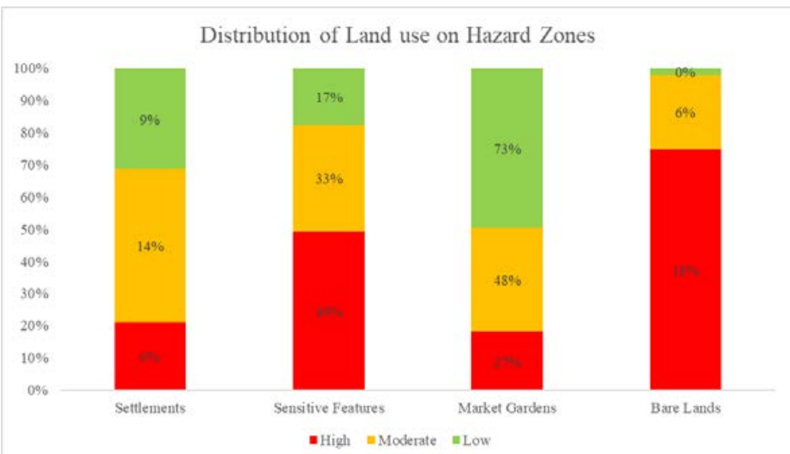


Figure 6: Distribution of Land use on Hazard Zones

4.6. Distribution pattern of settlements with vulnerability to landslide

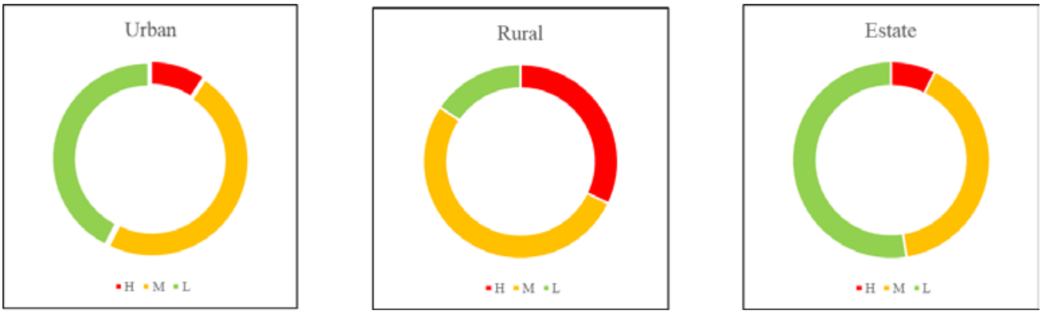


Figure 7: Distribution of Settlements on Hazard Zones

The above figure shows the types of settlement distribution in landslide hazard zones. It can be observed that more than half of the urban, rural, and estate-type settlements are located in high and medium-hazard zones. This needs to be addressed by relevant stakeholders who are responsible for preparing and implementing any kind of development activities in this area.

5. Conclusion

This study concluded that 76% of the mapping area has high and medium landslide threats to its inhabitants. Considering settlement distribution, more than 80% of the rural settlements are located in high and medium-hazard zones. The relevant authorities need to pay enough attention to reduce the associated risk by implementing appropriate risk mitigation measures. For such projects, the authorities can use the landslide hazard maps as a guiding tool for decision-making on land use planning and management.

Further, this work strives to enhance the awareness of using the landslide hazard zonation map in development activities. It is observed that there is no specific settlement pattern or concept to follow in hazard-prone areas of Sri Lanka. It is encouraged professionals to have more research on introducing a settlement concept regard with landslide susceptibility in hilly areas. Further, this study emphasized how vulnerable the land use features are in terms of landslide hazards in a particular area. The stakeholders need to consider about most vulnerable people and elements in these areas when any kind of development is taking place.

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Building Resilience amidst Economic Challenges

Landslide monitoring and slope stability analysis for evaluation of landslide vulnerability - A case study at Hakgala McDonalds landslide

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Abstract

Landslide is considered one of the major natural hazards that are mainly triggered by heavy rains in Sri Lanka, causing enormous social and economic losses. The Climate Resilience Improvement Project (CRIP – UVA) was implemented by the Government of Sri Lanka in Uva Province to rectify landslide-related components with the financial assistance of the World Bank. Five landslide-prone areas were selected to carry out a detailed investigation which consists of geotechnical investigation, instrumentation and, monitoring. Among them, the Hakgala McDonalds landslide is located at CH 3+500 on the Rendapola – Ambagaswewa (A05) road which had two major axes at the initial stage of the landslide investigation. The landslide was initiated as a cut slope failure at the side of the road along with ground subsidence and the development of cracks on the slope along with the appearance of a few cracks in the house which is located near the slope. Since the location is a hotspot and economically and socially viable, landslide monitoring was proposed in order to obtain reliable design parameters. Landslide monitoring was processed using inclinometers, piezometers, water level meters and extensometers along with detailed geological and geotechnical investigations. Based on the detailed geological and geotechnical investigation results, a soil profile was developed to assess the stability of the slope using SLOPE/W software.

According to the results obtained from the study, a properly planned and specified instrumentation program can greatly contribute in increasing safety, reducing the cost or environmental impact of construction, and reducing potential failure.

Keywords: Extensometer, Geotechnical investigation, Inclinometer, Instrumentation, Landslide, Monitoring, Piezometer, Slope stability

1. Introduction

A landslide is a phenomenon in which the soil mass on one or more failure (slip) surfaces deep in the ground gradually shifts downward, triggered by heavy rain, earthquake, river erosion, and earthworks (NBRO, 2013). Landslides, slope failures and rock falls have become frequent and severe, seriously affecting the life and livelihoods of communities residing in the central hilly region of Sri Lanka. More than 20% of the Sri Lankan landmass is landslide-prone as indicated by the Landslide Hazard Mapping Project (LHMP), and studies conducted by the National Building Research Organisation (NBRO)have indicated that around 80% of the landslide events are due to man-made activities rather than natural causes due to inappropriate construction and land development leading to the creation of landslide blackspots in the hilly areas.

Instrumentation related to the landslide is a collective term for measuring instruments that are used for indicating, measuring and recording physical quantities. Instrumentation and monitoring technology are increasingly used to monitor landslide signs, progression and behavior in order to comply with and incorporate the existing natural ground conditions into actual ground conditions to reduce the risk by proposing proper mitigation designs.

Slope stability analysis is performed to assess the safe design of human-made or natural slopes and the equilibrium conditions (Digvijay P. S, et al,2017). The most commonly used method to evaluate the stability of slope is the limit equilibrium method and SLOPE/W software is widely used for assessing the stability of slope with the availability and convenience of the software.

2. Study area

The study area is located at CH 3+500 on Rendapola – Ambagaswewa road (A05), roughly 7 km from Hakgala Botanical Garden at an altitude of 1431 m near Rendapola village. The precise geographic location as seen in Figure 1 is Latitude 6° 55' 24.5" N and Longitude 80° 50' 39.1" E. The average slope of the slide area is about 45° towards the East. The signs of movement were evident from road subsidence, cracks opening at the crest and settlement cracks on the walls of a house located at the side of the slide. The land is used to cultivate various types of vegetables at different times of the year. Therefore, water is directed to the land periodically throughout the cultivation period without having a proper drainage system. This caused more soil erosion on the slope, which could be a major factor in forming local failures around the area.

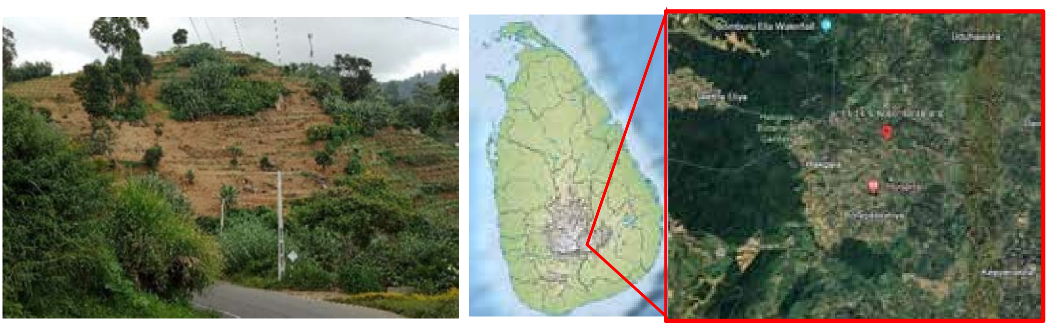

Figure 1: (a) Hakgala McDonald landslide **(b) Location of the landslide**

3. Geomorphological setting of the area

Geomorphologically, the landslide-prone area is an undulating ground with steep hill slopes and is unconfined. According to the lithological observation using borehole investigations conducted at the site, the rock level was encountered at intermediate depths, varying from 5.90 m to 23.50 m depth within the site. This location is situated in the Highland complex according to the geological map of Sri Lanka. Furthermore, Table 1 illustrates more geological features observed at the landslide location.

Table 1: Description of Geological features

Natural slope angle/Slope direction	$45^0/55^0$
Bedrock visible	YES
Foliation-Strike/Dip/Dip Direction	$N25^0W/4^0NE$
Joints-Strike/Dip/Intensity (m^{-1})	$N45^0W/80^0SE/3m^{-1}$
Bedrock type	Biotite Gneiss
Weathering Condition	Moderately weathered to Highly weathered
Escarpment (ES)/Dip slope (DS)	ES

4. Landslide hazard and the risk

The landslide was initiated as a cutting slope failure and progressed as a landslide with 2 major axes as shown in Figure 2. Moreover, during the initial observations, 2 scars were identified in the major axis of the landslide. As a result of the progression of this landslide, A5 road users and the dwellers in the downslope were identified as the high-risk elements associated with this landslide.

5. Instrumentation and monitoring

Instrumentation was implemented to assess the monitoring of mass movements of the landslide and instrument layout was prepared by the NBRO staff after evaluating the landslide features. Inclinometers, Piezometers, water level meters and Extensometers were installed according to the layout plan given in Figure 2.

Figure 2: Instrument layout

Figure 3: Installation of Inclinometer

5.1. Inclinometer

In the Hakgala McDonald landslide, four inclinometers were installed separating two for the major axis and others for the minor axis. Digital MEMS inclinometer, a product of SISGEO has been used in this landslide and Figure 4 and Figure 5 illustrate the instrument used to obtain the inclinometer readings.

Figure 5: Inclinometer monitoring apparatus

Figure 4: Obtaining data

5.2 Water level meter

The manufacturer of the water level meters used in this location was HOBO and the type of the sensor was a HOBO titanium water level logger. The HOBO Waterproof Shuttle provides convenient readout and relaunching of underwater and outdoor HOBO data loggers with an Optic USB interface, and is waterproof to 20 m (66 ft). The HOBO Waterproof Shuttle can also be used as a base station. In order to transfer the data to the PC, Couplers are used which are prepared for compatibility with optical communication. Reading was taken by the operator mobilizing to the site physically with a laptop after installing HOBO onset software after which by taking away the logger from the standpipe using a relevant coupler data was transferred to the laptop.

5.3 Piezometer

In this landslide, Geokon Model 4500 Standard Piezometer is used which consists of the Vibrating-Wire Strain method. The vented version (ALV) provides automatic compensation for barometric pressure changes. Thermistors are included to measure temperatures.

The Model GK-405 Vibrating Wire Readout is designed for use with all GEOKON vibrating wire sensors. It comprises a battery-powered readout unit, which communicates, via Bluetooth® transmission, to a handheld Field PC running the GK-405 application. The Model GK-405 can also read the thermistors included with most GEOKON vibrating wire sensors, and display the temperature directly at °C.

5.4 Extensometer

In this landslide, the DP-E displacement transducer is used, which is designed for the measurement of large displacements. A stainless-steel wire is drawn out to measure the displacement. The wire tension is constant regardless of the displacement. It is a small and light transducer with excellent accuracy.

This Digital Load Meter is used in combination with a strain-gauge-type transducer, such as a load cell and displacement transducer, for direct measurement of physical force. The compact and lightweight unit resists water and operates on AA-size alkali or Ni-Cd batteries for easy measurement at any location.

6. Evaluation of soil parameters

Two boreholes were advanced along the worst section in order to obtain the subsurface soil strata. Table 2 summarises the results obtained by the borehole investigation.

Table 2: Details of the boreholes

Depth of the Borehole (m)		Average SPT Value	Soil Type	Unit Weight (kN/m^3)	Cohesion (C, kPa)	Friction Angle (ϕ)
BOR 1	BOR 3					
0 – 0.80	0 – 1.00	Top Soil	Colluvium	18	5	27
0.80 – 12.45	1.00 – 9.00	15	Silty sand	19	7	30
12.45 – 14.50	9.00 – 10.55	40	Completely Weathered Rock	20	14	36
14.50 – 20.50	10.55 – 13.00	>50	Highly Weathered Rock	22	15	42
20.50 – 22.50	13.00 – 17.00	>50	Bed Rock	Bed Rock Properties		

A Standard Penetration Test (SPT) along with laboratory tests such as index property tests, were conducted to obtain the above soil strength parameters. These soil strength parameters were derived from SPT values as per the method proposed by Bowels and they were assigned to the soil layers which were identified using the field observations taken during the borehole investigation.

7. Monitoring results, observation and evaluation of the monitoring results

Monitoring of the Hakgala McDonalds landslide was carried out in April 2018 after the installation of an inclinometer at borehole no. 03. The implemented monitoring schedule is illustrated in Table 3.

This study is mainly concentrated on the results and observations which were obtained from inclinometers. Inclinometer readings and graphs created from KLION software are interpreted as the failure surface of the particular landslide which is more important to compare with results obtained from SLOPE/W software.

Table 3: Details of the implemented monitoring plan

Instrument	Installed Location	Monitoring Period	Instrument Monitoring Sequences (Field visits to check-ups)
Inclinometer	BOR 02	2018. 05. 15 to 2020. 07. 22	Two times per month (once per week in a rainy period)
	BOR 03	2018. 04. 10 to 2020. 07. 22	
	BOR 04	2018. 05. 15 to 2020. 07. 22	
	BOR 05	2018. 06. 12 to 2020. 07. 22	
Extensometer	Main Scarp	2019.05.04 to 2019.05 10	Once a month
Water Level Meter	BOR 01	2018.12.23 to 2019.05.09	Once a month
Piezometer	BOR 05 (Scheduled)	A piezometer was not installed.	

Based on the following charts which were created using the graphs obtained keeping the first reading as the reference, shown in Figure 6 (a) to Figure 6 (d), the slip surfaces were constructed and the earlier estimated slip surface was modified. Table 4 describes the differences made for the slip surface based on the monitoring data.

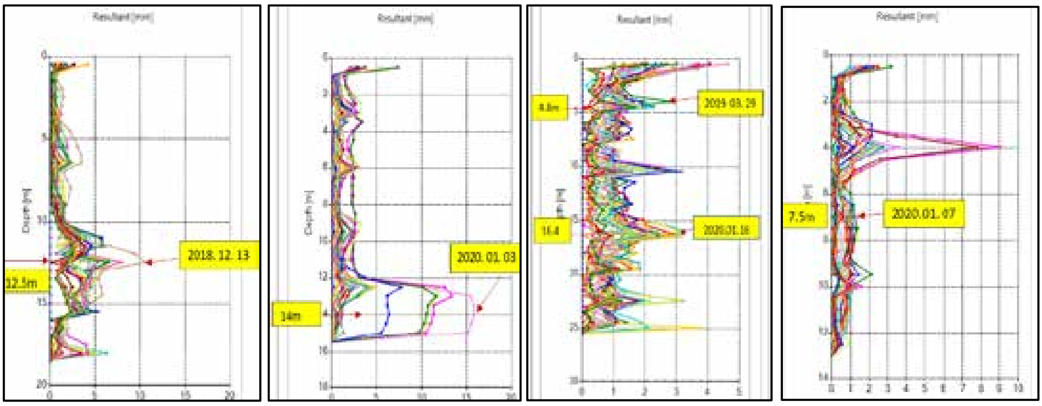

Figure 6: (a). BOR 02 (b). BOR 03 (c). BOR 04 (d). BOR 05

Table 4: Summary of slip surfaces derived

Borehole No.	Earlier Slip Surface (m)	Slip Surface Based on Monitoring Data (m)
BH 2	12.5	12.5
BH 3	9.0	14
BH 4	4	Minor – 4.9, Major 16.4
BH 5	4	7.5

Based on the monitoring data for two rainfall seasons, it was able to make modifications to the slip surface which was earlier predicted by the field (visual) observations where deep slip surfaces couldn't trace only along with the visual observations. That means, a deeper slip surface which technically could not be identified from the geotechnical site investigation was traced with the aid of monitoring of the data of instruments over time.

Therefore, with the results of the inclinometer, extensometer, and water level meter monitoring results, the final layout plan was constructed as shown in Figure 7. Subsurface geological profiles along with critical slip surfaces were prepared for the engineering design of mitigation based on the details given in Table 3 are shown in Figure 8.

Figure 7: Final layout plan

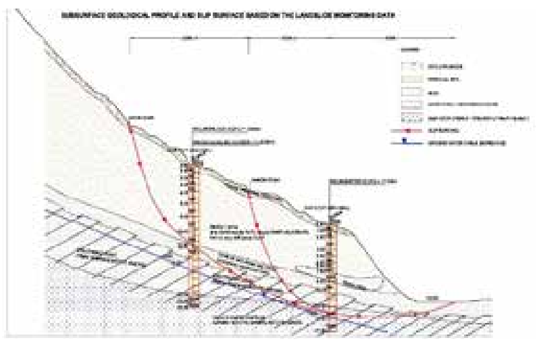

Figure 8: Subsurface geological profile with slip surfaces

8. Stability analysis, results and evaluation of stability analysis results

Stability analysis was carried out after the preparation of the subsurface geological profile along sections A – A, based on the results obtained from a detailed geotechnical investigation including the relevant laboratory tests. Figure 9 shows the stability analysis and the Factor of Safety (FOS) observed. Stability analysis of the proposed sections was carried out using the 'Geo Studio SLOPE/W software considering the Spencer method. The 'Grid and Radius' option was used to obtain the critical slip surface with a minimum FOS. In the analysis, it was assumed that the potential failure plane strikes parallel to the maximum slope direction.

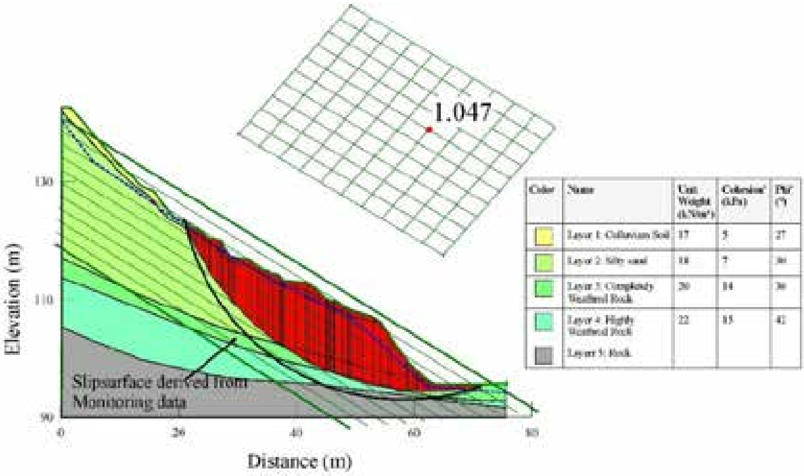

Figure 9: Stability analysis result

Figure 9 illustrates the critical failure surface of the section A – A, is close to the critical failure surface obtained from the monitoring results which is indicated by the black line. Also, the FOS of the failure surface is 1.047 which is almost close to 1, indicating that the vulnerability of the landslide in the particular region is much higher during the rainy season and the cultivation periods. Because during those periods, the water table of this area was moving upwards, enhancing the occurrence of an enormous failure.

9. Conclusion

According to the slip surfaces derived from monitoring results and slope stability assessment, the vulnerability of occurring a landslide in a particular region is much higher at any time of the year because the location is periodically subjected to water infiltration which could lead to having a higher water table throughout the year.

Stability analysis for the corresponding site using the actual shear strength parameters and the groundwater level fluctuation data at the site which was obtained from the laboratory testing and monitoring data respectively reveal the possibility of the occurrence of a landslide in this location. Also, a closer surface of rupture (slip surface) was able to obtain from the slope stability analysis which indicates the suitability of using the two methods for slope stability assessment. The modelled data from the field investigations and stability analyses were proven by the monitoring data in order to take strong management decisions as this area is a hot spot economically and socially, as well as to provide a reliable design to overcome the unnecessary or construction costs to reduce to a greater extent.

Acknowledgement

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Building Resilience amidst
Economic Challenges

Effectiveness of restoring directional gravity drains by hydro-jet cleaning - A case study at the Watawala landslide, Sri Lanka

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Abstract

The Sri Lankan up country railway line is regarded as Asia's most picturesque train route, which influences the national economy as a component in the tourism industry and plays a major role in the socio-economy of people. In 1992, the railway line was obstructed by a significant landslide in Watawala that is considered to be an old, repetitive, and retrogressive landslide. Due to the huge damage caused to the country's economy, it was well investigated and long-term remedial measures were implemented in 1995. However, the directional gravity subsurface drains installed at the landslide have recently become blocked, and water discharge has decreased. Hence, it may not cater to the requirement of draining water out from the slip surface area.

Restoration of flows in subsurface directional gravity drains was carried out by the National Building Research Organisation (NBRO). Significant number of obstructive materials were removed during the cleaning and flushing process using cleaning devices and thereafter, the discharge flow rate significantly increased by around 120% compared to the previous discharge. Consequently, the water levels of the functioning piezometers have dropped about 1m, illustrating that the average flow rate follows the regional rain fall intensity at the site, and the response of the underdrains to heavy rainfall is rapid, revealing the hydraulic connection between the soil and the underdrain of water from the landslide body. Also, the water jet cleaning method has proven to be successful in the improvement of the functioning and effectiveness of directional gravity drains.

Keywords: Watawala landslide, Directional gravity drains, Piezometric levels, Hydro-jet cleaning

1. Introduction

The primary motive for constructing a railway system in Sri Lanka was to transport goods from the hill area to Colombo. However, because of insufficient recognition and maintenance in the upcountry railway line, as well as unauthorized human interference into railway reservations, there have been a number of confirmed cases of ground subsidence, landslides, and severe soil erosion in this stretch, leading to an increase in train delays and cancellations.

Rainfall triggering landslides are the most common type of natural mass movement disaster that has affected the upcountry railway line for a long period of time in Sri Lanka (Rathnayake and Herath, 2005). The causal factors that affect a landslide are geology, morphology, hydrology, etc. (Berti et al., 2012; Akcali et al., 2010; Gardner and Walsh, 1996). During the dry season, the prevailing of metric suction, high effective stress, cohesion, and less bulk weight increases the resisting force and keeps the factor of safety value high on a slope. However, during the wet season with water saturation, the factor of safety value of a slope decreases due to the increasing of driving forces and decreasing of resisting forces as a result of loss of metric suction, decrease of effective stress and cohesion, and increase of bulk weight (Muntohar and Liao, 2010). In addition to that clays on the rupture surface will get expanded and behave as a lubricant during the rainy season making the surface more slippery.

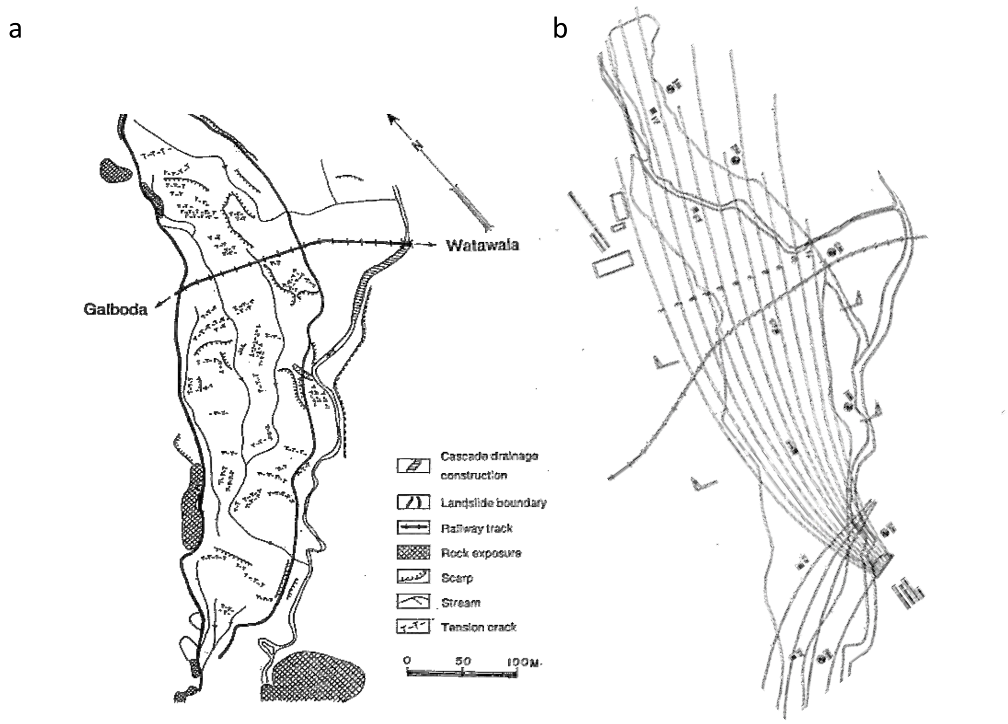

Figure 1: (a) Plan view of Watawala landslide; (b) Existing Directional gravity subsurface drains at Watawala landslide (after Rajaratnam and Bhandari, 1994)

When discussing the landslides that affect the upcountry railway line, the Watawala landslide receives the most attention. The Watawala landslide occurred in 1992, with rainfall density instantly reaching an alarming, day-long rain shower of 196 mm, impeding the railway line between Nawalapitiya and Hatton by a significant landslide that is regarded an ancient, recurrent, and retrogressive landslide (Rajaratnam and Bhandari, 1994). Rajaratnam and Bhandari (1994) reported that the landslide in June 1993, covered an area of 22,920 m^2 (approx.) and about 322,700 m^3 (approx.) of slide volume. The heavy rainfall is the main triggering factor for this landslide as Watawala has the highest rainfall intensity throughout the year. Since then, it has been reactivated several times usually during periods of heavy rain from May to October.

After the major landslide in 1992, several ad-hoc measures had been taken to repair the railway line, but they had aggravated the landslide in the long term. Due to the huge impact caused to the country economy, stabilisation of the slide was of paramount importance. Hence, it was well investigated and long-term remedial measures were implemented in 1995. Stabilization was implemented by installing a subsurface drainage system beneath the slide to permanently lower the water table using directional drilling techniques. Deep wells and an educator system were used to aid in quick drawdown and dewatering, this is the first large-scale installation of directional gravity drains to landslide stabilisation (Chandler and Broise, 2000).

Watawala landslide directional gravity subsurface drainage system plays major role in reducing Factor of safety (Figure 1 & 2). The subsurface drainage helps to lower the groundwater table by removing groundwater from the slopes. However, recently there were doubts about the functioning of drains (which were found to be blocked) and there was a need to assess the current state of the stabilizing measures. Since the early mitigation of Watawala Landslide, no significant maintenance work has been done in past few decades in order to maintain the precise Factor of Safety. As a result, the existing lateral drains and directional gravity drains are poorly functioning. Therefore, it is utmost important to restore the water removal capacity of? subsurface directional gravity drains by cleaning them and thereby, enhance the stability of the landslide.

Figure 2: Directional gravity subsurface drains, which installed passing through the active landslide

2. Site Description and geology

The landslide area is located on either side of the railway track in Watawala, Uva Province between Nawalapitya to Watawala Railway Station, about 2.0 km from Watawala Railway Station. Elevation difference of the earth slip area is about 150 m and that varies from 1000 m MSL to 850 m MSL levels towards the Southern direction. The area of landslide is covered by mixed vegetation, plants and trees covering the land mass of affected area which was formerly a tea plantation. Streams flow through the existing valley located in the centre of the catchment area.

The slide is located in a prominent 'V' shaped valley in an area of high-grade metamorphic faulting and fracturing. The metamorphic rocks include quartzites, marbles and Charnockitic gneisses. The site overlies a fault zone which is deeply weathered, eroded and filled with colluvium comprising mostly sandy silts but also zones of clayey silt up to 6 m thick (Chandler and Broise, 2000). Existing Colluvium deposits indicate previous occurrence of the landslide.

Depths of colluvium increased gradually from the top end, to a maximum of 26 m a short distance above the toe. Cavernous limestone was reported in two test bores at depths of about 66 m. Water levels recorded over many months (Chandler and Broise, 2000) indicated artesian conditions at the top of the slide and groundwater levels varying up to 14 m from wet to "dry" season. Groundwater level was therefore very sensitive to rainfall and mainly affected by south west monsoon during which the average annual rainfall is about 5500 mm from May to September.

3. Restoration process and methodology

The field work of the above restoration of subsurface long gravity drains using the cleaning device was carried out by National Building Research Organisation (NBRO). The device included a water tank, a compressor, hoses and a control unit mounted on a tracked vehicle Figure 3. A high-speed water jet powered by pressurized air was used to clean the inside of the lateral drains Figure 3. It works as a hydro-jet to flush any kind of blocking materials including silt, mud and algae, and clean the inside and the ends of the drain.

The restoration process of each directional gravity drain was done through three separate stages of cleaning. Ground water table and piezometric water levels of all available Piezometers and Pumping Wells were checked using a dip meter. Additionally, rain fall report data were obtained as raw data from the rain gauge at Watawala railway station. The cleaning process was conducted from June 8 to June 20, 2022, and the fluctuation of the flow rates of each drain was recorded from June 5 to July 5.

Figure 3: (a) The cleaning device, b) Illustration showing the cleaning of blocked pipes using high-speed water, c) High-speed water system used for cleaning at Watawala Landslide, d) Hydro jet cleaning process of gravity drains in progress

4. Observations and results

During the site inspection, the NBRO team observed that all the piezometers were stuck at comparatively shallow depth levels indicating that those may have either broken or bended due to ground movement. All the six pumping wells were also blocked at shallow depth levels much above their design termination depths. (Based on the design report by consultants D J Douglas and partners these six pumping wells were installed in boreholes drilled up 60m). Further, concrete safe dams have been separated with mass concrete layers indicating that the landslide is still creeping.

It was found that a total number of fifteen (15) directional gravity subsurface drains were not functioning properly at the Watawala Landslide. Hence, the existing drains may not cater for the requirement of draining water out from the slip surface area. After the restoration process was completed, the amount of average discharge rate was significantly increased by about 120% when compared to the previous discharge of each drain as shown in Figure 4.

It was observed that draining out water from the slip surface was not properly functioning through subsurface drains before the cleaning. However, significant number of obstructive materials such as fine sediments, chemical and biochemical clogging with iron oxides, and plant root overgrowth inside the drain, were encountered during the cleaning and flushing process using cleaning devices Figure 5.

Figure 4:Photographs of the cleaning Directional gravity subsurface drain No. 10 a) before and b) after

Figure 5: Obstructive materials encountered during the cleaning and flushing process using cleaning devices. a) Chemical and biochemical clogging with iron oxides b) Plant roots overgrowth inside the drain

5. Discussion

The restoration of directional gravity drains at Watawala Landslide enhanced the draining out of water from the land mass, which contributed to reducing the risk of mass movement, which was influenced by the increase in piezometric levels. At the beginning of cleaning, discharge through directional subsurface drains were very low as they were not functioning properly and the requirement of draining water out from the slip surface through subsurface drains was not met. The cleaning process encountered significant amounts of obstructive materials, such as fine sediments, chemical and biochemical clogging with iron oxides, and plant root overgrowth inside the drains. These materials were ultimately leading to a significant decrease in the rate of ground water outflow resulting in a lower factor of safety for the slope stability than the designed value.

According to above observations and results, almost all of the discharge flow rates of directional gravity drains have been significantly increased, as shown in Figure 6 in percentages of increment for the 3 stages of hydro-jet cleaning. After the cleaning, the flow rates increased on average by about 120%, with a higher increase observed during the first stage of cleaning.

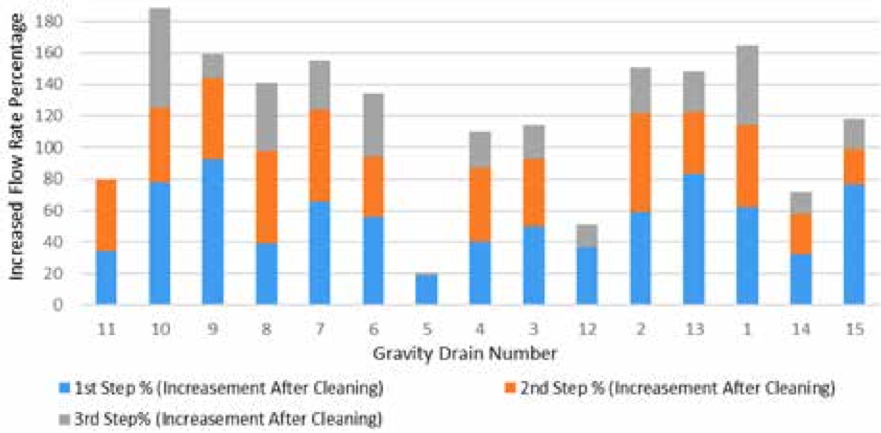

Figure 6: Percentage (%) of flow rate of subsurface drains in three (3) stages of cleaning process

The average discharge at horizontal drains was increased with the progress of the cleaning process (Figure 7a). But it was subsequently observed that flows in some of the drains decreased with time as a result of the decrease in piezometric levels Figure 7. The variation of each piezometric level with the rain fall exhibits its own significant pattern, revealing the influence of the hydrological variations within the landslide. Deeper piezometric levels experienced a considerable drop in piezometric levels during the cleaning process Figure 7, that could be caused by an increase in groundwater release through gravity drains.

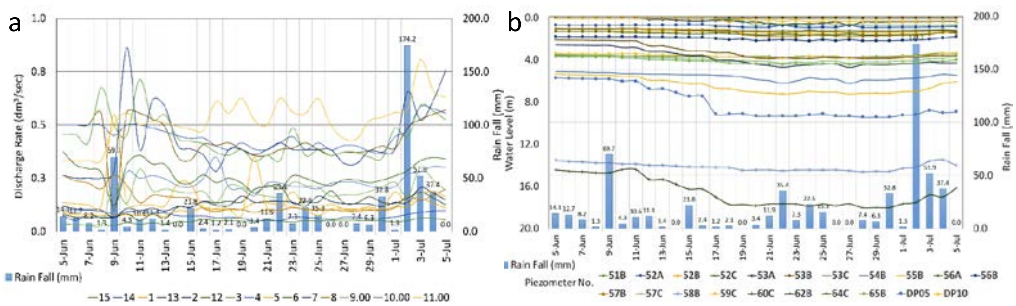

Figure 7: Total discharge (dm3/sec) of subsurface drains, b) Piezometric / Groundwater Levels in Watawala Landslide during the cleaning process.

At the beginning of the installation of directional gravity drains in 1995, the relationship between site rainfall and the total discharges from the 15 underdrains has been reported by Chandler and Broise, Douglas & Partners in 2000 as shown in Figure 8. The total discharge flow rate from the underdrains during relatively low rainfall in March 1995 was slightly less than 1.6 dm³/sec. and the peak flow rates coincided with periods of heavy rain over several days (Chandler and Broise, 2000). The pattern of average flow rate in our case study is consistent with regional rain fall intensity in Watawala landslide Figure 9.

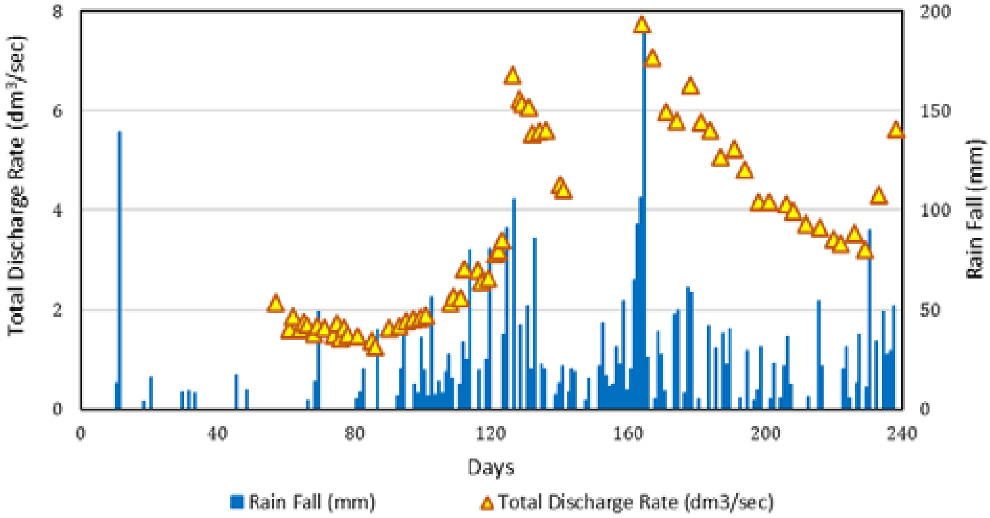

Figure 8:Total Discharge Rate and Rain fall, from 1st January 1995 in Watawala Landslide (Chandler and Broise, 1996)

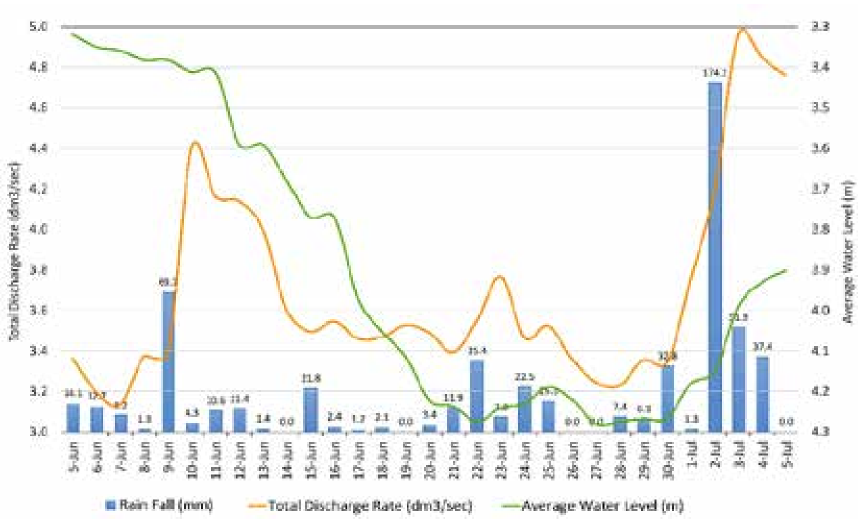

Figure 9: Average Piezometric/Groundwater Levels and Total discharge rate compared to rainfall in Watawala Landslide during the cleaning process

Significantly, isolated storms have a noticeable but small effect on the overall flow rates, unless followed by successive days of prolonged heavy rainfall as shown in Figure 8. The response of the underdrains to heavy rainfall is rapid, within about one day. The average water levels of these piezometers have dropped with the period of restoration process of subsurface directional gravity drains (Figure 8), which shows the cleaning of drains has effectively affected the removal of groundwater from landslide mass with the influence of regional rainfall. This suggests that the colluvium is more permeable than the data obtained from the permeability tests (Chandler and Broise, 2000), and that draining out water from landslides has been improved by the cleaning. This observation is encouraging that there appears to be good hydraulic connection between the colluvium and the gravity drains.

6. Conclusion

The saturation of water plays a dominant role in destabilising the Watawala slide, and draining out the excess water during the rainy season reduces the risk factors, aiding in conducting? the reasonable factor of safety on the slope. According to the data, the hydro-jet cleaning method has proven to be successful in the improvement of the functioning and effectiveness of lateral gravity drains resulting in a decrease in piezometric levels compared to the rain fall. It is highly recommended to practice proper cleaning and flushing processes, especially using cleaning devices, to assure undisturbed functioning of the subsurface lateral gravity drains to maintain the slope stability. Hence, it is advised to maintain proper cleaning practices for the lateral gravity drains and monitoring practices in the mitigated landslides to avoid unforeseen events in a disaster-resilient future.

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Building Resilience amidst
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Development of road slope risk assessment tool for Sri Lanka

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Abstract

Sri Lanka has experienced a huge number of slope failures, cutting failures and landslides along the road network throughout the island. Most of these failures are triggered by rainy weather and road closures, property damages and sometimes loss of human lives are reported after monsoonal rains. Usually, slope risk assessments are carried out after such failure or with the appearance of early signs of failure. Consequent risk mitigation design and construction are carried out considering only the area subjected to failure or susceptible to failure. Although a considerable region along a particular road may have the same geological and geomorphological conditions with a possibility of failure, currently, there is no proper methodology to assess the overall risk along the road. Due to the lack of such a practice, failures along the road network are repeatedly reported causing continual socio-economic impacts to the country.

There is a necessity to streamline the process of slope risk assessment, to ensure the minimization of the probability of further failures along a mitigated road. A nationally applicable procedure should be implemented in order to assess the level of risk associated with slopes along the road network and to develop a proper mitigation plan, based on the identified risk levels. One of the most preferred methods for a proper assessment is to maintain a checklist as a tool that can be used by a professional with knowledge and experience regarding road slope failures. This research focuses on the development of the checklist, application of the developed checklist, and verification of the results obtained from the assessment done through the checklist.

Keywords: Hazard, Road slope failure, Risk assessment, Vulnerability

1. Introduction

Sri Lanka is a developing nation which has achieved remarkable growth in the road sector in the past few years through expanding the highway network, widening the existing road system and constructing an expressway network in the country. With such development projects, road construction and widening in hilly areas have become a common aspect. As a result, more cut and fill slopes are created along the road network. In the planning and design of roads in hilly areas, there are many factors which must be taken into consideration in order to have a most economical but safe road system (Z.C.Moh, 1986). It is common to see most of the projects are done without paying due attention to the long-term stability of the road slopes, due to the limitation of time, funds and sometimes due to lack of concern towards maintaining the slope stability.

Regardless of whether it is a newly constructed road or the widening of an old road, Sri Lanka is experiencing a huge number of slope failures, cutting failures and landslides along the road network throughout the island. Generally, this type of failure event and resulting road closures are reported repeatedly during monsoonal season. There is a major concern towards those events, as they are capable of creating direct effects on human lives and properties as well as a great impact on the economy. If such critical locations can be identified at the planning stage or construction stage and site-specific risk mitigation measures are implemented, failures could be minimized. Therefore, this research concentrates on developing a tool that can be used to assess the risk associated with road slopes and to categorize the assessed risk levels for future planning work.

2. Current practice in Sri Lanka

During the planning and design stages of large-scale road development projects, proper attention is paid to minimizing the slope risk associated with the construction stage and the operation stage. The slope stability checks are done with the aid of geological assessments and geotechnical investigations. Therefore, relevant authorities generally issue guidelines/ method statements that should be followed during the construction stage of road development, which include stable slope heights, slope angles and also drainage facilities to be established as early measures to avoid long-term slope failures.

But in most of the road widening projects, construction is done without a prior geotechnical assessment. The stability of road slopes becomes a concern if only a failure occurs. As a result of the inadequate systematic approach in this aspect, some road segments are repeatedly subjected to closure after every monsoon. Usually, slope risk assessments are carried out after such failure or with the appearance of early signs of failure in the road slope. Consequent risk mitigation design and construction are carried out considering the area subjected to failure or susceptible to failure.

Figure 1: Road cut failure at Ch 140+560 of Peradeniya - Badulla - Chenkaladi Road (A5)

Figure 1 shows one of the failure locations of a series of cut slope failures that occurred after road widening along Peradeniya – Badulla – Chenkaladi Road (A5). The high rainfall received in this region triggered a series of cut slope failures, where unsupported cut slopes were left after widening the road. The stability of the road cuts became a concern only after the occurrence of a number of failures causing the closure of roads and disruption to road traffic.

3. Developing the checklist

Assessment of risk associated with road slopes is not a simple task. There are various factors to be assessed including slope characteristics, soil/ rock properties, groundwater conditions and road characteristics (Guide to Slope Risk Analysis version 4, 2014). Among these factors, assessment of soil/rock properties is much difficult due to the high variability in Sri Lankan soils. Due consideration shall be given to the high variability associated with metamorphic rock terrain. Therefore, site-specific assessments shall be done in order to determine the actual risk of failure.

There should be a compatible tool to identify all the variables easily to make a proper risk assessment. Also, the assessed level of risk should not depend on the personal judgment of the person doing the assessment. Therefore, it is necessary to streamline the process of risk assessment of road slopes. The most preferred method for a proper assessment is to maintain a checklist as a tool that can be used by a professional with some knowledge and experience regarding road slope failures.

A quantitative risk assessment can be done by combining the hazard frequency and failure consequences (H. El-Ramly, 2003). The basic concept adopted to develop the checklist can be presented by the 'Disaster Risk Equation' in which, 'Risk' is calculated using the correlation between 'Hazard', 'Vulnerability' and 'Capacity'.

$$Risk = \ (Hazard \ \times Vulnerability)/Capacity$$

Hazard is defined as a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation. Vulnerability is defined as the conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards. Capacity is defined as the combination of all the strengths, attributes and resources available within an organization, community or society to manage and reduce disaster risks and strengthen resilience. (UNDRR Terminology, 2017).

Accordingly, hazards associated with road slopes can be simply termed as a failure event that may directly cause loss of life, damage to road infrastructure, damage to road vehicles, and socio-economic disruption. Vulnerability can be simply assessed by the 'elements at risk' which can be damaged from a failure event. The hazard level and vulnerability of a selected failure location will be assessed separately by giving a score to identified factors in the checklist. The capacity of the relevant organizations to reduce road slope risks remains a constant for all road slopes. Hence, capacity is not separately considered in the scoring system. Therefore, the risk level will be calculated by multiplying the Hazard score and Vulnerability score as per the above equation. The following sections detail the assessment criteria and scoring of the checklist.

3.1. General details

Location details including road name, chainage/culvert numbers of the failure point, GPS coordinates, RHS/LHS, length of the failed stretch shall be collected under general details for identification and easy reference. Hand-drawn sketches of the plan, elevation and cross sections of the location shall be included in the checklist.

3.2. Failure categories

The person who is doing the assessment should be able to categorize the potential failure among the three types; landslide/slope failure, soil cut slope failure or rock slope failure according to his/her knowledge and experience. The assessment factors and scoring system change depending on the failure category.

3.3. Hazard assessment

There are a wide variety of factors which contributes to the hazard level of a failure location. Among them, the most relevant factors; soil/rock properties, slope geometry, water condition, etc. were selected for the assessment considering the features of past failures and literature (Harwant Singh, 2008). Table 1 summarizes the common factors that were used for the assessment of hazard levels. Additional factors like land use and management, landform, instability of in-situ boulders/rock boulders resting on the slope, detailed rock discontinuity properties, etc. are considered for landslide risk assessment (P.H.E.Dulanjalee, 2017) and rock slope risk assessment (Lawrence A. Pierson, 1993).

Table 1: Summary of the common hazard assessment factors

No	Assessment factor	No	Assessment factor
1	Potential Failure type	3	Slope geometry
	• Interface		• Natural slope angle
	• Material type		• Natural slope height
	• Movement type		• Cut slope angle
2	Material properties		• Cut slope height
	• Bedrock properties	4	Water condition
	○ Rock type		• Surface water condition
	○ Slope orientation		• Ground water condition
	○ Rock face orientation		• Existing drainage & management
	○ Weathering condition	5	Special features
	○ Rock discontinuities		• Evidence of previous failures
	• Soil properties		• Tension cracks
	○ Soil type		• Old Landslide scars
	○ Overburden thickness		• Subsidence/Heaving/ Bulging
	○ Moisture condition		• Overhanging, etc.

The above features shall be thoroughly observed by the person making the assessment and the hazard score is to be calculated first. A hazard level will be defined as High, Medium or Low according to the obtained score.

3.4. Vulnerability assessment

Vulnerability is assessed based on the elements which are at risk due to any possible failure event, where the failure consequences are addressed. The elements at risk are divided into three categories; critical elements, moderately critical elements and non-critical elements, as shown in Table 2. The road and associated infrastructure are obviously at risk of any type of road slope failure. Therefore, the vulnerability of the road is not separately assessed in the checklist.

Table 2: Elements at Risk under three categories

Critical elements	Moderately critical elements	Non-critical elements
• Hospital buildings • School buildings • Railways • Major water services • Transmission towers • Archeological site	• Compact settlements • Commercial buildings • Open public spaces • Telephone/ electricity/ water supply lines	• Dispersed settlements • Estates • Unoccupied buildings • Local roads

3.5. Assessed risk factor

Once the hazard and vulnerability are quantified as per the scoring system, the 'Assessed risk factor' is calculated by the multiplication of the above two scores. Based on the result, the location is categorized as High, Medium or Low risk. This categorization will be the most important outcome of the risk assessment. Therefore, defining score limits shall be done after a thorough assessment process. This can be achieved only by applying the draft checklist to a considerable number of locations where failures have occurred already (as a back analysis) and refining the checklist until it makes a reliable prediction of the failure event.

4. Application of the checklist

The application of the drafted checklist to selected road segments with known past failures/ potential failures is the key methodology to assess the accuracy of the outcome given by the checklist. This task was done as the next step of the research in order to refine and improve the drafted checklist. A thorough examination was done to select a suitable model road for the assessment. The location of the road, road category, frequency of reported failures and future developments associated with the road were considered for the selection. Accordingly, Kegalle – Bulathkohupitiya Road (A21) was selected for the first assessment.

The road segment passing through a sloping terrain from Hettimulla Junction to Undugoda was selected for the assessment; covering a 10 km stretch of the road. Thirty (30) locations with a potential for failure were identified within this segment and categorized according to the risk level based on the score given from the checklist. Figure 2 and Figure 3 show two locations which were categorized under Medium level of risk and High level of risk. A summary of the assessment is given in Table 3.

Figure 2: KB 04 – Medium level risk

Figure 3: KB 10 – High level risk

Table 3: Summary of road slope risk assessment at Kegalle – Bulathkohupitiya Road (A21)

Location Number	Location GPS (Longitude)	Location GPS (Latitude)	Failure Category	Hazard Level	Risk Level
KB 01	80.36334	7.207099	Soil Cut Slope	Medium	Medium
KB 02	80.36348	7.206359	Soil Cut Slope	Medium	Medium
KB 03	80.36268	7.205394	Soil Cut Slope	Medium	Medium
KB 04	80.36232	7.205089	Soil Cut Slope	High	Medium
KB 05	80.36190	7.204565	Soil Cut Slope	High	Medium
KB 06	80.36135	7.204103	Soil Cut Slope	Low	Low
KB 07	80.36154	7.203032	Soil Cut Slope	High	High
KB 08	80.36091	7.202661	Soil Cut Slope	Medium	Medium
KB 09	80.36091	7.201835	Soil Cut Slope	Medium	Medium
KB 10	80.36063	7.201377	Soil Cut Slope	High	High
KB 12	80.36076	7.200682	Soil Cut Slope	Medium	Medium
KB 13	80.36076	7.199640	Soil Cut Slope	Medium	Medium
KB 14	80.36089	7.198937	Soil Cut Slope	Medium	Medium
KB 15	80.36051	7.198198	Soil Cut Slope	Medium	Medium
KB 16	80.36076	7.197678	Soil Cut Slope	High	High
KB 17	80.36076	7.197001	Soil Cut Slope	High	High
KB 18	80.36067	7.195904	Soil Cut Slope	Medium	Medium
KB 19	80.36065	7.195272	Soil Cut Slope	High	High
KB 20	80.36050	7.194906	Soil Cut Slope	Medium	Medium
KB 21	80.36043	7.194138	Soil Cut Slope	Medium	Medium
KB 22	80.36005	7.193376	Soil Cut Slope	High	High
KB 23	80.35991	7.191803	Soil Cut Slope	High	High
KB 24 - 1	80.35987	7.190611	Soil Cut Slope	Medium	Medium
KB 24 - 2	80.35987	7.190611	Soil Cut Slope	High	Medium
KB 25	80.35988	7.188971	Rock Fall	High	Medium
KB 26	80.35992	7.188329	Soil Cut Slope	High	High
KB 28	80.36044	7.180255	Soil Cut Slope	Medium	Medium
KB 29	80.36392	7.171098	Soil Cut Slope	Medium	Medium
KB 30	80.36602	7.164030	Soil Cut Slope	Medium	Medium

5. Way forward

The draft checklist shall be applied for more locations and refined and updated accordingly to get the best outcome of it. This will be done with the collaboration of the District offices of the National Building Research Organisation, which are located in landslide-prone districts and the Road Development Authority of Sri Lanka which holds the authority and responsibility for the maintenance and development of the National Highway Network. In addition, the results obtained from the checklists shall be verified with slope stability analysis along with modelling of infiltration. A set of selected road slopes will be analyzed using the limit equilibrium method incorporating the factors; failure mechanism, slope geometry, material properties, groundwater condition, and rainfall as the triggering factor.

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Building Resilience amidst
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A comparative study on the use of limit equilibrium methods and finite element methods in evaluating rain-induced slope failures

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Abstract

Most of the slope instabilities in Sri Lanka are triggered by excessive rainfall which leads to the loss of matric suction and the development of perched water table conditions. The state of failure within a slope can be determined using deterministic methods such as limit equilibrium (LE) and finite element (FE) methods. Although LE methods are used commonly by practitioners, less attention has been given to the more comprehensive FE methods, as it is complex. In this study, LE and FE analysis has been conducted to assess the suitability of the methods and variations considering two different groundwater levels in homogenous slopes. For the LE method, SLOPE/W software was used coupled with the finite element infiltration analysis using SEEP/W software. Plaxis 2D FE software was used for the coupled hydro-mechanical FE slope stability analysis. In both approaches, the pore water pressure computation was done through a FE formulation. The differences are in the stage of stability computation. Based on the results obtained the LE method and FE method predict similar FoS values for a higher groundwater table but when the groundwater table is low FE shows higher FoS compared to LE.

Keywords: Slope stability, Limit equilibrium, Finite element, Unsaturated soil, Seepage analysis

1. Introduction

Landslides can be considered as one of the major natural hazards that affect humans frequently. Different intrinsic and extrinsic factors can result in landslide events (Dahal and Dahal, 2017; Jayathissa *et al.*, 2019). Further, the causes of landslide have been more systematically categorised as preparatory and triggering causative factors in WP/WLI, (1994). This is further elaborated as; ground causes, geomorphological causes, physical and man-made causes accounting for all the other factors which can act as preparatory or triggering factors to bring the slope into a marginally stable state (Cruden & Varnes, 1996). The major triggering factor for landslides is rainfall and more than 90 % of the world's fatal landslide events are triggered due to excessive rainfall (Haque et al., 2016). These rain-induced landslide events in the world are spatially concentrated in the tropical and subtropical regions due to the torrential rainfall conditions and high-relief hilly terrains. In Sri Lanka landslides have become a common natural hazard due to the heavy rainfalls received in the central hilly areas throughout the year.

Identifying the level of landslide susceptibility in different regions would be beneficial for the communities living in these areas, government authorities, organizations and other stakeholders for mitigation of the risk. For the assessment of landslide susceptibility more accurate models with coupled infiltration and slope stability analysis can be used. Threshold rainfall values leading to failure could be established through this approach. This can capture the mechanistic basis of slope instability due to rainfall infiltration and associated shear strength reduction due to loss of matric suction. However, this approach needs many parameters and extensive investigations would be required.

Methods such as LE, FE and limit analysis have been developed over the years but LE and FE methods are the most widely used. These methods are coupled with infiltration and groundwater flow analysis to determine the variation of the Factor of Safety (FoS) as the rainfall prolongs In many studies, the LE or the FE methods are separately used in stability analysis, and the available literature on comparisons of these two methods are limited. Although FE method is widely accepted within the research community for slope stability analysis, practitioners are reluctant to use the FE method due to the complexity, lack of understanding of the FE method and inadequate quality of the soil data available. Comparisons of LE and FE studies for slope stability have not been considered in previous studies. This paper attempts to compare the results from the LE method and FE method to identify the suitability in modelling homogenous slopes with different geometry and groundwater conditions.

2. Theory

Landslides in tropical countries are often triggered by rainfall and the associated contribution from the terrain factors such as geological structures, heavy weathering and heterogeneity in soils is significant. When rainwater percolates into the ground significant changes occur in the pore pressure regime. Usually, the subsurface at shallow depths is unsaturated in most tropical regions as the groundwater table is at deeper levels. With the advancement of the wetting front, matric suction is lost, perched water table conditions may develop, and the groundwater table would rise. This results in a decrease in shear strength and the safety margins of the slope (Rahardjo et al., 1995).

For the accurate computation of infiltration in unsaturated or saturated soils, a combination of Darcy's Law and continuity equation can be used. For heterogeneous and anisotropic soil, two-dimensional transient flow can be expressed as

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial h}{\partial y}\right) + q = \frac{\partial \theta_w}{\partial t}$$

Where k_x and k_y are the coefficient of permeability of the soil along x and y directions, h is the hydraulic head, q is the applied flux to the domain and θ_w is the volumetric water content. When the soil is unsaturated the coefficient of permeability and volumetric water content are functions of the matric suction and therefore, the above equation is highly non-linear. Solving the equation requires analytical techniques or numerical analysis. For slope stability analysis, theories have been developed for unsaturated soils based on the extended Mohr-Coulomb failure criterion as shown in Equation 2 by Fredlund et al., (1978).

$$\tau = c^{/} + (\sigma_n - u_a)\tan \emptyset^{/} + (u_a - u_w)\tan \emptyset^{b}$$

τ- Shear strength of unsaturated soil
$c^{/}$-effective cohesion
$(\sigma_n - u_w)$- effective normal stress
$(\sigma_n - u_a)$- net normal stress
$(u_a - u_w)$- matric suction
σ_n- total normal stress
u_a- pore air pressure
u_w-pore water pressure
$\emptyset^{/}$- effective friction angle
$\emptyset^{b}$-the angle of the rate of increase in shear strength relative to matric suction

Later a non-linearity in shear strength curves for unsaturated soil was observed by Vanapalli *et al.*, (1996) & Fredlund *et al.*, (1996) and equations have been developed considering the nonlinearity. The method of slices is widely used to analyse the stability of the slopes using LE. The FoS is used to interpret the stability of the slope and the FoS based on stress can be defined as the ratio between shear strength (τ) and the mobilized shear stress for equilibrium (τ_m).

$$FoS = \frac{\tau}{\tau_m}$$

In numerical analysis the porewater pressure, stresses, deformations and stability can be determined. In FE slope stability shear strength reduction method is used where c and $c_{reduced}$ are initial and reduced cohesion and $\tan(\emptyset)$ and $tan(\emptyset_{reduced})$ are initial and reduced friction angles respectively. Repeated analysis is done with reduced shear strength parameters to identify the condition where deformations tend to increase rapidly.

$$FoS = \frac{c}{c_{reduced}} = \frac{\tan(\emptyset)}{tan(\emptyset_{reduced})}$$

3. Methodology

A parametric study was conducted to evaluate the effectiveness of the LE methods and FE methods for the analysis of stability. The study was conducted on a homogeneous soil slope of different angles and different levels of groundwater table for a cut slope of 30 m in height (Table 1). A silty sand type of soil was used in the model and the particle size distribution for the soil (Figure 1). For the parametric analysis using the LE method, SLOPE/W software was utilized along with the SEEP/W software for the infiltration and seepage modelling. In SLOPE/W software Morgenstern Price method was used as the analysis type which considers both moments and force equilibrium of slices. The grid and radius method with optimization was used for the slip surface determination. The porewater pressure distribution for the slope stability analysis was calculated numerically using transient seepage analysis from SEEP/W software. A rainfall step function was included to simulate the porewater pressure variation with rainfall where the varying intensity has occurred over three days (Figure 2). For the numerical analysis boundary conditions have to be provided (Figure 3). These boundaries were placed at a sufficient distance away from the area of concern for the seepage and stability analysis. The initial groundwater table was established using a steady-state groundwater flow calculation from the applied total head boundary conditions (H1 & H2).

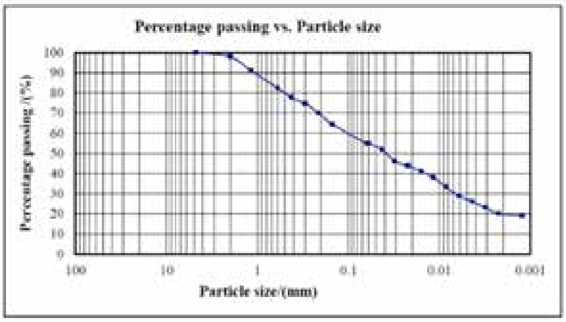


Figure 1: Particle size distribution for Sandy silt (after Vasanthan, 2016)

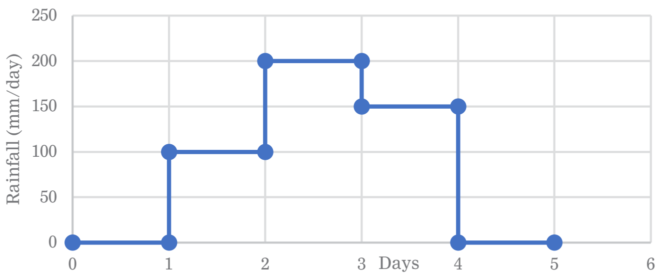


Figure 2: Rainfall unit step function

FE analysis of the slope was done with Plaxis 2D software The software is capable of conducting coupled flow deformation analysis. Boundary conditions similar to SEEP/W were used for the Plaxis 2D analysis also. In Plaxis 2D software, the initial stresses were calculated using Gravity loading, considering the non-horizontal ground layers. For the infiltration and seepage analysis, a fully coupled flow deformation analysis was conducted which incorporates time-dependent deformation and porewater pressures. The Factor of Safety was obtained using the deformation analysis with the shear strength reduction method.

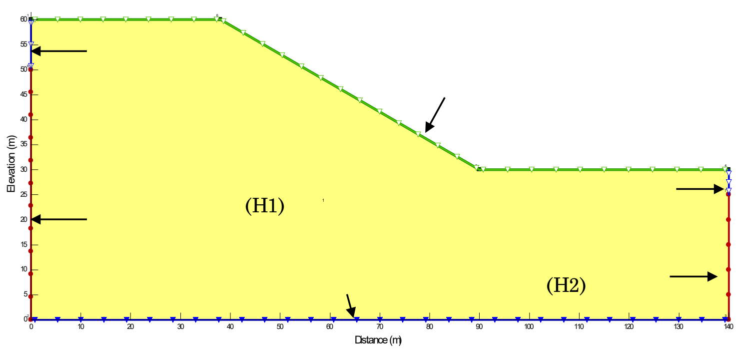


Figure 3: . Boundary conditions used in the analysis

Table 1: The analysis cases for Geoslope and Plaxis 2D

Case	Slope angle (degrees)	Ground Water Table (GWT)	
Case 1	30	Lower GWT	H1=30 m, H2= 15 m
		Higher GWT	H1=40 m, H2= 20 m
Case 2	45	Lower GWT	H1=30 m, H2= 15 m
		Higher GWT	H1=40 m, H2= 20 m
Case 3	60	Lower GWT	H1=30 m, H2= 15 m
		Higher GWT	H1=40 m, H2= 20 m

Table 2: Material Properties

Used for the Geoslope analysis		Used for the Plaxis 2D analysis		
Unit weight	19 kN/m^3	Unit weight	γ_{unsat}	18 kN/m^3
			γ_{sat}	19 kN/m^3
Saturated volumetric water content	0.52	Saturated degree of saturation (S_{sat})		1.0
Residual volumetric water content	0.138	Residual degree of saturation (S_{res})		0.266
k_x/k_y ratio	1.0	Dilatancy angle (ψ)		3^0
Friction angle (ϕ)	33^0	Friction angle (ϕ)		33^0
Cohesion (c)	5 kPa	Cohesion (c)		5 kPa
Diameter of the particles passing 10 %	0.001	Poison’s ratio		0.3
Diameter of the particles passing 60 %	0.1	Elastic modulus		30,000 kPa
Liquid limit	54 %	Fitting parameters	g_a	0.125
			g_n	1.959
			g_l	0.826
Saturated permeability	3.3x10^{-6} m/s	k_x		3.3x10^{-6} m/s
		k_y		

The material properties of the homogeneous soil used are illustrated in Table 2. For the infiltration and seepage analysis of unsaturated soils using SEEP/W software, soil water characteristics curve (SWCC) (variation of volumetric water content variation with matric suction) and Hydraulic Conductivity Function (HCF) (variation of coefficient of permeability with matric suction) has to be included. The SWCC and hydraulic conductivity functions were obtained using the correlations with particle size distribution for a sandy silt type soil encountered in the Welipanna slope failure area in the Southern Expressway project (Figure 4). For the Plaxis 2D software, Van Genutchen method based on fitting parameters for SWCC and HCF has been used for seepage analysis. Therefore, curve fitting was conducted to obtain the fitting parameters based on the SWCC and HCF.

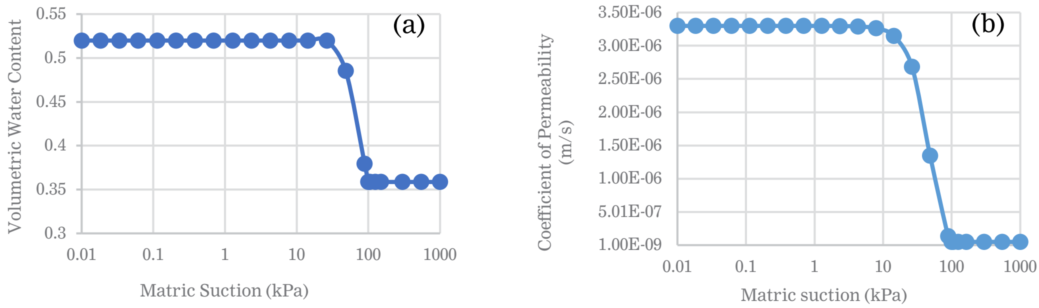
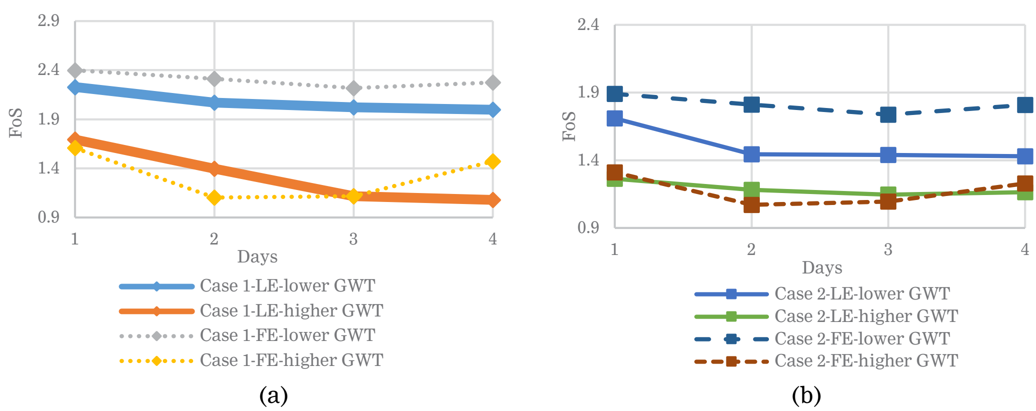


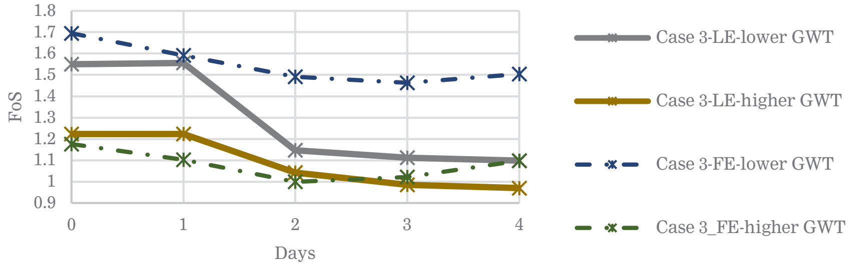
Figure 4: (a). SWCC & (b). hydraulic conductivity function for sandy silt

4. Results and discussion

The Factor of Safety reduction has been observed with the water table rise in both the LE and FE analysis (Figure 5). In the figure results for the LE analysis with Geostudio software were represented as 'GS' and results for the FE analysis using Plaxis 2D software were represented as 'PL'. Irrespective of the initial groundwater level the lowest FoS for the LE method was observed at the end of Day 4. However, the lowest FoS for the lower groundwater table was observed on Day 3 and for the higher water table on Day 2 in the FE analysis. This can be attributed to the fact that rainfall can infiltrate and reduce matric suction quickly when the water table is close to the ground surface. However, such observation was not made in the LE method because it assumes the slip surface and does not depend on the stresses and deformations with the seepage forces. For the higher groundwater table in the 3 cases, LE and FE analysis show closer results for the FE and LE analysis. However, for the lower groundwater table, the FoS is marginally higher for the FE analysis compared to the LE analysis.

The critical failure surface variation with the rainfall for the Case 2 (higher initial groundwater level) for LE and FE illustrates that the critical slip surface varies for LE and FE methods (Figure 6- a & b). When the distribution of porewater pressure and groundwater table variation is considered with rainfall both LE and FE analysis shows similar trends. The variation of the groundwater table for case 2 at the of the slope (higher initial groundwater table condition) with rainfall is similar for both LE and FE approaches (Figure 6 - c & d). This is due to the fact that in both approaches the pore water pressure is predicted by a FE formulation.





(c)

Figure 5: Factor of safety distribution with time for (a) Case 1, (b) Case 2 and (c) Case 3

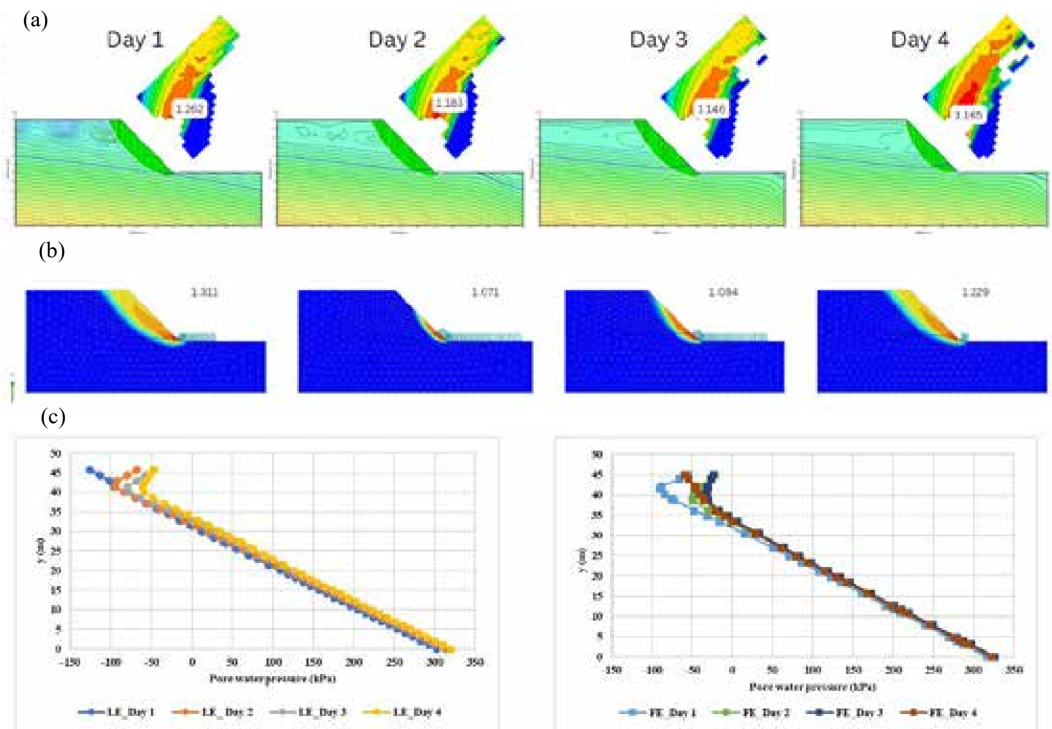


Figure 6: (a) Critical failure surface from LE method, (b) Critical failure surface from FE method, (c) Pore water pressure distribution for LE and (d) Pore water pressure distribution for FE, for Case 2 initial high groundwater table

5. Conclusion

This study focused on evaluating the suitability of LE methods compared to FE methods for slope stability coupled with infiltration and seepage analysis. A homogeneous unsaturated soil slope with different slope angles and groundwater levels was analysed using LE and FE methods incorporating rainfall infiltration. The following conclusions were made from the results of the analysis.

1) LE method would result in lower FoS compared to the FE method when the groundwater table is below the slip surface. However, when the groundwater table is within the slip area the FoS variation is less between the two methods.

This can be attributed to the variations in the assumed slip surface in the LE method.

2) The FoS variation trend for the LE method is similar for all the cases irrespective of the groundwater level. Minimum FoS reached at the end of the 4th day.
3) In FE method the minimum FoS was reached at the end of Day 2 for higher groundwater table conditions and for lower groundwater table conditions on Day 3. This variation has not been identified in LE method as it does not incorporate stress conditions for stability analysis.

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RISK REDUCTION FOR

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Building Resilience amidst Economic Challenges

Assessment of potentially toxic elements in commercially available inorganic fertilizers in Sri Lanka

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Abstract

Sri Lanka being an agro-economy-based country uses fertilizers for a wide range of crops to supply the needed plant nutrients. The same land is used for cropping cycles of many short-term crops such as paddy at least twice a year over generations. Repeated application of fertilizer over several cropping cycles on the same land could lead to the accumulation of heavy metal residues in soil and water. The harvest can contain a fraction of heavy metal residues gained from the soil and water in addition to those from direct fertilizer application. Heavy metal residues in the harvested products are a serious health risk concern due to their suspected etiology with Chronic Kidney Disease in several dry zone districts of Sri Lanka. The study is to ascertain the level of potentially toxic elements of commercial fertilizers available in the country with the recommended safe limits. Commercially available four inorganic fertilizers (TSP, Urea, MOP, and Dolomite) were randomly selected for the analysis. Potentially toxic elements (Cr, Co, Ni, Cu, As, Se, Cd, and Pb) were measured by an Inductively Coupled Plasma Mass Spectrometer (ICP-MS). The study revealed that 20% of samples of TSP and 70% of both MOP and Dolomite exceeded the safe limits of potentially toxic elements (Pb, Cd & As) while TSP contained the highest amount of potentially toxic elements. The study recommends the need for a better fertilizer standardization protocol, and the use of organic farming to reduce health risks by incorporating toxic elements into the food chains via soil contamination.

Keywords: Crops, Potentially toxic elements, ICP-MS, Inorganic fertilizers, Health risks

1. Introduction

Naturally trace elements and the most abundant nutrients like Nitrogen, Potassium, and Phosphorous are found on the earth's crust assists to balance nature reactions, plant nutrient levels and etc. But over the growing population, the nutrient requirement of plantation for consumption is gradually increased but naturally occurring levels is not sufficient on demand, therefore synthetic fertilizers are used as a supplement source of plant nutrient and trace element on the ground long years back (Ahialey *et al*, 2014). Soil fertility is the quality of soil that enables it to provide compounds in adequate amounts and proper balance to promote the growth of plants when other factors (such as light, moisture, temperature, and soil structure) are favourable. Where the fertility of the soil is not good, natural or manufactured materials may be added to supply the needed plant nutrients. These are called fertilizers. However, repeated application of fertilizers without prior awareness of usability by ground-level users (Farmers and retailers) has already created a critical impact on ground fertility, sustainability, and also on human health (He *et al*. 2005).

The heavy metal contaminant has gained serious concern in the past few years due to their toxicity in presence of minor levels and environmental persistency over many years, which enters the human food chain through bioaccumulation, leaving fatal health issues (Duruibe *et al*, 2007). Studies show the long-term simultaneous application of fertilizer and manure on a commercial farm with high metal accumulation in the soil and plants. The presence of cadmium (Cd) in some fertilizers at high concentrations is of most concern due to the toxicity of this metal and its ability to accumulate in soils and its bioaccumulation in plants and animals (Shallari *et al*, 1998).

Heavy metal accumulation in agricultural products is not only associated with the total metal concentrations in soil but is also strongly dependent on the uptake mechanisms, soil physicochemical properties, chemical speciation of metals, soil texture, nature and quantity of nutrients, climate, and other factors. The availability of heavy metals (such as Copper (Cu), Zinc (Zn), Nickel (Ni), and Lead (Pb)) in the soil is significantly related to crop uptake of metals (Herawati *et al*, 2000).

Chronic kidney disease of unknown etiology (CKDu) has emerged as a serious health issue in Sri Lanka. The disease has been recorded in the North Central Province of the country. While studies have elicited many hypotheses concerning the pathogenicity of CKDu, none adequately explain the cause of CKDu and the measures needed to minimize its occurrence. Recent global studies on chronic kidney disease (CKD) revealed a low concentration of heavy metals in diseased patients. Research findings indicated that CKDu patients in Sri Lanka demonstrated similar blood levels of Cd, Pb, and higher concentrations of Cr than that have been reported globally (Goyer *et al*, 2001). Therefore, every effort is to be made to reduce the consumption of heavy metal-contaminated water and food.

This research study was initiated to assess the heavy metal contamination of commercially available fertilizer in Sri Lanka and to emphasize the requirement of regular monitoring or controlling direct heavy metal contaminant sources to reduce the risk of exposure. The study covered the heavy metal profile by Inductively Coupled Plasma- Mass Spectroscopy technique; Chromium (Cr), Cobalt (Co), Nickel (Ni), Copper (Cu), Arsenic (As), Selenium (Se), Cadmium (Cd) and Lead (Pb) in commercially available and frequently used inorganic fertilizers, applied heavily on ground yearly to fulfil the nutrient requirement of plants. Tested values were compared with specifications declared by SLSI (Sri Lanka Standard Institution). These are recommended safe limits for the heavy metal content of fertilizers and are based on the dose of application, plant uptake, bioavailability, retentions in the environment and etc.

2. Method

2.1. Market sample collection

The fertilizer samples, Triple Super Phosphate (TSP), Urea, Muriate of Potash (MOP), and Dolomite, were randomly purchased from the retail shops in the Colombo district, which is the centre of distribution of imported fertilizer across the country. The brand names were not considered when selecting these fertilizers.

2.2. Calibration graph preparation

Calibration graphs from 1.0 to 250 µg/L with six calibration points (1.0, 10.0, 50.0, 100.0, 200.0, and 250.0 µg/ L) were prepared from the multi-calibration standard (10 mg/L) and intermediate stock solution (0.5 mg/L) for selected metals.

2.3. Sample preparation and analysis

Approximately 0.2500 g of pre-air dried, the ground sample was weighed into a high-pressure microwave vessel made of PTFE (Poly Tetra Fluoro Ethylene), and weight was recorded to 0.0001 g. Concentrated nitric acid (10.0 mL) was added to the vessel, and it was kept for 10 minutes inside a fume cupboard for pre-digestion. The vessels with samples were placed in a digester, and digestion was carried out at 170˚C & 400 W for 20 minutes. After digestion, samples at room temperature were quantitatively transferred in a 25.0 mL volumetric flask filtering through ashless filter paper and mark-up with de-ionized water. Then samples were measured by ICP-MS (Agilent 7900) for selected trace elements as per the operating conditions mentioned in Table 1.

Table 1: ICP-MS operating conditions

RF power	1000 W	Outer gas flow	15 l /min
Auxiliary flow	0.8 l /min	Solution uptake rate	0.85 ml /min
Nebulizer flow			0.8 l /min

2.4. Compliance

Measured heavy metal concentrations were compared with the Maximum Permissible Levels (MPL) given in specifications in SLS 812:2014 for TSP, SLS 618:2014 for urea, SLS 644:2014 for MOP, and SLS 823:2014 for Dolomite.

2.5. Statistical analysis

Principal component analysis was carried out to determine the risk level of repeated usage of selected fertilizer samples using Minitab software (version 16).

3. Results and discussion

The analysis of heavy metals in 10 TSP samples revealed the heavy meals (Cr, Co, Ni, Cu, As, Cd, and Se) of all tested samples comply with the specification; SLS 812: 2014. However, 20% of the samples tested exceeded the maximum permissible levels for Pb (MPL Pb = 30.0 mg/kg). The resulting maximum Pb concentration was 32.2 mg/kg (Figure 1).

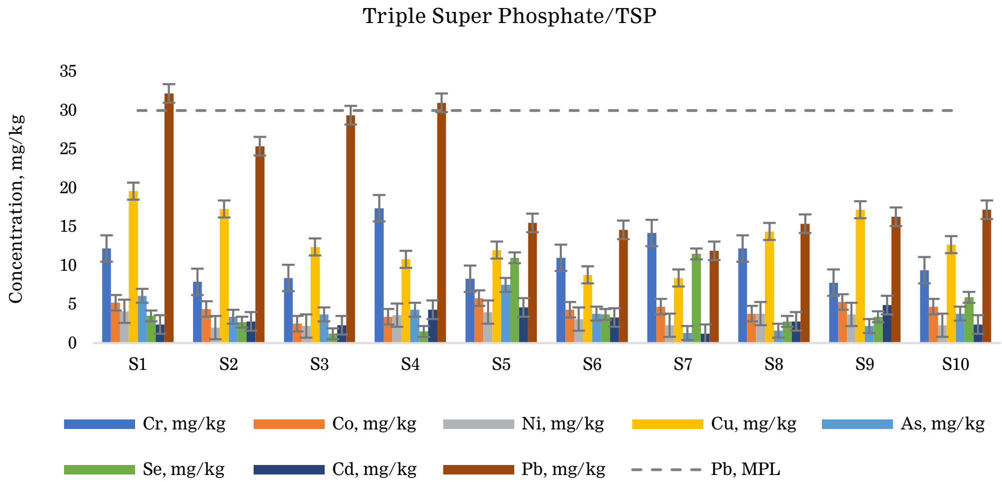

Figure 1: Heavy metal concentrations of TSP and compliance of Pb levels with the specified MPL

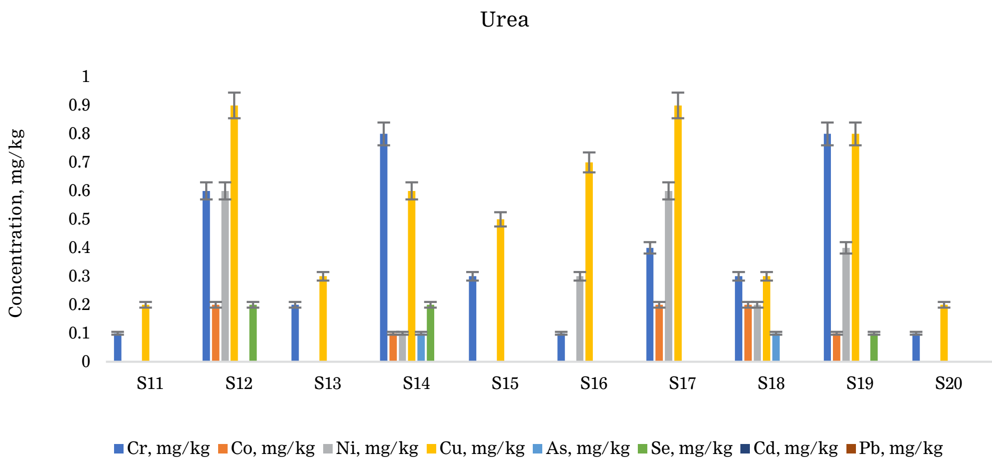

Figure 2: Heavy metal concentrations of Urea

The analysis of heavy metals in 10 Urea samples revealed that the heavy meals (Cr, Co, Ni, Cu, Se, Cd, Pb, and As) of all tested samples comply with the specification SLS 618:2014 (Figure 2).

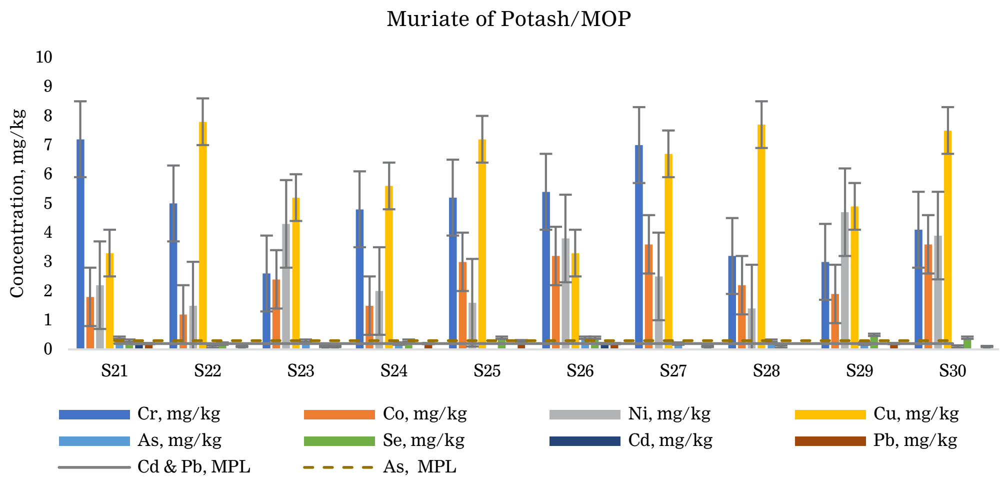

Figure 3: Heavy metal concentrations of MOP and compliance of Pb, Cd, & As with the specified MPL

The analysis of heavy metals in 10 MOP samples revealed the heavy meals (Cr, Co, Ni, Cu, and Se) of all tested samples comply with the specification SLS 644: 2014. However, 40%, 40%, and 20% of the samples tested exceeded the MPL for Pb, As, and Cd respectively. (MPL for Cd = 0.2 mg/kg, Pb = 0.2 mg/kg and As = 0.3 mg/kg). The resulted maximum concentration for Cd, Pb, and As were 0.2 mg/kg, 0.3 mg/kg, and 0.4 mg/kg respectively (Figure 3).

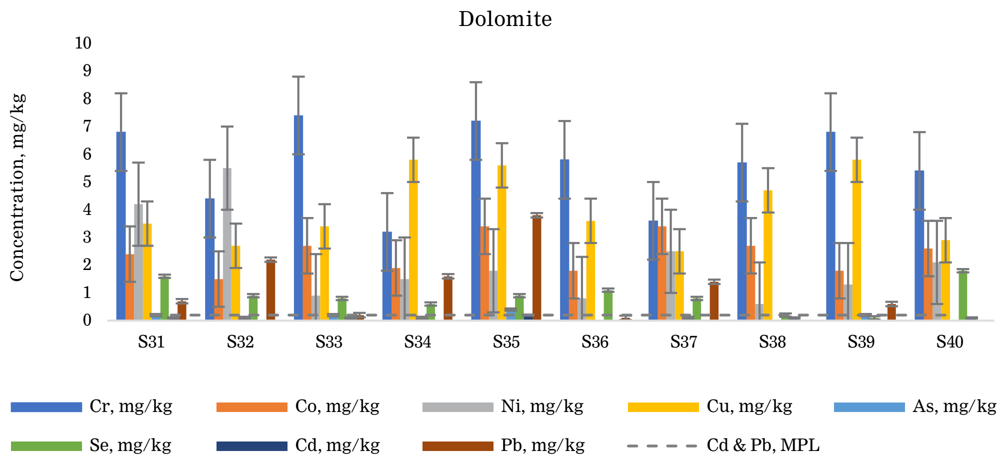

Figure 4: Heavy metal concentrations of Dolomite and compliance of Pb and Cd with the specified MPL

The analysis of heavy metals in 10 Dolomite samples revealed the heavy meals (Cr, Co, Ni, Cu, Se, and As) of all tested samples comply with the specification SLS 823: 2014. However, 10% and 70% of the samples tested exceeded the MPL for Cd and Pb respectively. (MPL for Cd = 0.2 mg/kg and Pb = 0.2 mg/kg). The resulted maximum concentrations of Cd and Pb were 0.2 mg/kg and 3.8 mg/kg respectively (Figure 4).

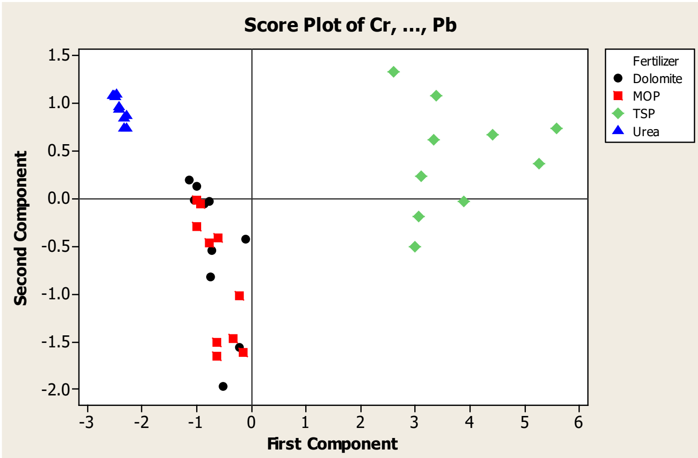

Figure 5: Principle Component Analysis (PCA) chart of selected fertilizer samples

PCA analysis reveals that the most of TSP samples are in the area with positive loading in the first component (PC1). In other words, if the same dosage is used in the field, then TSP samples are associated with higher risk levels of potentially toxic element contamination than other fertilizer samples selected for the study (Dolomite, Urea, and MOP samples).

4. Conclusion and recommendations

Analysis of 4 inorganic fertilizer products shows that 20% of TSP and 70% of both MOP and Dolomite exceed the maximum permissible levels of Cd, Pb and As. None of the Urea samples exceeded the maximum permissible levels recommended by SLSI. 32.5 %, 10 %, and 7.5% from 40 samples exceeded maximum permissible levels for Pb, As, and Cd, respectively. Among the four fertilizers tested, TSP has more impact on overall soil heavy metal (potentially toxic elements) contamination.

The long-term application of these agrochemicals may be responsible for the accumulation of heavy metals in soils, and this situation is triggered as in Sri Lanka, application of fertilizer doses higher than the recommended doses by the Department of Agriculture has been a common practice among farmers for many years. Analysis of heavy metal concentrations in soils and identifying the sources are essential to implement control measures to reduce heavy metal inputs to soils through agrochemicals.

Recent studies have produced evidence supporting Cd and As as contributory nephrotoxic agents for the mysterious endemic renal disease of Sri Lanka therefore a better fertilizer standardization protocol, especially for imported fertilizer, is essential.

This research opens a serious human health risk concern pertinent to heavy metal residues in inorganic fertilizers used in the country. Due to their inherent properties (bioavailability, long-term environmental retention, bio-concentration, biomagnification in food chains), risk management is challenging. Understanding the risk dimensions, the use of organic farming systems to reduce environmental entry, soil treatment to flush the residues with integrated crop management, etc., are important aspects in reducing the human health risks associated with heavy metal residues in inorganic fertilizers.

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Building Resilience amidst
Economic Challenges

Prioritisation of parameters to be concerned in urban air quality monitoring in Sri Lanka

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Abstract

Air pollution plays a major role in the country economy since it affects health of the people and impacts adversely on productivity. Therefore, much concern should be drawn to urban air quality management since outdoor air pollution is higher in most urban areas than in rural areas of the country. Each and every pollution source emits a different type of pollutant that results in prevailing air pollution conditions. Air pollutants depend on the type of sources and their environmental behaviour. Therefore, air quality monitoring programs should align with the monitoring of important parameters which significantly contribute to air pollution.

Most countries including Sri Lanka, are concerned about monitoring criteria air pollutants in their monitoring programs. However, monitoring all criteria air pollutants involves very high costs even though some of the pollutants may not contribute significantly. Prioritizing monitoring parameters that significantly contribute to air pollution could reduce the cost of monitoring. In this study, the significance of criteria pollutants in the Colombo urban area was studied and pollutants that significantly contribute to the air quality index were identified. Accordingly, pollutants that highly contribute to air pollution conditions were identified and prioritized for recommending for monitoring continuously in air pollution monitoring programs. Disregarding parameters showing very low concentration when compared to national and international standards is found to be cost-effective in sustainable air quality monitoring program in Sri Lanka.

Keywords: Air pollution, PM_{10}, $PM_{2.5}$, WHO health guidelines

1. Introduction

Urban Air Pollution (UAP) has become a major concern in the world. affecting both the developed countries as well as the developing countries. Contributing pollutants are emitted by many sources such as vehicles, industries, and commercial, domestic and other urban activities. It was estimated that over 60–80% of air pollution in urban areas is due to vehicular emissions caused by poorly maintained vehicles, low-quality fuels and inadequate road infrastructure etc. Many industrial and commercial activities release various pollutant emissions and activities in highy densed residentil areas also contribute significantly to UAP. Usually, the major pollutants responsible for deteriorating urban air quality include Particulate Matter ($PM_{2.5}$ & PM_{10}), Oxides of Nitrogen (NO_X), Sulfur Dioxide (SO_2), Carbon Monoxide (CO), Ozone (O_3) and Volatile Organic Compounds (VOCs). Also, road dust due to the movement of traffic, and tire and brake wear are also some of the significant sources of ambient Particulate Matter concentrations in urban areas (Amato, et al., 2014). Further atmospheric composition of urban areas is highly complex in nature due to the influence of meteorological and topography conditions. Resulting in giant chemical reactions of various gasses and particles such as hydrocarbons and oxides of nitrogen and sulphur that react under the influence of sunlight create a variety of products, including ozone and sub-micrometer aerosols. (Seinfeld, 2017)

Policies, strategies and actions in urban air quality management are developed mainly based on the existing air pollutant levels and pollutant sources which are determined and identified by air quality monitoring data. In this regard, a sustainable continuous air quality monitoring program is an essential step in air quality management. Most of the air quality monitoring programs include measuring of criteria air pollutants and specific pollutants identified by international knowns and relevant country regulations. Data obtained from such monitoring systems are used for emission inventory, prediction and forecasting, control strategy development and public awareness creation. However, air quality monitoring in urban areas especially in developing countries still remains a challenge due to the lack of government commitment, insufficient financial allocation and absence of investments etc. However, prioritization of monitoring parameters, introducing and using low-cost techniques, polluter pay concepts, etc. could be solutions to develop a cost-effective monitoring network in urban areas.

In Sri Lanka, UAP became a major issue due to rapid urbanization that resulted in increasing vehicular usage, industrial and commercial activities etc. Usage of fossil fuel burning in motor vehicles, power generation and other commercial activities resulted in increasing air pollutants in Colombo.

In Sri Lanka, an air quality monitoring program was implemented in Colombo to measure all criteria pollutants; Particulate Matter (PM2.5 & PM10), Oxides of Nitrogen (NOX), Sulphur dioxide (SO2), Carbon monoxide (CO), and Volatile Organic Compounds (VOCs) along with the meteorological parameters from 1997 to 2005. Based on the results of this monitoring program, it was found that 60% of air pollutants were generated by motor vehicles and 15% by thermal power plants. The Sri Lankan government implemented several programs to manage air pollution in the country, especially in urban areas. Those include, fuel quality improvement programs, introducing cleaner fuel vehicles, road infrastructure improvement programs, vehicular emission testing programs, etc. are some of the key programs that were implemented under "clean air action plans" as the road map in air quality management. (AirMAC, 2016)

At present, an air quality monitoring network is being implemented to measure urban air quality in selected urban areas in Sri Lanka by using a highly sophisticated Automated Ambient Air Quality Monitoring Station (AAQMS), and in addition, using passive sampling and real-time air quality monitoring sensor technologies. But more attention is paid to measuring all criteria pollutants using automated monitoring systems. However, the initial and operational costs of the monitoring system are significant to the country's economy and there is a need to minimize the monitoring cost involving with air quality monitoring. In this paper, we discuss evidence-based prioritization of monitoring parameters to be included in the monitoring network for the development of a cost-effective sustainable monitoring network.

2. Methodology

Air quality levels with respect to criteria pollutants, Particulate matter ($PM_{2.5}$ & PM_{10}), Nitrogen dioxide (NO_2), Sulfur dioxide (SO_2), Carbon Monoxide (CO), Ozone (O_3) along with the meteorological parameters were monitored at Colombo Municipal Council (CMC) premises, the heart of the Colombo urban area from 2020 to 2022. The monitoring techniques are highly sophisticated automated monitoring methods as summarized in Table 1.

Table 1: The measuring principle of each analyser

Parameter	Testing Method	Minimum Detection Limits	Instrumentation
O_3	Gas Analyser with Non-dispersive Ultraviolet Absorption (NDUV)	< 0.5 ppb (1 $\mu g/m^3$)	Serinus 10 Ozone Analyser
SO_2	Gas Analyser with UV Fluorescent Radiation (UVF)	0.3 ppb (0.8 $\mu g/m^3$)	Serinus 50 Sulphur Dioxide Analyser
NO_2	Gas Analyzer with Gas Phase Chemiluminescence (CLD)	0.4 ppb (0.8 $\mu g/m^3$)	The Serinus 40 Oxides of Nitrogen Analyser
CO	Gas Analyser with Gas Phase Non-Dispersive Infrared Spectrophotometry (NDIR)	< 0.04 ppm (46 $\mu g/m^3$)	Serinus 30 Carbon Monoxide Analyser
PM_{10} & $PM_{2.5}$	Beta Ray Attenuation (BAM)	< 4.8 $\mu g/m^3$ (1 hour) < 1.0 $\mu g/m^3$ (24 hour)	EPA Class III $PM_{10-2.5}$ FEM: EQPM-0709-185

Monitoring frequency is 10 minutes and data were gathered by the data logger which downloads data and averages hourly and processes to obtain quality control data using statistical software. Then the data were averaged as 24-hour averages for $PM_{2.5}$, PM_{10}, NO_2, SO_2 and 8-hourly for CO and O_3. Air Quality Index (AQI) values were calculated for each parameter according to US EPA criteria (USEPA, 2018). Each pollutant level was then compared with National Ambient Air Quality Standard and WHO Guideline Values to assess the significance of pollutants.

3. Results and discussion

The 24-hour average levels of $PM_{2.5}$ during the study period were presented in Figure 1.

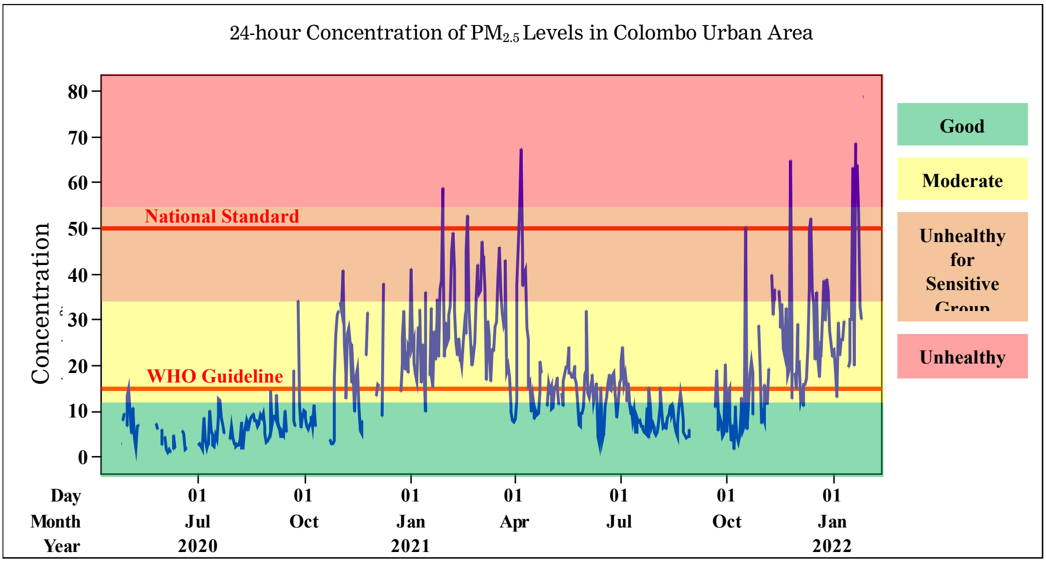

Figure 1: 24-hour concentration of PM2.5 levels in the Colombo urban area.

24-hour $PM_{2.5}$ levels indicate that levels significantly increased from 2020 to 2022 during the North East monsoon period (November to March). Also, AQI values indicate 88% of the time is at good or moderate levels. The remaining 22% is at unhealthy levels for sensitive groups or unhealthy levels during the study period. Further, 34% of days exceeded the 24-hour WHO guideline value and 1% exceeded the 24-hour national standard level with respect to $PM_{2.5}$. The 24-hour average levels of PM_{10} during the study period were presented in Figure 2.

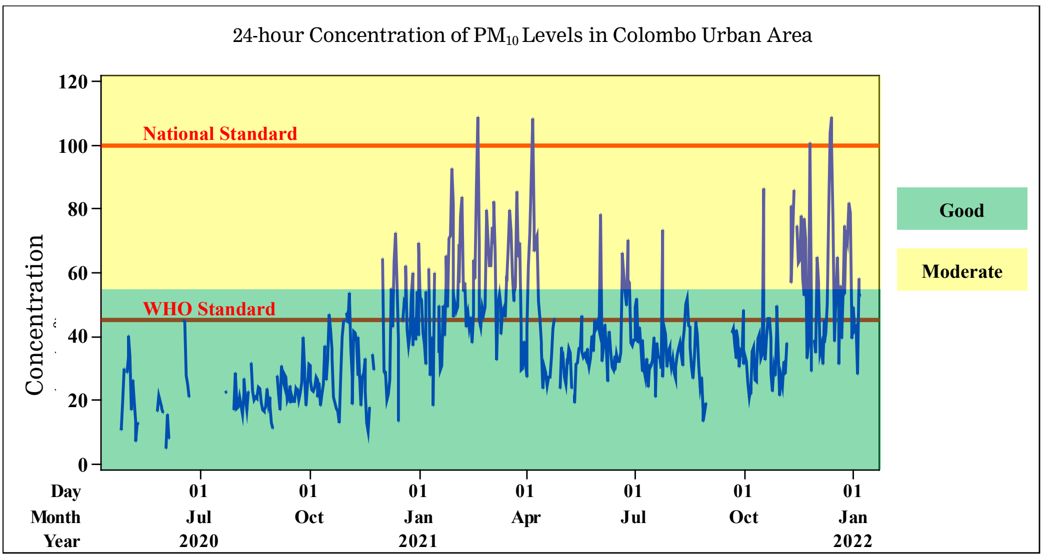

Figure 2: 24-hour concentration of PM10 levels in the Colombo urban area

As in $PM_{2.5}$, 24-hour PM_{10} levels significantly increased from 2020 to 2022 during the North East monsoon period (November to March). Also, AQI values indicate that 74% of the time air quality is at good levels. The remaining 26% is at moderate levels during the study period. Further, 22% of days exceeded the 24-hour WHO guideline value and 0.4% exceeded the 24-hour national standard level with respect to PM_{10}. The 24-hour average levels of NO_2 during the study period were presented in Figure 3.

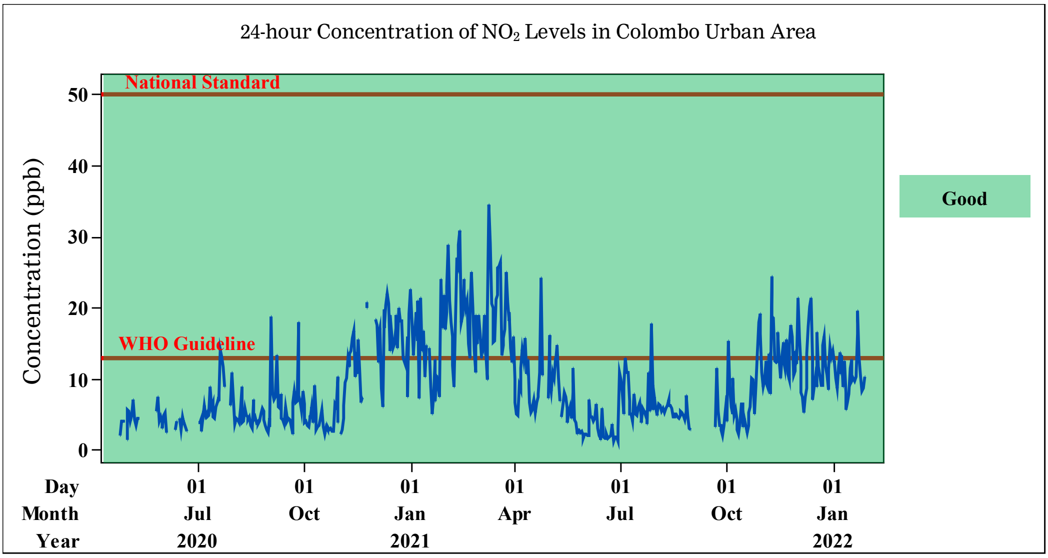

Figure 3: 24-hour concentration of NO2 levels in the Colombo urban area

According to the graph, the 24-hour average of NO_2 levels was in the good range during the study period. Further, 23% of NO_2 levels exceeded the 24-hour WHO guideline value whereas it did not exceed the 24-hour national standard level with respect to NO_2. The 24-hour average levels of NO_2 during the study period were presented in Figure 4.

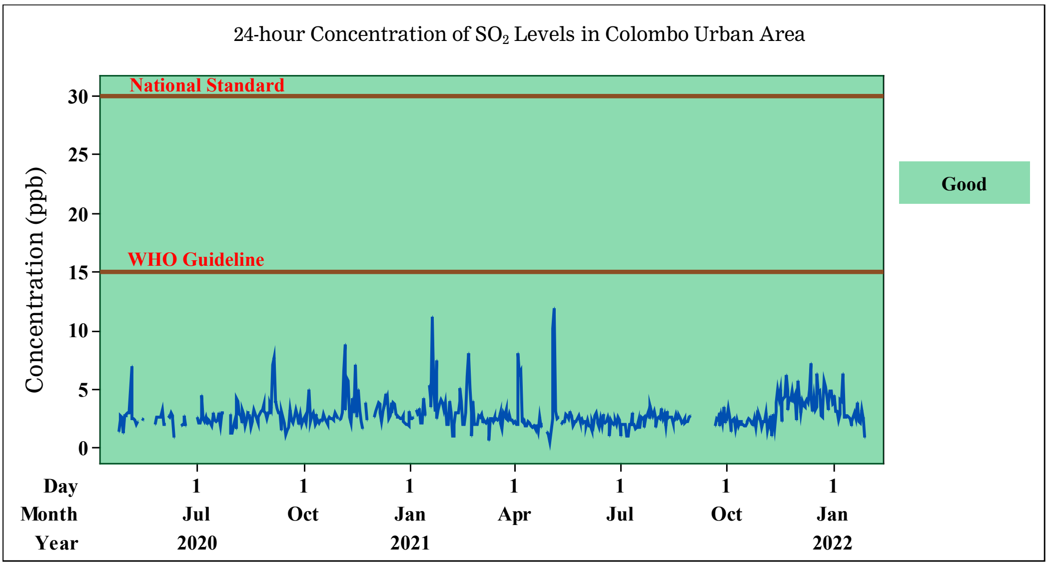

Figure 4: 24-hour concentration of SO2 levels in the Colombo urban area

According to the graph, the 24-hour average of SO_2 levels was in the good range during the study period. Further, SO_2 levels have not exceeded the 24-hour WHO guideline value and the 24-hour national standard level. The 8-hour average levels of CO and O_3 during the study period were presented in Figure 5 and Figure 6 respectively.

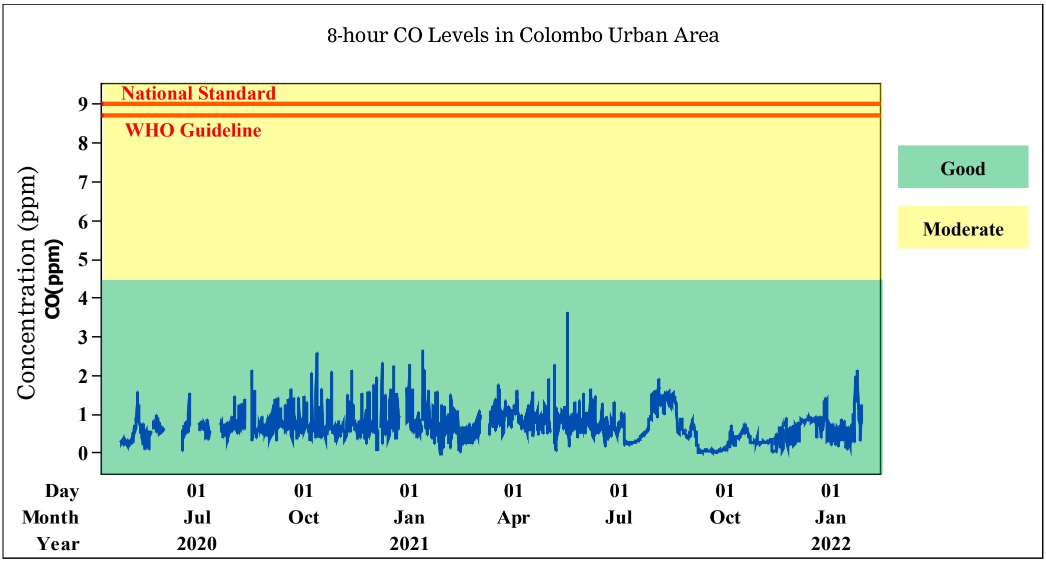

Figure 5: 8-hour concentration of CO levels in the Colombo urban area

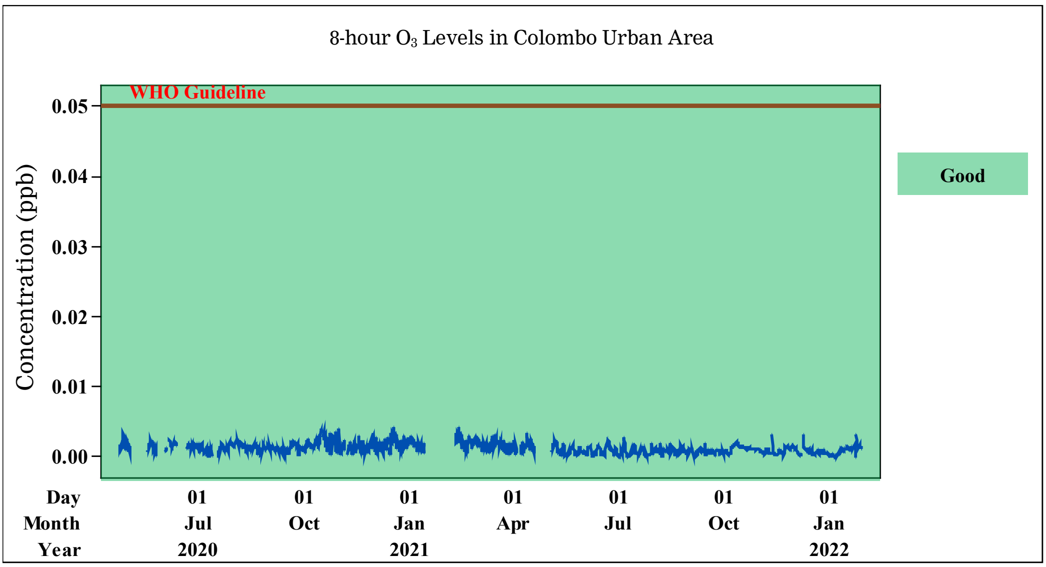

Figure 6: 8-hour concentration of O3 levels in the Colombo urban area.

According to the graphs, the 8-hour average of CO and O_3 levels were in the good range during the study period. Further, both CO and O_3 levels have not reached the 24-hour WHO guideline value and the 24-hour national standard level.

All the above evidence indicates that, only Particulate Matter ($PM_{2.5}$ and PM_{10}) levels occasionally exceeded the national ambient air quality standard level. Sometimes levels are within unhealthy for sensitive groups and unhealthy range mostly during the North East monsoon period.

When compared to the WHO guideline values, Particulate Matter ($PM_{2.5}$ & PM_{10}) and NO_2 levels sometimes reached WHO guideline values whereas SO_2, CO and O_3 have not reached WHO guideline values.

The data further indicates parameters such as SO_2, CO and O_3 were well below both national standard and WHO guideline values. Therefore, measuring SO_2, CO and O_3 parameters can be omitted in urban air quality monitoring programs unless otherwise in a special situation. Continuation of monitoring network with Particulate Matter ($PM_{2.5}$ and PM_{10}) and NO_2 in urban areas only with reference locations that measure all criteria parameters is a cost-effective sustainable monitoring system for countries like Sri Lanka.

4. Conclusion

Particulate Matter ($PM_{2.5}$ & PM_{10}) sometimes exceeded the WHO guideline value and occasionally exceeded the national standard level. Also, Nitrogen Dioxide levels sometimes exceeded the WHO guideline value but did not reach the national standard level of 50 ppb. Other pollutants such as SO_2, CO and O_3 stay at good levels and did not reach both national standards and WHO guideline values during the study period.

It was found that $PM_{2.5}$, PM_{10} and NO_2 are undoubtedly the most important pollutants and other pollutants such as SO_2, CO and O_3 are still well below both national and WHO standard guidelines values. Therefore, special attention should be given to $PM_{2.5}$, PM_{10} and NO_2 when developing a cost-effective sustainable monitoring system in the country.

Acknowledgement

Authors would like to greatly acknowledge the support provided by the National Building Research Organisation through provision of collected original data and granting permission to utilize them in the study. The views expressed in the paper are however those of the authors only.

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Building Resilience amidst
Economic Challenges

Outcomes of the JICA Project "SABO"

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Abstract

"Project for Capacity Strengthening on Development of Non-structural Measures for Landslide Risk Reduction in Sri Lanka (SABO)" was implemented from 2019 to 2022 to promote and improve landslide hazard zonation, early warning and risk-based land use planning and regulation. Through the Project, NBRO establish Yellow/Red zoning methodology referring to Japanese hazard mapping under Sediment Disaster Prevention Act. The newly develop zoning maps were utilized in early warning and land use planning at three pilot sites in Matara, Kegalle and Badulla districts. It was recommended to discuss the legal arrangement between the government agencies to ensure risk-based land use and regulations.

Keywords: Non-structural measures, Hazard zonation, Soil water index, Early warning, Land use regulation

1. Introduction

Sediment Disaster is one of the most serious natural disasters in Sri Lanka. In the central and southern mountainous area, sediment disasters such as slope failures, landslides and debris-flows frequently occur in the monsoon period because of the fragile geology and steep topography. In recent years, sediment disasters caused by heavy rainfall in the spring SW monsoon season become sever. It was a remarkable event that the large-scale landslide in Aranayake, Kegalle district killed 130 lives in May 2016. In addition, increasing exposure to the hazards due to rapid reclamation and development has been raising sediment disaster risks in urban and rural areas. Establishment and improvement of the early warning system and legal arrangement for land use planning and development standards are urgent issues in Sri Lanka.

National Building Research Organization (NBRO) under Ministry of Defense is responsible for implementing landslide risk management strategies in the country by both structural and non-structural measures. The NBRO has made efforts of prevention and mitigation for sediment disasters such as preparation of sediment disaster hazard maps, technical support for land use planning and development standards in the mountainous area, capacity development of relevant agencies, awareness and education activities for developers, resettlement of disaster victims.

Japan International Cooperation Agency (JICA) and NBRO has implemented a technical cooperation project "Technical Cooperation for Landslide Mitigation Project (TCLMP)" in the high-risk areas of sediment disasters in Kandy, Matara, Nuwara-Eliya and Badulla districts from 2014 to 2018 in order to construct countermeasures for three types of sediment disasters (rock fall, landslide and slope failure) and develop standards and manuals for the construction. Following to the TCLMP, JICA and NBRO agreed to implement the "Project for Capacity Strengthening on Development of Non-structural Measures for Landslide Risk Reduction in Sri Lanka (SABO)" from 2019 to 2022 to enhance non-structural measures such as risk assessments, improving early warning system, and land use and development standards based on the risk assessment.

This paper is to introduce the outcomes of the Project SABO, and to discuss for future sustainable implementation of the outcomes.

2. Outline of the project

The Project SABO is composed of three outputs of landslide hazard and risk assessment (output 1), improving landslide early warning (output 2) and land use and development standards based on the hazard and risk assessment (output 3) to achieve the Project purpose of "NBRO's capacity to implement non-structural measures for sediment disasters based on enhanced hazard and risk assessments are strengthened" (Table 1).

To implement each activity, three pilot sites were selected (Figure 1) from;

1) Morawakkanda, Matara district
2) Udapotha, Kegalle district
3) Weeriyapura, Badulla district

The Project was expected to be completed in December 2021, however due to the influence of the COVID-19 pandemic, it was extended to the October 2022.

Figure 1: Pilot sites of the Project SABO

le 1: Frame of the Project

Overall Goal	In high-risk areas of sediment disasters, non-structural measures based on strengthened hazard and risk assessments are implemented.
Project Purpose	NBRO's capacity to implement non-structural measures for sediment disasters based on enhanced hazard and risk assessments are strengthened.
Output 1	Capacities to conduct hazard mapping and risk assessments are strengthened.
Output 2	Capacities to issue landslide early warning alerts are strengthened.
Output 3	Capacities to apply risk assessments of sediment disaster (s) to land use planning / development standards are strengthened.

3. Outcomes

Working Groups (WG1, WG2 and WG3) composed of NBRO officials and JICA experts were organized to implement the activities for each output. The outcomes of each WGs are summarized as follow.

3.1. Hazard and risk assessment (WG1)

The hazard maps (Yellow/Red zone maps) of the three pilot sites have been develop and finalized. WG1 referred to Japanese Yellow/Red zoning method and customized it according to the historical landslides in Sri Lanka (Figure 2). The method was applied to the three pilot sites, and then the maps were verified by field inspections (Figure 3). By doing so, the Yellow/Red zoning manual was finalized among WG1 members and senior geologists of NBRO. The developed maps were uploaded at the NBRO's geo-portal site.

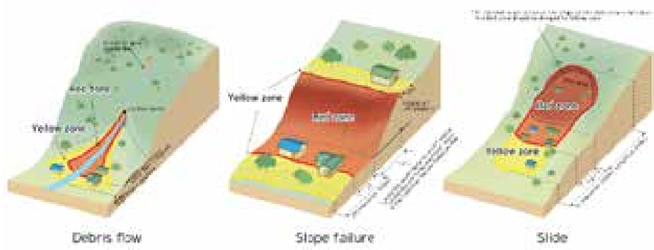


Figure 2: Yellow/Red zoning concepts and criteria

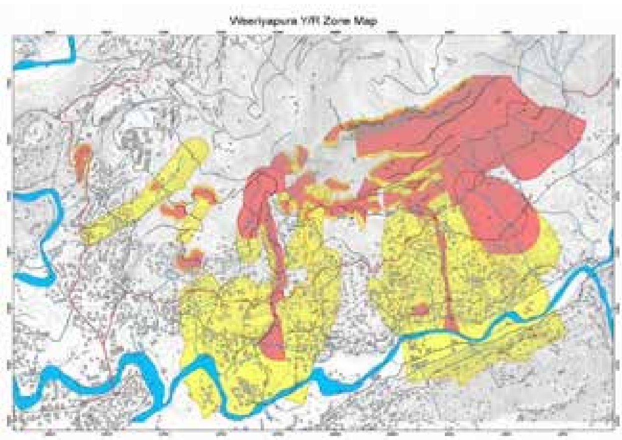


Figure 3: Developed Yellow/Red zoning map (Weeriyapura, Badulla)

3.2. Landslide early warning system (WG2)

To improve the rainfall thresholds for the landslide early warning, Soil Water Index (SWI) represents water behavior in the ground considering previous rainfall in addition to the current rainfall. WG2 have been verifying the rainfall characteristics and actual landslide events over 50 cases. Based on the evidence, The waning thresholds were tentatively proposed. In addition, a rainfall monitoring system in which SWI and several rainfall indexes can be graphically shown was developed in early warning room of NBRO (Figure 4). The warning operators can visually observe the current status of SWI in real-time.

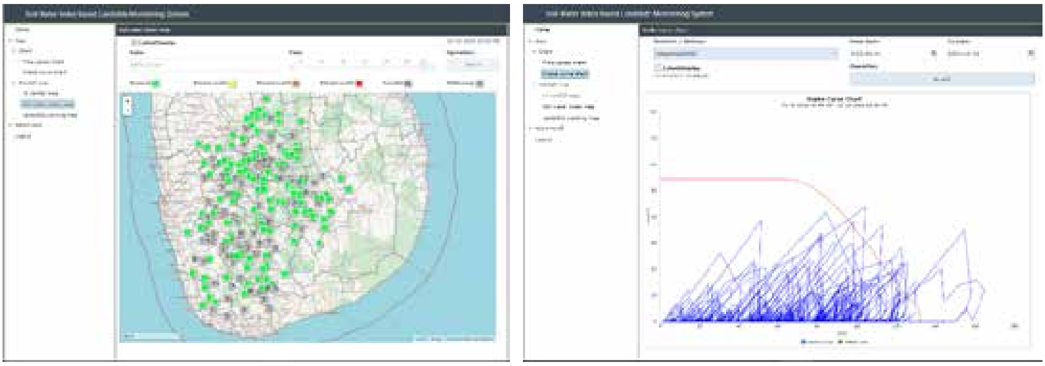


Figure 4: Developed SWI rainfall monitoring system

In addition, WG2 installed landslide remote monitoring systems at Udapotha in Matara district and Weeriyapura in Badulla district. The systems are composed of extension meters, surface tilting meters, rain gauges and data transmission / siren devises (Figure 5). Those monitoring system can detect in-situ landslide movement and give warning to the local residents.

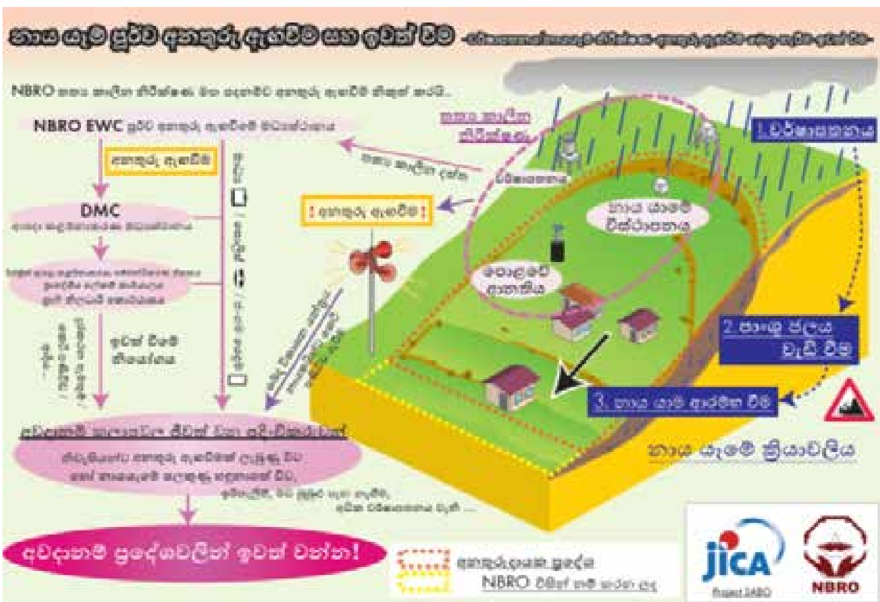


Figure 5: Outline of installed landslide remote monitoring system

3.3. Land use planning (WG3)

Based on the hazard and risk assessments developed by WG1, WG3 studied how to utilize the results to the land use planning and development activities. WG3 proposed to convert the hazard zoning to the land use categories, namely restricted, controlled, warning and development zones. Each categories have suitable and recommended land uses of residential, commercial, industrial and agricultural activities. Those land use categories were summarized in a "Guideline for Disaster Resilient Land Use Regulation / Development Standards".

In the same way of the hazard and risk assessment manuals, the developed guideline has been revised based on the case studies in the three pilot sites and discussion with local stakeholders including chairpersons of Local Authorities (LAs). As the results each local authorities formulated sediment disaster risk reduction plans including not only land use planning but also structural measures and early warning / evacuation plans (Figure 6).

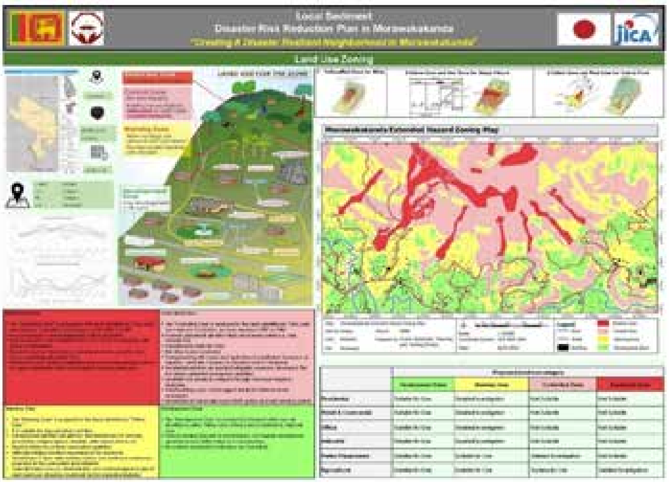


Figure 6: Conceptual poster for Sediment Disaster Risk Reduction Plan at Morawakkanda

4. Discussion

Through the Project, Joint Coordination Committees (JCC) were regularly held to monitor and review the activity progress among the key stakeholders including NBRO, JICA, pilot LAs, Disaster Management Centre, Urban Development Authorities, National Physical Planning Department, Land Use Policy Planning Department, National Planning Department, etc. In addition, a wrap-up meeting held in October 2022 summarized the outcomes and recommendation as follows.

4.1. Harzard and risk assessment

NBRO has already started expanding the Yellow/Red zoning to the other than three pilot sites. Throughout the Project, the zoning was mainly led by the Landslide Research and Risk Management Division (LRRMD) of NBRO headquarter and mapping team which is a team of geologists without fixed office. In order to expand the Yellow/Red zoning sustainably in future, it is recommended that NBRO should carry out trainings to the regional office staffs.

In addition, the Yellow/Red zoning criteria and methods developed in the Project were established based on limited past disaster cases. It is quite conceivable that there will be issues and necessity of revisions according to the actual topography and disaster affected area. Therefore, NBRO is required to continuously update the manual as necessary.

WG1 decided to utilize existing Landslide Hazard Zonation Map (LHZM) for landslide initiation area evaluation. The criteria of LHZM have established based on the landslide data collected in the 1990s. Since then, many large and small landslide disasters have occurred. Based on these data, the LHZM itself should be improved and updated. In the Project, WG1 considered the way of improvement adjusting the risk level threshold of LHZM and weighting each element such as geology, soil cover, landform, etc.(Figure 7). NBRO needs to proceed the improvement of LHZM.

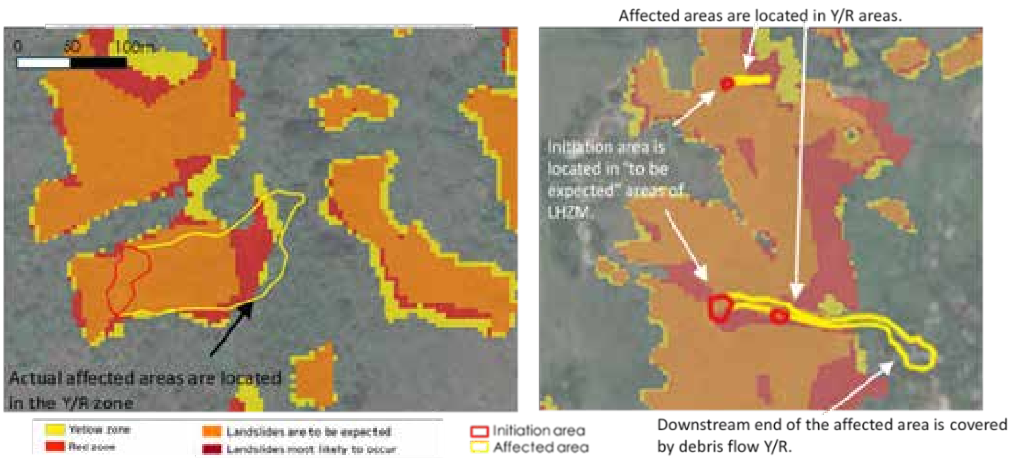


Figure 7: Verification of LHZM based on the newly occurred landslides in southwestern region

Accumulation of past landslides data is essential for the revision and improvement of the Yellow/Red zoning and LHZM as well as setting the threshold for landslide early warning. In the Project, Landslide Information Management System (LIMS) was developed to manage the landslide inventory, investigation and risk assessment. The information will be recorded by the regional offices and shared with headquarter on-line. NBRO is strongly requested to continue strengthening the data management capacity of regional site officers to secure the quality of the information.

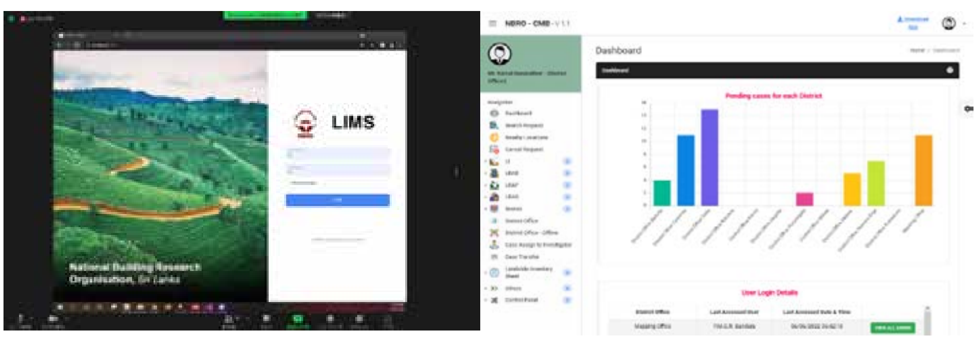


Figure 8: Landslide Information Management System (LIMS)

4.2. Landslide early warning system

NBRO officials have sufficient ability to evaluate the occurrence and rainfall characteristics of landslide disasters using the SWI. Evaluation of the relationship between short-term and long-term rainfall indexes continues. However, due to the lack of landslide occurrence data, it was not possible to finalize the warning thresholds that reflect regional characteristics within the Project period. NBRO should continue to accumulate landslide data and develop more accurate and appropriate landslide warnings.

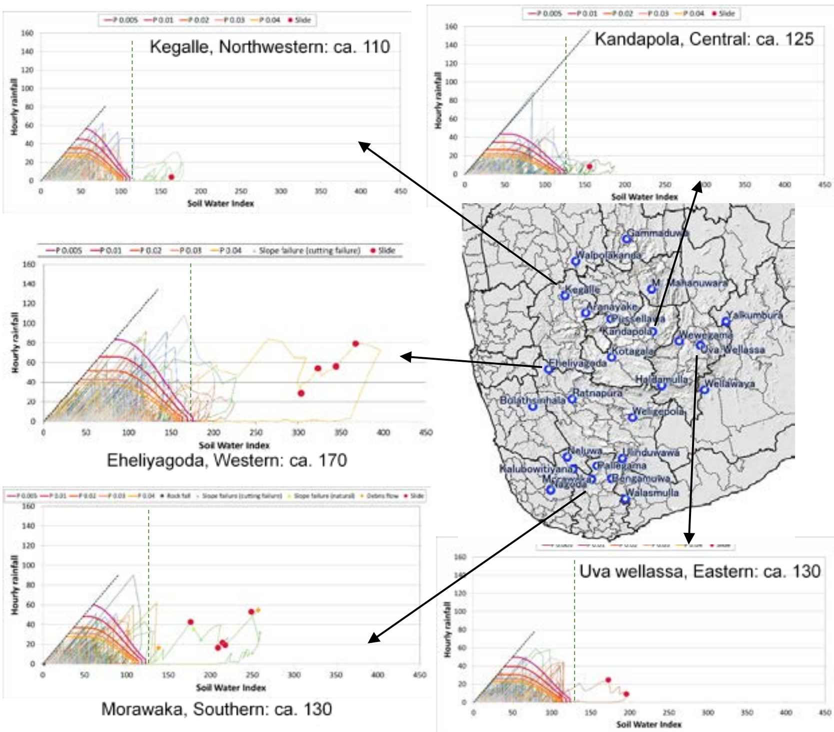
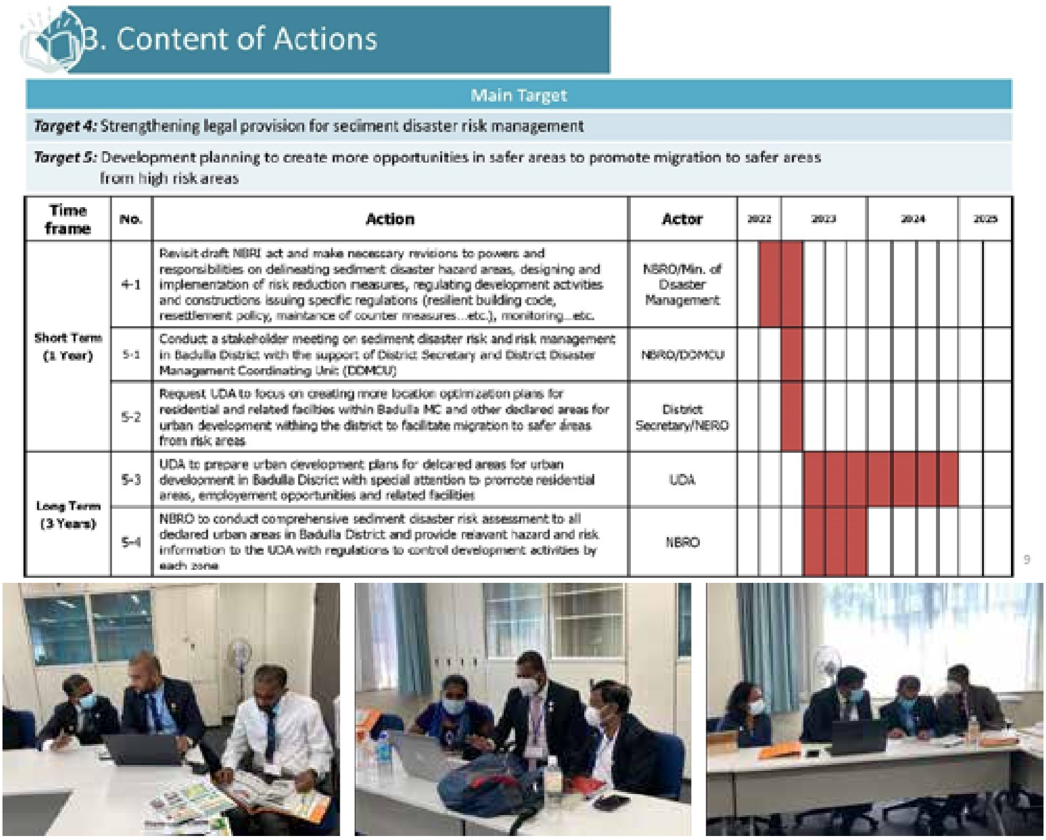


Figure 9: Verification of landslide occurrence and rainfall characteristics by WG2

4.3. Land use planning

Implementation of the land use planning and regulation is significant topic throughout the Project. With regard to land use regulations, although a trial was conducted at a pilot site, the Local Authorities recommended to establish a legal system to ensure the enforcement of the regulations (such as By-law). To do so, participation of the Provincial government and the central authorities are essential. In addition, there is a significant effort that Kegalle district has issued a letter to the Ministry of Land to officially demarcate the Red zone as conservation area based on the Law on Forest Conservation, so that the land cannot be developed in future. It is also considerable approaches to incorporate the Yellow/Red zoning into the urban development plans by UDA. Those were important lessons learned that the land use regulation will be in effect based on the existing laws or ordinances, not developing new system. NBRO is required to initiate the discussion to ensure the effectiveness of land use regulations in cooperation with related organizations.

In the Project, counterpart trainings in Japan were held. During the training, the pilot Local Authorities and NBRO officials were closely working to propose action plans to implement appropriate land use in their area (Figure 9). Based on the action plans, the pilot Local Authorities have already started their efforts. It is strongly recommended for NBRO to monitor and review their activities.



Time frame	No.	Action	Actor
Short Term (1 Year)	4-1	Revisit draft NBRI act and make necessary revisions to powers and responsibilities on delineating sediment disaster hazard areas, designing and implementation of risk reduction measures, regulating development activities and constructions issuing specific regulations (resilient building code, resettlement policy, maintance of counter measures...etc.), monitoring...etc.	NBRO/Min. of Disaster Management
	5-1	Conduct a stakeholder meeting on sediment disaster risk and risk management in Badulla District with the support of District Secretary and District Disaster Management Coordinating Unit (DDMCU)	NBRO/DDMCU
	5-2	Request UDA to focus on creating more location optimization plans for residential and related facilities within Badulla MC and other declared areas for urban development withing the district to facilitate migration to safer áreas from risk areas	District Secretary/NBRO
Long Term (3 Years)	5-3	UDA to prepare urban development plans for delcared areas for urban development in Badulla District with special attention to promote residential areas, employement opportunities and related facilities	UDA
	5-4	NBRO to conduct comprehensive sediment disaster risk assessment to all declared urban areas in Badulla District and provide relavant hazard and risk information to the UDA with regulations to control development activities by each zone	NBRO

Figure 10: Example of action plans by Local Authorities and collaborative work with NBRO official in the counterpart training in Japan

5. Conclusion

The Project SABO has launched in 2019, following to the previous technical cooperation project TCLMP. Through both projects, the capacity of NBRO on structural and non-structural measures for sediment disaster risk reduction were strengthened. Those outcomes are significantly effective to promote administration of sediment disaster risk reduction in Sri Lanka.

In addition to those projects, JICA and NBRO are currently executing a science and technology research partnership project "Development of Early Warning Technology of Rain-Induced Rapid and Long-Travelling Landslides". This project is focusing on research and development rather than administration of sediment disaster risk reduction. Furthermore, there are several PPP projects between JICA and NBRO such as landslide remote monitoring system and X-band weather radar system. Though those projects, JICA and NBRO have encouraged close partnerships between two countries.

Since NBRO is the agency which has both responsibilities of administration services and research and development to reduce sediment disaster risk in Sri Lanka, it is strongly recommended for NBRO to continue both approaches as two wheels of a cart. In addition to the technical capacity development, discussion on the legal arrangement is indispensable to ensure risk-based land use and regulations.

Acknowledgement

The Project SABO has been implemented by NBRO under supports of JICA. We are deeply grateful to both governments of Sri Lanka and Japan. In addition, we would acknowledge Eng (Dr.) Asiri Karunawardhana, Director General, NBRO for strong leadership and supports to the Project always.

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Building Resilience amidst
Economic Challenges

Case study on the adopted rectification procedures after the leakage through a secant pile retaining wall at Galle Face iconic building

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Abstract

A secant pile retaining wall had been constructed to retain a 20 m deep excavation for the construction of three basement floors of the proposed Galle Face Iconic Building at Colombo 03. Secant piles have been socketed 1 m into the bedrock and the wall has been laterally supported by a system of internal steel props temporarily during the excavation process. Although the secant pile wall has been designed as a watertight structure, a massive water leakage occurred through the wall when the excavation was at a depth of 15 m below the ground level. As a result, a large amount of soil was lost through the seepage path and very significant ground subsidence occurred on the retained side within a few hours. A four-storied building founded on pad footings on the retained side was severely affected by the ground subsidence. The building was evacuated immediately and rectification measures were applied to bring it back to service. Cavities formed in the subsoil due to the loss of soil mass were identified by geophysical surveys and direct probing techniques. Thereafter, grouting was conducted at each pad foundation that was identified to be affected by the formation of cavities underneath. Close monitoring was done with observation holes at each grouting location to ensure that all cavities are filled up. After the completion of the operation, the success of the process was evaluated by another geophysical survey and a series of direct probing.

Keywords: Cavities, Geophysical surveys, Secant pile wall, Subsidence, Water leakage

1. Introduction

With the urbanization, the use of available space of the land must be optimized. Therefore, underground space is utilized for parking and other service requirements. In this regard deep excavation with several levels of basements is common feature in all new high-rise buildings. Most of these deep excavations extend below the groundwater level and hence the retaining structures supporting the excavation need to be watertight.

Normally, these excavations extend very close to the site boundaries and is a critical concern during the execution of the deep excavation is the control of the excessive ground movements to safeguard neighboring structures. In this regard, field instrumentation and performance evaluation of deep excavations are essential.

Secant pile walls are made watertight due to the interlocking of adjacent piles. However, if there is a lapse in quality assurance a void can be formed at any isolated location leading to seepage across the wall. Seeping water will carry soil from the retained side. If this happens at a deeper level, a large mass of soil could be lost within a short period due to the prevailing high head difference.

In this research paper, the details of subsidence occurred at the site of a building on the retained side National Gem and Jewelry Authority Building (NGJA) due to the leakage of water through the secant pile and rectification process adopted to bring the building back to service will be discussed.

2. Project details

The proposed development is an office and leisure development with 32 floor levels and 3 basement floors. There were two excavations, of depths around 15 m to 20 m supported by a secant pile wall and an internal excavation of depth of 19.8 m supported by a solider pile wall. Details of the depths of the excavation are presented in Figure 1. The secant pile wall system consists of 880 mm diameter primary and secondary bored and cast in-situ concrete piles, located at 750 mm centers with a 1 m socketed into bedrock [1].

Five boreholes had been advanced to identify the subsoil profile. According to the borehole results, subsoil is mainly sandy approximately up to a depth of 13 m. completely weathered rock was encountered thereafter up to the bedrock. The groundwater level was encountered at a depth of 2 m[1].

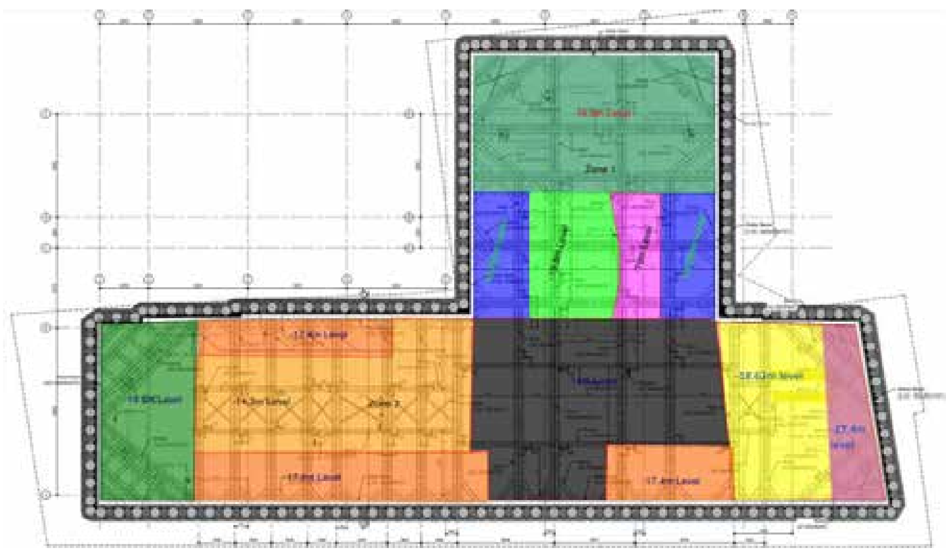


Figure 1: Details of Excavation Depths

3. Details of incident

A sudden water leakage was observed through the secant pile wall at the location marked in Figure 2 when the excavation proceeded to a depth of 15m in the morning of 16th July, 2021. The leakage could not be stopped due to the high pressure of the water flow. This continued for few hours and at the night, around 8.45 p.m. sudden subsidence of the security hut of the NGJA occurred without causing any personal injury. However, several new cracks were formed on the NGJA building and a few existing cracks got further propagated. Figure 3 presents the immediate damages to the NGJA building due to the incident. Considering the condition of the building, it was recommended to evacuate the people until the stability of the building is assured[2].

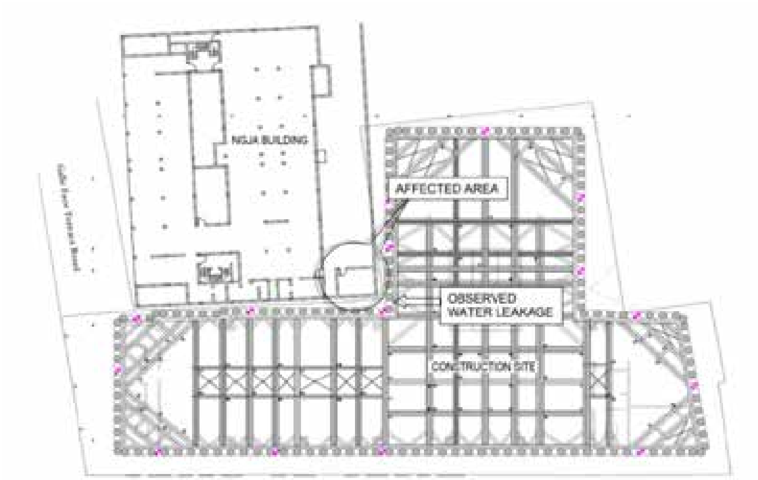


Figure 2: Plan view of the leakage point and the damaged location [2]

(a) (b) (c)

Figure 3: (a) Subsidence of building; (b) Propagated cracks; (c) Developed cracks[2]

As an immediate action, on the same night cavity formed by the subsidence was filled with high flow concrete to prevent further settlements and damage to the structure. However, the water leak could not be stopped for a period of 5 days and during that period any further minor subsidence has not occurred. The flow of large quantities of sand has stopped by this time. Water leaked through the secant pile wall was taken away by a 110 mm diameter PVC pipe [3]. Some grouting was done behind the secant piles but a line of grout piles could not be constructed at the interlocking locations along the pile wall due to the presence of the capping beam over the secant pile wall. As such, a line of grout piles was installed as presented in Figure 4.

Thereafter, the leaked location of the secant pile wall was immediately grouted from inside the excavation and a skin wall was constructed over the exposed surface of the secant pile wall.

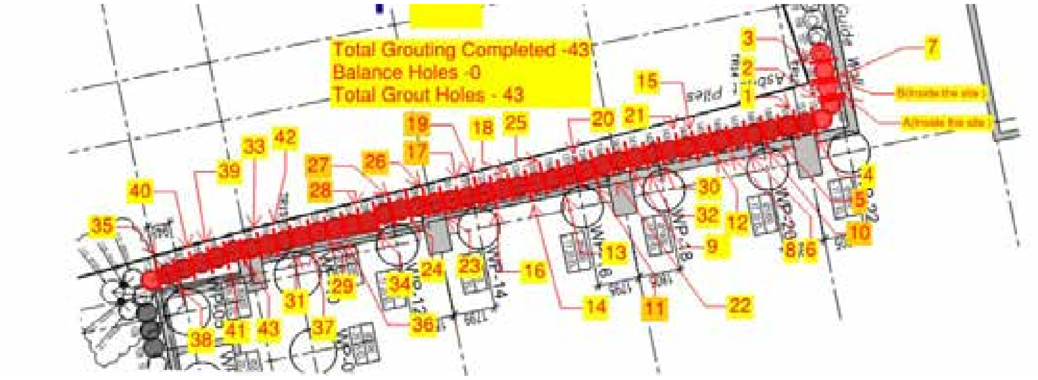


Figure 4: Grout Piles

3.1. Method used to grout the location water leakage from inside the excavation

First all loosen particles were removed manually and then cleaned with water or compressed air. Then a 1'' PVC pipe was inserted and fixed horizontally by applying a water plug. After that, the hole was covered with wooden square-type pocket formwork. Thereafter a mechanical packer was inserted into the PVC pipe and pressure injection of cement grout with sodium silicate was started after 24 hours (maximum up to 2 bar). Finally, casted pocket concrete was cured for 7 days and excess concrete was removed. Figure 5 illustrates the typical setup used for grout injection[4].

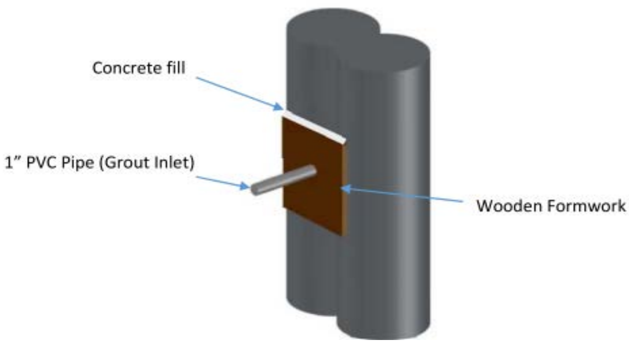


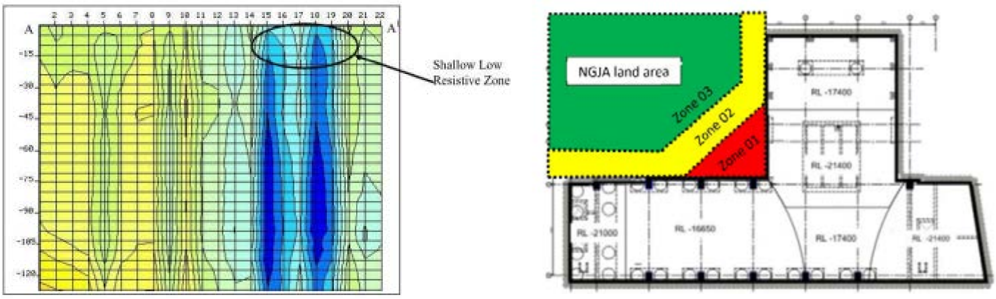
Figure 5: Typical Setup for Grout Injection [4]

4. Rectification works

With the construction of the grout piles and sealing the leak followed by the construction of the skin wall, the leakage was completely stopped. The task thereafter was to assess the damages to the NGJA building and implement the necessary rectifications. The rectification of the building has to be done in two stages. The first stage was to rectify the ground underneath the foundation by filling cavities and the second stage was to strengthen the structural capacity of the building. This paper presents the rectification works adopted for the ground underneath the foundations

4.1. Identification of cavities of the ground after the failure

The main challenge was to identify and quantify the damage that occurred underneath the foundation by the formation of cavities due to the loss of soil (mainly sand) along with seeping water. In this regard, an indirect method of resistivity geophysical survey was conducted in the site of the NGJA premises. Results of the geophysical survey revealed that several cavities have been formed up to approximately depths of around 6 m at several locations under the foundations of the NGJA building due to internal erosion. Figure 6(a) shows a sample of low resistivity zones obtained from the geophysical survey, which indicates the possible cavity zone. Figure 6(b) shows the three zones identified based on the risk level at the NGJA building [5]. Zone 1 is the most critically affected and with the highest risk. Risk levels are lower in Zone 2 and Zone 3.



(a) (b)

Figure 6: (a) Sample Electric Resistivity Profile; (b) Categorization of zones based on risk levels[5]

To confirm the results of the geophysical survey, two boreholes were drilled at locations shown in Figure 7 as a direct method. Borehole 1 was drilled at a location very closer to the subsidence to calibrate the results indicated in the geophysical survey and borehole 2 was drilled at a location far away from the subsidence for comparison purposes. However, due to the non-availability of instruments to recover continuous sampling, the exact details of cavities could not be identified.

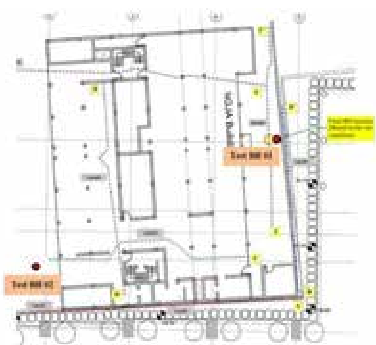


Figure 7: Borehole locations [6]

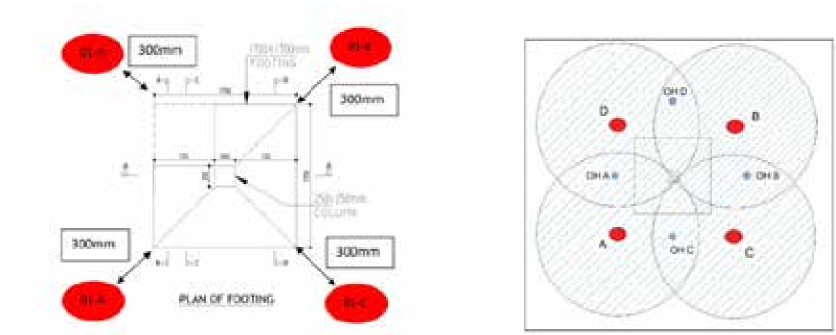
Results of the borehole investigation indicate that the presence of a loose layer approximately up to the 6 m depth only in borehole 1 confirms the results of the resistivity survey [6].

4.2. Method used to grout underneath the foundations

Since the details of the foundations of the NGJA building were not available, the first step was to identify the size and depth of the foundation. In this regard, a typical foundation was exposed by manual excavation and it revealed that 1.7 m x 1.7 m pad footings had been used at a depth of around 1.5 m below the existing ground level. Accordingly, it was decided that an approximately 5 m depth from the existing ground level will have to be improved to achieve the necessary improvement within the depth of influence of the pad footing (2B) [7].

The second step was to finalize the grout mix to fulfil the requirements of grout filling with low shrinkage and high followability. To fulfill the requirement of followability flow cable was used as an admixture and to achieve the shrinkage requirement Nippon Blended Hydraulic Cement was used with a 0.5 w/c ratio [8].

The third step was to identify a proper method to grout under the foundation while confirming the lateral flow of the grout mix. For that purpose, four grout holes were used for grouting 300 mm away from the foundation (Figure 8(a)) and four observation holes were used to confirm the distribution of the grout mix. Figure 8(b) shows the locations of grouting holes (A, B, C & D) and observation holes [8].



(a) (b)

Figure 8: (a) Locations of Grouting Holes; (b) Locations of observation holes [8]

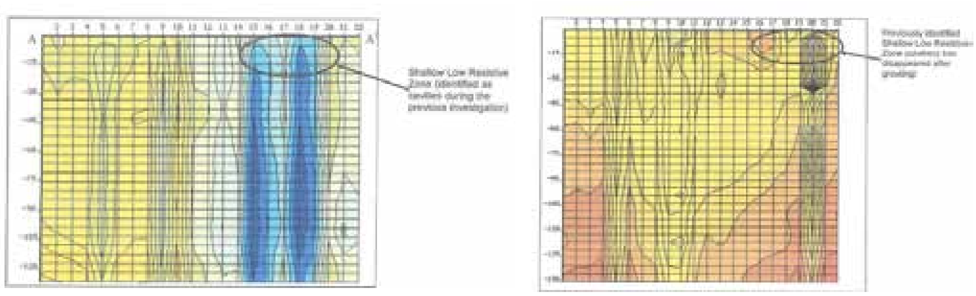
Initially, grout was fed to the bottom of the hole and waited until the pressure reached 5 bars or overflowed from the observation hole. Once one of the conditions is achieved grout hose was raised to the mid position of the hole and grouting was started again while monitoring the pressure. This was continued up to the top of the foundation level.

Considering the vulnerability of the building, low pressure was used during the grouting process (3-5 bars). The flow rate and pressure of grout were recorded at 2-minute time intervals, to maintain the quality of the grouting work[8].

4.3. Methods used to verify the ground improvement

Mackintosh tests were conducted immediately before the grouting and after the grouting very close to the locations to be improved. The results of the tests show that the strength of the soil has improved to an adequate level to withstand the building load.

To assess the conditions of previously identified cavities, a resistivity survey was carried out again and compared with the previous results. The comparison revealed that the previously identified cavities have already been filled with grout. Figure 9(a) presents the resistivity survey results before grouting and Figure 9(b) presents the results after grouting[9].



(a) (b)

Figure 9: (a) Results before grouting; (b) Results after grouting[9]

5. Conclusion

This incident highlights the importance of adopting stringent quality assurance measures in the construction of secant pile walls to ensure water tightness. A void could develop within a pile or at the interlocking zone. If the integrity of the secant pile had been confirmed before the commencement of excavation work, water leakage would not have occurred. Therefore, it can be concluded that confirmation of the integrity of the earth retaining system before the commencement of excavation is very important.

If there are any doubts regarding integrity, it is recommended to have a line of grout piles (maybe of diameter 150-200mm) installed behind the secant pile interlocking locations to enhance the water tightness further.

It is also critically important to have a construction team ready onsite during the excavation to seal any leakage immediately after it was noticed. The sealing is done more effectively at the back of the secant pile wall on the retained side. But some effort could be made at the face of the excavation.

The placement of large quantities of high-flow concrete after the initial subsidence had been effective in minimizing the flow of sand although the seepage of water continued for five days.

During the grouting process, several methods had been adopted to confirm the distribution of grout under the foundation. Those are, use proper mix design with high followability and less shrinkage, checking the pressure and flow rate during grouting and confirming the flow of grout using observation holes.

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Building Resilience amidst
Economic Challenges

An evaluation of audio-visual communication as a tool for disaster risk management: A case study from Ratnapura MC area

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Abstract

The disaster risk of the existing communities varies because of the hazard frequencies and magnitudes that can directly and indirectly impact their livelihoods. These hazard impacts should address and identify the contingency planning approaches for making a resilient environment. Therefore, there is a problem with transferring the technical language to the communities and administrative officers. Accordingly, National Building Research Organisation (NBRO) prepared a disaster simulation based audio-visual tool for disaster risk communication. The objective behind the novel approach is to transfer technical knowledge and bring the communities to the disaster environment to advocate them on the drawbacks of their decisions.

A historical narrative was converted into a 3D model, and the disaster impact was simulated. A community member explained the entire narrative, which develops according to their language pattern. Initially, disaster scenario video showed to the vulnerable communities and disaster management practitioners. Then, an open-ended questionnaire was distributed among the participants. The questionnaire includes, (1) baseline information, (2) understanding of the video, and (3) effectiveness of the video as a tool for risk communication. Finally, a one-to-one discussion was conducted. The findings indicate that (1) none of the participants received a similar kind of awareness method in their lifetime (2) community participants stated that this audio-visual method is more understandable than other conventional methods of risk communication like awareness programmes, leaflets, etc. (3) people who have poor education also got a better understanding of disaster situation and preparedness actions and (4) constructive suggestions were made by community and officers with their experience on the area to upgrade this tool for effective risk communication environment. Therefore, this research will be useful for practitioners to create awareness by using the audio-visual tools for disaster risk communication among vulnerable communities.

Keywords: Risk Communication, Disaster simulation, Audio visual, Novel approach

1. Introduction

Floods and landslides, the most common natural disasters that occur every year in Sri Lanka, affect the lives and livelihoods of a large number of people. In the year 2022, over 15,000 people (4,000 families) have been affected across ten districts by floods and landslides (Disaster Management Center, 2022). The economic losses from disasters in Sri Lanka for the period 1998-2017 are estimated to be around 0.3% of GDP annually (Siriwardana, et al., 2018). As per the above records, it is evident that several individuals become victims as a consequence of their lack of disaster awareness. The importance of education and awareness-raising programs have been agreed upon as the top goals in disaster policy in the post-2015 framework for disaster risk reduction (DRR) (Briceno, 2015). Grothmann and Reusswig (2006) stated that by increasing public awareness, disaster damage could potentially be reduced and the challenges of rescue operations can be lessened. Hence, the government must raise awareness, in order to enhance socialization about DRR and disaster prevention.

Accordingly, under the Sendai Framework for DRR, the government of Sri Lanka along with the partner institution initiated several community awareness programmes by using materials such as guidelines, manuals, leaflets, posters, and newsletters. Nevertheless, in light of technological innovation, awareness should be conveyed creatively in order to inspire and increase interest in learning what constitutes a disaster, what are the warning signs, and what to do in its event (Yusnaidi, 2017). Numerous professionals in the education and communication field verified that using audio-visual communication is the most successful technique to convey the information (Yusnaidi, 2017; Rifai, 2020; Desai & Bhadre, 2020). At the same time, Sovocom Company in America conducted a research on the ability to remember, and the findings indicate that it varies with the mode of the technique uses; verbal (writing) 20%; audio only 10%; visual only 20% and audio-visual 50%. The finding justifies that the audio-visual is the dominant method of conveying information that could last long in people's mind.

In light of the aforementioned conclusions, this study was aimed to investigate the effectiveness of a DRR campaign using audio - visual communication to deliver disaster knowledge among the flood and landslide vulnerable communities as an awareness tool for Disaster Risk Management (DRM). The main objectives of this research are to understand the effectiveness of audio-visual digital approach to risk communication among the stakeholders to enhance the preparedness activities in the local disaster risk reduction activities and to obtain suggestions from the effected communities and disaster management officials to improve the tool for an effective risk communication. Accordingly, this paper has been organized as follows: The section 2 explains the importance of developing the audio-visual tool as a disaster risk communication. In section 3, methodology and materials of the study are presented. Results and discussion of the study are presented in section 4. Finally, conclusion and future.

2. Literature review

As communities around the world face an increasing frequency and variety of disasters that can have both direct and indirect effects, an urgent need to reduce disaster risk (Moe, et al., 2007) and build a resilient community capable of recovering from disasters (Rotim, et al., 2009) is growing in many countries.

Disaster management is an integrated process of planning, organizing, coordinating, and implementing actions to effectively cope with the effects of a disaster on people. Prevention, mitigation, capacity building, preparedness, response, evaluation, rescue, and rehabilitation are all included in this aspect (Deshmukh, et al., 2008). According to Warfield (2004), disaster management initiatives, attempt to prevent or avoid possible losses from hazards, encourage timely and appropriate aid to disaster victims, and accomplish rapid and successful recovery.

Knowledge management can play an important role by guaranteeing the availability and accessibility of accurate and reliable disaster-related information when it is needed, as well as by enabling effective lesson learning (Seneviratne, et al., 2010). It is the process of creating, sharing, and utilizing knowledge (Deshmukh, et al., 2008). Tatham and Spens (2011) define knowledge management as a technique for collecting, storing, and retrieving knowledge in a systematic manner, and then distributing the results to people who require it in a timely manner (Tatham and Spens, 2011). In a nutshell, knowledge management is all about delivering the appropriate knowledge to the right people at the right time. It should be noted, however, that knowledge management systems can only provide decision support, and people in emergency situations are the ones who deal with the real emergency or disaster. As a result, due to unforeseeable circumstances that occurred during the crisis, people's specific actions and responsibilities cannot be predicted (Otim, 2006).

Disaster effect awareness is essential for instilling a culture of disaster preparedness, prevention, and mitigation in citizens. As a result, both official and informal disaster education approaches are promoted. Campaigns for public knowledge and enlightenment in print and electronic media, as well as through community-based groups (e.g., women and youth associations, neighbourhood organizations, market/trade and religious organizations) should be undertaken aggressively. Numerous professionals in the education and communication field verified that using audio-visual communication is the most successful technique to convey information (Yusnaidi, 2017; Rifai, 2020; Desai & Bhadre, 2020). Kemp and Dayton (1985) made a similar claim concerning the usefulness of audio-visual communication in conveying messages.

Mishra (2004) discusses numerous benefits and drawbacks of using audio-visual media as a message conveying tool. Integrating technology through audio-visual media allows disaster vulnerable communities to experience things electronically or vicariously. Although firsthand experience is the ideal approach to gain educational experience, it cannot always be done practically. To adapt to the current situation, some changes and creativity are required. The use of audio-visual aids in community discipline because all the vulnerable communities' attention is to safeguard their life and properties. At the same time, communities are more bored of the traditional verbal awareness sessions and the audio – visuals provide intrinsic motivation to vulnerable communities by responding to their curiosity and encouraging their interest in the subject.

Audio-visual media, on the other hand, has a number of drawbacks. It is important to remember that using too much audio-visual material at once can also leads to boredom. Most of the time, the equipment such as a projector, speakers, and headphones are quite expensive, thus certain local authorities or the disaster management communities are reluctant to use this method. The major disadvantage is, it is not possible to employ audio-visual aids that require energy in rural locations where electricity is not available. To sum up, along with the technological advancement it's required to adopt some new effective mechanisms to aware and prepare disaster vulnerable communities. It may contain certain disadvantages still as per the practitioners' statements the audio – visual methodology is more effective to create awareness.

3. Methodology

This research has been conducted as experimental research. The landslide and flood disasters are selected as base events for the experiment since those are frequently occurring and highly impact disasters in the island. The scenario-based video was selected as the experimental audio-visual tool to create awareness among vulnerable communities. Two cases from the study area were selected to develop the scenario-based videos as follows;

- Landslide event occurred in Hela-Uda area - 1993
- Flood event occurred in Mudduwa area

The affected community of the above cases and disaster management practitioners of the case study area have been selected to get feedback for videos and identify the effectiveness of this tool for disaster risk communication.

Open ended questionnaire and discussion methods were used to obtain feedback from the audience on following;

- Baseline information
- Understanding of the Video
- Effectiveness of the video as a tool for risk communication

The questionnaire tried to capture the baseline information such as knowledge about associated disaster risk, getting the idea about disaster preparedness, and identifying how to get information/ awareness about disaster and pre-preparedness; the understanding of the video capture through the understanding of the area, introduction to disaster situation, information on disaster preparedness, Understanding of resilient construction, information about the entire video and feedback on effective methods.

4. Case study

The land extend of Ratnapura District is 3,275 sq. km with 17 Divisional Secretariat Divisions. As per the 2012 census and statics report, the total population of the district is 1,088,007. The highest rainfall (3,000mm) which has been recorded in Sri Lanka was from Ratnapura District between 1883 to 2017. It caused major flood and landslide. Many areas of the district are highly vulnerable to floods during the North-western monsoons. Considering this Ratnapura Municipal Council area is selected as the case study area to conduct this study. The main disasters in the area are landslides and floods. Therefore, those disaster scenarios (landslide and flood) have been selected for the simulation and computer visualization.

Grama Niladhari (GN) Divisions of Muwagama, Mudduwa and Mihidugama are highly prone to flood disaster every year. Therefore, Ratnapura city area including those GN divisions was selected for flood disaster simulation and computer visualization.

The Hela-uda landslide which occurred in 1993 was selected for the landslide disaster simulation. This site, situated on the southern slope of the Godigamuwa hill range, could be reached by Gillimale Wewalwatta road from Ratnapura. Two videos were prepared for those disaster scenarios using simulation and video editing software. This video is able to provide information on the impacted area, disaster situation, preparedness and disaster resilient construction.

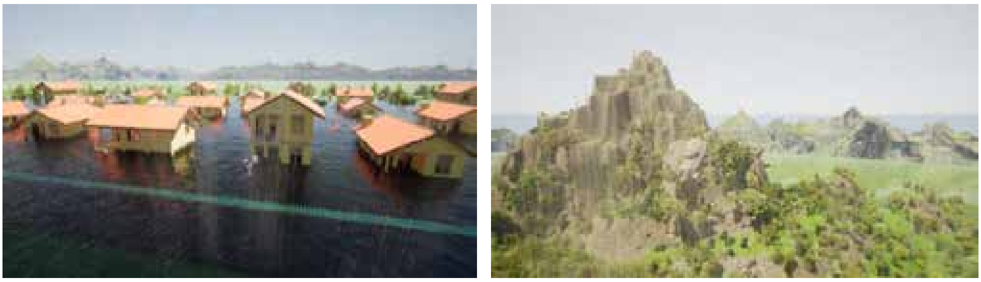

Figure 1: Snapshot of disaster simulation videos

5. Result and discussion

5.1. Community feedback and responses

Fifteen participants who are living in flood prone areas and landslide high risk locations participated in the discussion and filled the questionnaires. All the participants were well aware that they are living in a risk area and therefore they have taken preparedness actions during the disaster period.

More than 90% of the participants received awareness on disaster management and preparedness. Majority of the participants (41%) have been received awareness through the disaster awareness programmes organized by different government and non-government organizations. Apart from it, 29% received the information from government officers (Grama Niladhari and other disaster management officers), 18% of the participants received handouts and another 12% of the participants got the information and awareness from mass media and social media platforms. The important thing is that none of the participants have received awareness through audio-visual video mode before.

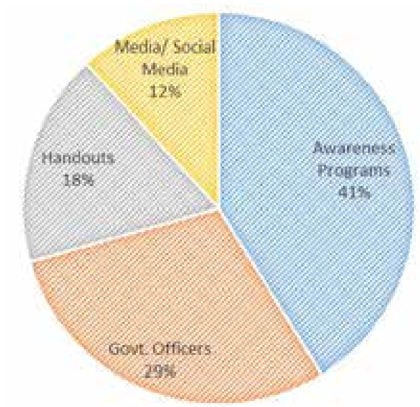

Figure 2: Community feedback on mode of awareness reviewed

Disaster simulations videos displayed to the community and the feedback from the community were obtained about understanding of the videos under the content of 1.) Introduction of the area, 2.) Information on disaster situation, 3.) Information on preparedness, and 4.) Information on disaster resilient construction. Polar interrogative questions and comparative cross questions were asked to know the level of understanding on the video from the community. Accordingly, all participants stated that they have fully understood all the above content included in the video. As none of the participants have received this kind of awareness method before, the participants stated that this method is very effective due to the following reasons.

- Ease of understanding with visuals
- Simple explanation with dialogues
- A large area and a lot of information can be shared in a shorter period
- A sense of practical experience

Specially, there was a participant who lacked reading and writing skills. He stated that such audio-visual explanation would be very important for people like him to have a better understanding of the magnitude of the disaster and the preparedness.

Furthermore, participants were asked to answer which feature/s they were most focused on in this video. More than 60% of the participants stated they focused on the disaster-resilient construction part of both landslide and flood videos. They stated that they got better understanding on how to practically build disaster-resilient houses in sloppy lands and flood-prone areas.

The participants suggested to include followings information for better understanding of the video and to upgrade the tool for an effective risk communication.

i. Include the hazard zone – by including hazard zones (flood and landslide) in this video, the particular community can understand what is their risk level and in which stage they have to be prepared especially in a flood disaster.
ii. Details/ magnitude of the damage –by including the magnitude of the damage, people will be more responsible for their preparedness.
iii. Include Disaster-resilient House Plans – most people are not aware enough about the disaster-resilient house construction. Therefore, it is better to include disaster resilient house plans and models for better understanding.

5.2. Disaster management professionals feedback and responses

Fifteen officials from different stakeholder organisations involved in disaster management in the Ratnapura Municipal Council area were interviewed and their feedback was collected for the disaster simulation video. Those included District Secretariat office, Divisional Secretariat office, Urban Development Authority, Municipal Council, Disaster Management Centre, and National Disaster Relief Services Centre in Ratnapura District.

All officials stated that they have fully understood all the above content included in the video. Further, they stated that this method is very effective in risk communication due to;

- Explanation given corresponds with the real situation on the ground
- Ease of understanding by individuals without any educational background
- New generation are more interested in these kinds of video simulations

Further, following suggestions were received from the officials to improve this Audio-Visual Video tool for risk communication.

i. *Prepare the video as easy to transfer to the community* – this kind of video should be easily transferable to the community. Introducing a mobile app or creating small GIF-type of videos would be more effective. Otherwise, distributing the videos with CDs or other devices would not be effective.

ii. *Revise the flood levels according to rivernet.lk* – rivernet.lk is the online application which anyone can access to see the water level of the Kalu River. This is very popular in the Ratnapura District and most of the general public access this app to see the flood levels. Therefore, it would be appropriate to align with existing flood level.

iii. *Include Common places/ landmarks / road network including minor roads* – general public feel and identify the area with common places, landmarks and road network. Therefore, including such places as much as possible would be effective to recognize the area.

iv. *Consider the interior design in resilient construction* – mostly people think only about the structural frame when designing a disaster-resilient house. But, it is most important to consider the interior design and arrangement in disaster-resilient housing, especially in flood prone areas. For example, in two-storied houses stair case is very important to lift the furniture and other items to the upper floors to project those from flood water. Therefore, more attention should be given to designing internal features of the house in order to ensure complete resiliency of the household. Further, furniture of the ground floor, in flood-prone areas can be designed in concrete base. Then, the economic loss and time/ labor consumption to lifting them would be reduced during the flood.

v. *Include speeches of people in particular area* – including ideas, dialogues, and interviews of the people in a particular area can give the real experience to the audience.

vi. *Weightage of mental depression should be increase in the video* – mental depression of the people is very high during the disaster situation and recovering phase. Therefore, considerable weight should be given to explaining how people perceive disaster psychologically.

vii. *Community behaviours after the disaster* – although this video has been prepared to explain disaster preparedness, most of the officers requested to include the difficulties faced by the community after the disaster including cleaning the area, houses, and recovering process.

6. Conclusion

The main objectives of this research are to identify the effectiveness of disaster simulation-based audio-visuals in risk communication and obtain suggestions to improve audio-visuals to upgrade as a tool for effective disaster communication. Accordingly, two videos were prepared for floods and landslides based on actual scenarios and simulations. Finally, community and disaster management officials in the simulated area were interviewed and their observations were received through an open-ended questionnaire and discussions.

The results indicate that none of the participants were received this kind of awareness method before and therefore all the community participants stated that this audio-visual method is more effective than other conventional methods of risk communication like awareness programmes, leaflets, etc. Further, people who lacked reading and writing skills also got better understanding of disaster situation they faced and preparedness actions. Further, constructive suggestions were made by community and officers with their experience on the area in order to improve the clarity of the video.

Accordingly, the communities suggested to include the hazard zones, details/ magnitude of the damage and requested to include disaster-resilient house plans. At the same time, professionals suggests to prepare the video to transfer information easily to the community and requested to revise the flood levels, include common places/ landmarks/ road network including minor road for easy reorganization of the area, consider the interior design in resilient construction method, include speeches of people in particular area, weightage of mental depression should be increase in the video and requested to include the community behaviours after the disaster.

The findings indicated that the developed audio-visual risk communication methodology is best suited for the situations where there are high disaster vulnerable communities with less literacy. It is also suggested as the most cost-effective method in comparison to the past experiences. At the same time, this method contains the capability to cover a huge area at a time. Lastly, the knowledge created from this exercise could be useful for decision-makers and disaster management practitioners for better disaster preparedness in terms of loss & damage assessment, planning & designing the area and to prepare the evacuation plans.

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Building Resilience amidst
Economic Challenges

Mitigation of cut slopes in Vijaya College at Welimada, Badulla District

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Abstract

This paper summarizes the mitigation approach with the techniques implemented to minimize the landslide disaster risk in Vijaya college at Welimada in Badulla district where some cut slope failures occurred in 2016. To determine the soil properties, both disturbed and undisturbed soil samples were collected. Sieve analysis and direct shear test were performed at the laboratory. Based on those values and field data, seven cross-sections were analysed using Geo slope SLOPE/W software with the aid of Spencer's method to identify possible failures and to suggest suitable mitigation measures. With the aid of the analysis, considering factors such as morphology, slope geology, failure scale, availability of technology, cost-effectiveness, durability as well as socio-economic aspect, succession have been developed to determine the most effective mitigation measures. Accordingly, Slope angle modification with surface drainage development was proposed, as it was the most cost-effective mitigation option. Then the structural methods such as retaining walls and soil nailing were proposed as appropriate.

Keywords: Cut slope failures, Textural analysis, Cohesion, Friction angle, Mitigation

1. Introduction

Recently, the most frequent slope instabilities have been recorded as cut slope failures mainly caused by human activities. As per the records of National Building Organisation (NBRO) from 2014 to 2016, more than 70% of the recorded incidents were cut slope failures. Hence, each and every year, considerable economic and human losses have been reported and the adverse impact have been rising up alarmingly in the country. It is well noted that, this has been resulted by the increasing trend of population of central highland of the country during the past few decades.

Among the other landslide prone districts of the country, Badulla district has been identified which has more susceptible hilly area for cut slope failures. A severe cut slope failure has been identified in Vijaya College at Welimada in Badulla district. A cut slope having 40° gradient created by a construction activity went on at the school premises. This cut slop was failed during extreme rainfall event occurred in September 2016. Considering the affected building at the failed slope, NBRO as the mandatory institute of landslide research and investigations decided to mitigate the failed cut slope at the school with immediate effect. In the stabilization process of the cut slope, reconnaissance survey has been carried out to find the possibility. This paper discusses the mitigation process conducted to mitigate the cut slop failure at Vijaya College at Welimada.

2. Study area

The study site is located at Vijaya college promises in Welimada Town. It is situated near No. 94/3 culvert of the Peradeniya-Badulla-Chenkaladi highway (A005). GPS coordinates of the location is 6.90737° N, 80.92085° E and it is located in center of Welimada basin of central highlands of Sri Lanka. .

2.1. Physiography of the study site

The study site located in Welimada which is a major city in the central highland. The elevation of the study location is about 1,053 m MSL. The study site is located in a valley surrounded by a mountain ridge. The area receives a considerably high rainfall (2,000 mm) mainly from North-east monsoon. The land use is characterized with built environment which have been located on terraced benches of the slope with a gradient of 400.

2.2. Soils and sediments of the study site

The study site is mainly composed of residual soil which is characterized with yellowish-brown silty-sandy-clay. Moreover, the thickness of the profile's ranges from 2-4 m. Some colluvial sediments can also be seen at the bottom of part of the slope areas in the study site.

2.3. Geological background of the study site

The study area belongs to the Highland Complex and the site is characterized with having Proterozoic high grade metamorphic rocks as the basement rocks. Major rock types found in the area are Garnet sillimanite biotite gneiss, Marble and Garnatiferous quartzo feldspathic gneiss. The structures in the area are dominated by meter-scale layering with an internal fabric showing evidence of ductile deformation, including transposition of layering, coupled with extreme flattening and stretching [3; 4]. Some observations on the geology and structures measured at the field is given in the Table 1.

Table 1. Different rock types/structures and description of the location as measured during the field study

Location	Strike/Dip	Joints	Rock type	Characteristics	Weathering condition
R 1	N20°E/25°NW	N80°W/90°/3m^{-1}	Quartzo feldspathic gneiss	Moderately jointed	Moderately weathered
R 2	N30°E/35°NW	N50°E/90°/3m^{-1}, N25°W/90°/3m^{-1}	Quartzo feldspathic gneiss	Highly fractured /fissured	Moderately weathered

3. Methodology

The methodology of the study is three-fold. First literature survey was carried out which included a desk study using topographic, geological, landslide hazard zonation maps, aerial photographs and physiographical data. Then the field investigation has been carried out to observe, measure and collecting samples. Finally, a laboratory analysis was conducted to analyze the samples and data collected from the field observations and measurements. Slope stability analysis including soil and structural analysis have been carried out to introduce a design including geotechnical mitigatory measures with the aim of reducing the vulnerability of the failed cut slope.

3.1. Field investigations and sampling

During the field investigations, visual observations were made to identify the geological background, soils, geomorphology and landforms. In addition, the failed cut slope was scrutiny investigated and examined. A contour survey (1 m contours) and samples were collected during the detailed field investigation. Mainly two types of samples were collected.

i. Disturbed soil sampling for the classification of soil
ii. Undisturbed soil sampling for find the shear strength parameters

Disturbed soil samples were extracted from the existing failed cut slope. Tube samplers were driven into the existing cut slopes and undisturbed soil samples were collected.

In addition to the above some field tests were conducted as follows. The JKR-Probe test was done at two locations. Each probing was advanced to the basement bedrock/possible hard layer. All probing procedures were carried out in compliance with BS 5930 and BS 1377 standards. Mackintosh test was used for confirmation of the thickness of soil/weathered rock layers where cannot be visually observed.

3.2. Laboratory analysis

The samples collected at the field were analyzed in the laboratory to perform the following test. Particle size distribution of the soils were carried out by performing the sieve and hydrometer tests. The coarse fraction of the soils was tested with sieve analysis while the fine fraction was determined using hydrometer analysis following the British Standard (BS 1377). Undisturbed samples were used for the direct shear test.

Initially, with the field observations, three cut slopes were identified as most critical locations. Using laboratory data and contour survey data, the stability analysis was carried out using the Geoslope SLOPE/W programme [5] for those cut slopes. Analyses were done using the Spencer's method [6]. Both the grid and radius approach and entry and exit approach were adopted and the minimum factor of safety obtained was reported.

Seven critical cross sections were selected for the analysis with the variation of slope geometry and based on the experience. The several approaches of mitigation measures were analyzed for each section to select the most suitable measure which satisfies the requirement of safety margin, durability as well as socio-economic aspect.

4. Result and discussion

4.1. Field investigation

The heights and angles of three cut slope created in residual soil profiles were given in Table 2.

Table 2:Summarized data of the selected critical locations

Location	Height (m)	Cut slope angle as built	Analysed cross sections
1	5	Vertical	A, B
2	12	70°-80°	C, D, G
3	10	Vertical	E, F

The Mackintosh probe analysis termination (220 blows per 0.30 m) value at the location 2 reached at 2.70 m at the upper part of cross section G showing two different soil layers in the subsurface. The Mackintosh probe analysis termination (200 blows per 0.30 m) value at the location 3 reached at 3.30 m at the middle part of cross section E showing two different soil layers in the subsurface. According to the results of the particle size distribution, soils can be categorized as silty-sandy clay. According to those graphs from the direct shear test, cohesion of the soil was 10 and friction angle was 27°. As revealed from the laboratory analysis, the unit weight of the tested soil was 17 kg/m^3.

Table 3: Results of direct shear test

Soil type (According to British Standards)	Bulk density (kN/m^3)	Cohesion (kPa)	Internal friction angle (ϕ')
Silty sandy clay	17	10	27°

4.2. Stability analysis for the selected cut slopes

Majority The stability of the slope was analysed using the Geoslope SLOPE/W software. The shear strength parameters were used in the analyses Table 4.

Table 4; Shear strength parameters used for the analysis and the results

Soil type of the layer	Colour code	γ kN/m^3	C kN/m^2	ϕ'
Residual soil (RS)	(yellow)	17	10	27°
Weathered rock (WR)	(green)	19	12	28°
Moderately weathered rock (MWR)	(red)	19	15	35°

The stability analyses performed for the sections under their existing conditions resulted in Factor of Safety (FoS) values of 1.090, 0.956, 1.011, 0.586, 1.011, 0.683 and 0.752 respectively. Although the FoS were less than unity, section B, D, F and G remains stable due to matric suctions prevailing under the unsaturated conditions. Hence, the primary remedial measure was the improvement of surface drainage and minimization of infiltration.

4.3. Stability at Location 1

Section A and B were the analyzed cross sections for the location 1. With the analyses for existing conditions, obtained FoS values were 1.090 and 0.956 for A and B respectively. Hence a mitigation procedure needs to be applied in addition to the surface drainage management.

The upper slope is having a gentle gradient (20°) and also weathered bedrock appeared in the bank. According to the previous experience and the literature, reshaping is the appropriate and most economical way to stabilize such a slope [7]. However, according to the local conditions, the slope couldn't be protected only using reshaping method Table 5. Hence, it was proposed to provide a toe support by a toe retaining wall. Thus, the analysis done for the reshaped (angle 40°) slope with a toe support (1.5 m high retaining wall), obtained FoS values were 1.510 and 1.501 for the cross sections A and B respectively. Those values verify that the above proposed measures are suitable to stabilize the particular slope.

Table 5: Summary of the FoS values with the succession of applied mitigation measures at location 1

Location	Countermeasure	FoS
1	Existing condition	0.956
	Surface drain (Internal stabilization 1 m drop of GWT)	1.035
	Surface drain +Reshaping	1.116
	Surface drain +Reshaping + Toe retaining wall	1.501

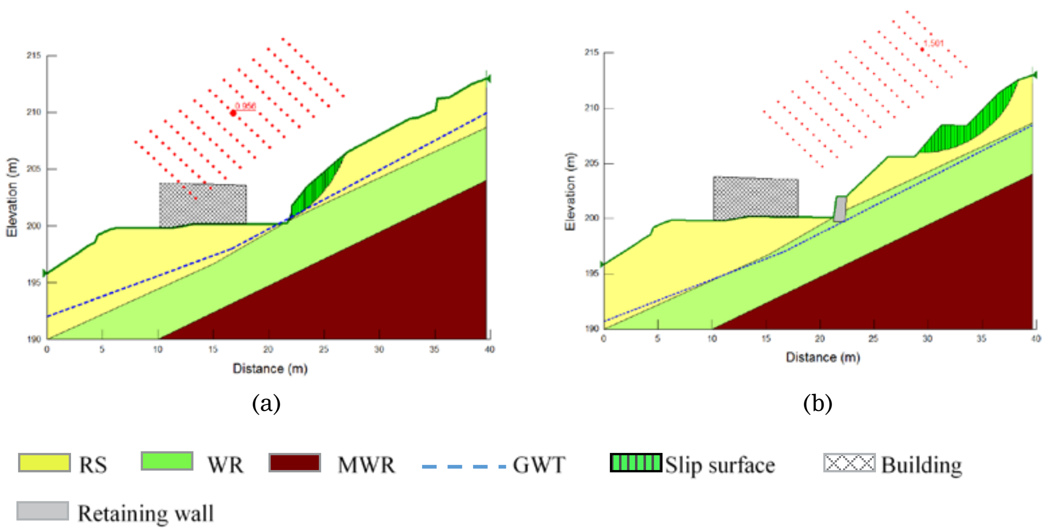

Figure 1: (a) Analyzed cross section-B under the present conditions, (b) Analyzed cross section-B with countermeasures at location 1

4.4. Stability at Location 2

C, D and G were the vital cross sections for location 2. With the analyses for existing conditions, FoS values obtained were 1.011, 0.586 and 0.752 for C, D and G respectively. a. Hence a mitigation procedure had to be introduced for this cut too in addition to the surface drainage management.

The upper slope from the particular location is consisted with a single store building and also cut height is about 12 m. A three stores building is located at the bottom level of the cut slop. Both buildings at top and bottom of the cut slope are constructed very close to the slop. Hence, reshaping method is not practicable as well as the construction of a retaining wall is also a difficult task. With considering those difficulties and the height of the slope as well as the previous experience and the literature, soil nailing was (trim the slope and support with nails) proposed as the appropriate way to stabilize the cut slope [8]. In addition to that, to gain appropriate FoS value, the toe of the slope had to be supported with a toe retaining wall (2 m high). To avoid the upsurge of the ground water table during the rainy periods, deep horizontal drains (8 m) has been proposed and to reduce the immediate sub-surface erosion, shallow horizontal drains (2 m) were also recommended.

With those counter measures (proposed angles to trim the slope are; C 53°, D 62° and G 59°), obtained FoS values were 1.511, 1.603 and 2.988 Table 6 for the cross sections C, D and G respectively. Those values verify that the proposed mitigation measures are suitable for the particular location.

Table 6: Summary of the FoS values with the succession of applied mitigation measures at location 2

Location	Countermeasure	FoS
2	Existing condition	0.586
	Surface & sub surface drain + Reshaping (Internal stabilization 2 m drop of GWT)	0.632
	Surface & sub surface drain + Reshaping + Soil nailing + Toe retaining wall	1.603

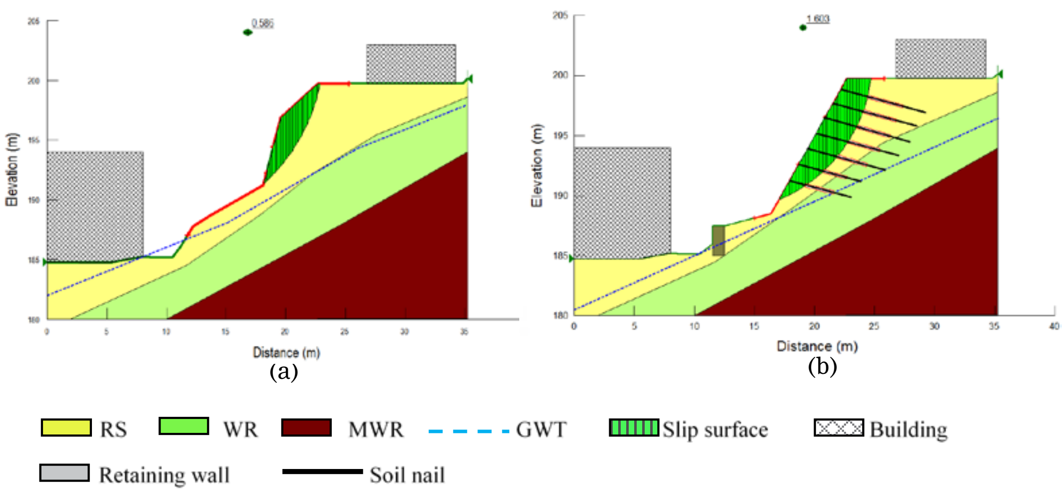

Figure 2: (a) Analyzed cross section-D under the present conditions, (b) Analyzed cross section-D with countermeasures at location 2

4.5. Stability at location 3

Existing cut slope at the location 3 using two cross sections which are named as E and F. Obtained FoS values for the existing site conditions were 1.011 and 0.683 for E and F respectively. Hence, surface drainage management alone is not adequate to stabilize this cut.

In here, the cut height is about 5 m and upper slope is having a gentle gradient (30°). Weathered bedrock was observed on the cut. With the modification of the slope angle, some of these kinds of slopes were stabilized (according to the previous experience), however, analysis results revealed that another mitigation measure(s) also had to be implemented to improve the FoS value up to a sufficient level. Hence, it was proposed to apply retaining walls as indicated in Fig. 3 (b). In addition to the reshaping (slope angle; E 34°, F 54°). Then the obtained FoS values were 3.022 and 1.596 (Table 6) for the cross sections E and F respectively. According to those values, proposed measures are suitable to stabilize the cut slope at the location 3.

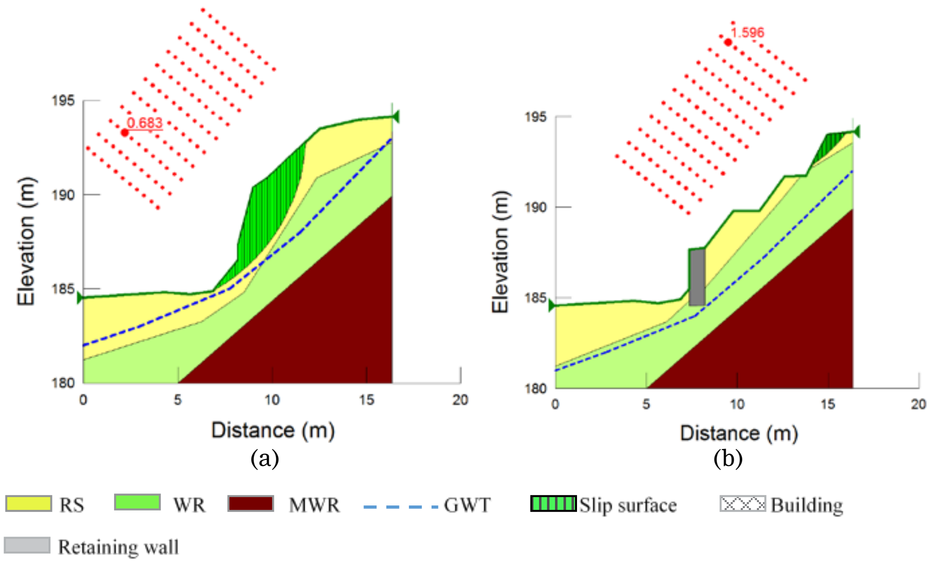

Figure 3: (a) Analyzed cross section-F under the present conditions, (b) Analyzed cross section-F with countermeasures at location 3

Table 7: Summary of the FoS values with the succession of applied mitigation measures at location 3

Location	Countermeasure	FoS
3	Existing condition	0.683
	Surface drain (Internal stabilization 1 m drop of GWT)	0.755
	Surface drain +Reshaping	0.944
	Surface drain +Reshaping + Retaining wall	1.596

Slope angle modification with applying a substantial toe support is proposed to stabilize the cut slope at location 1. The cut slope at the location 2 could be stabilized by constructing two retaining walls on the reshaped slope, one is proposed to the toe of the cut and the other one is to avoid the possible failure at the mid of the slope. The analysis demonstrates that the application of soil nails in to the surface (Length is 8 m and diameter of a nail is 25 mm) of the cut at the location 3 provide the reasonable FoS value, however, the toe of the slope has to be energized with a retaining wall.

4.6. Proposed code of practice to select the suitable mitigation measures for cut slopes stabilization

An adequate and effective measures for preventing cutting failures should be selected considering the surrounding morphology, geology, failure scale, space availability and meteorological conditions. The following criteria should be considered while selecting the countermeasures.

i. Reshaping work should be selected in removing of overhanging and highly fractured or weathered rock slopes.
ii. Surface and subsurface drainage improvements.
iii. As a low-cost measure, covering with vegetation to control the surface erosion due to rainfall.
iv. Where slopes are unsuitable for vegetation, such as fractured of weathered rock slopes should be considered shotcrete or crib wall.
v. Construction of retaining wall with a sound foundation was to retain the unstable soil masses at the slope.
vi. Soil nailing or anchoring works was proposed to strengthening the loos soil masses there.

5. Conclusion

As verified from the results from the analysis, it was proposed to apply mitigation measure to prevent future collapsing of the cut slopes. Hence, retaining walls have been proposed as the more applicable measure for strengthening the medium high (4-6 m) banks and spacious places. In addition, terracing is the cheapest method of slope stabilization and practicable for gentle slopes. Soil nailing for slopes with large heights is most practicable than construction of higher retaining walls. Since the soil nailing will be the best option of vertical and high slope mitigation with a good drainage system to control rain water infiltration.

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Building Resilience amidst
Economic Challenges

MOBILISE: Digital toolset for building resilient communities

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Abstract

Several institutes have been nominated as a focal points for disaster risk management in the country. Each institute has different frameworks for the implementation of its institutional mandates. As a result, various toolsets were developed for communication and data dissemination. Decision makers had a great challenge accessing all this information to convert it into a rational decision. Therefore, a requirement was identified to integrate all the hazard information and early warning information into one digital platform to enhance the collaborative environment to build resilient communities. A project was conducted supporting external funding to develop a comprehensive decision-making system. The system integrates different toolsets identified through various discussions conducted with different stakeholders. The developed system, MOBILISE, facilitates data sharing, visualization, scenario development, sharing of IoT information, and dissemination of early warning messages. The toolsets were tested on different scales, from stakeholder to community, and applied to various case studies. This research paper expresses the details of the toolset and case studies conducted to build resilient communities in the Kalutara District of Sri Lanka.

Keywords: Multi-hazard early warning, MOBILISE, Resilient communities, Digital applications

1. Introduction and background

This paper presents the outcome of a research project conducted by the National Building Research Organisation, in collaboration with the University of Salford in the UK and Tecxal systems Ltd, that focused on developing innovative digital solutions for building resilient communities in Sri Lanka. This project, funded by the UKAID and the World Bank, and coordinated by the Asian Disaster Preparedness Centre as well as the Global Challenges Research Funds and the Economics and Social Research Sciences, addressed two global challenges.

The first challenge stems from the lack of intelligence-driven approaches to addressing local disaster risk reduction activities in countries such as Sri Lanka. At present, important climate and disaster risk data are scattered across many government agencies, and as a result, it is difficult for government agencies, both at the national and local levels, to compile relevant intelligence necessary for understanding the local risks due to climate-induced hazards, and to build community resilience against climate change. This paper presents the development of a multi-agency collaboration platform that allows local stakeholders to work together to share their disaster risk information and engage in a collaborative approach to building local community resilience to disasters.

The second challenge is activating the community as an essential participant in a multi-hazard early warning system. Our research has shown that there is a lack of engagement with the local community in capturing and sharing their local knowledge of emerging hazards and the use of local community groups in disseminating hazard warnings among the isolated community members. The paper presents the design and implementation of a multi-hazard early warning system that embed the "whole society" approach to creating a community-based early warning system where community members and digital volunteers can offer important intelligence to relevant government officials and other community members through crowdsourcing techniques, and receive timely alerts and warnings in advance of possible disaster risks, hence saving lives of vulnerable communities.

2. Methodology

The research that is being addressed in this proposal is complex and inter-disciplinary in nature involving academics from a range of disciplines as well as practitioners and citizens. Therefore, it is necessary to ensure the research methodology adopted caters to the application of different research methodologies as well as bridging research and practices together. Therefore, the project deployed the Living Lab methodology to allow researchers from different disciplines and practitioners to work together to collaborate, experiment and learn using different research approaches. Kalutara district was selected as the Living Lab context since it is subjected to multiple hazards such as floods, landslides and droughts.

The project established Kalutara Living Lab as an "experimentation and learning environment" that can be used to investigate how current silo approaches in resilient building activities can be transformed into a collaborative and inclusive approach to building community resilience which is equitable. In this project context, the "resource view" of our Living Lab is comprised of the chosen urban areas (Kalutara), all the stakeholders (private & public organisations, researchers, citizens including vulnerable communities), and digital platforms (decision-making virtual workspace and multi-hazard early warning system). The "process view" of the Living Lab was introduced as a sequence of co-creation activities that support rapid learning and accelerate innovation, based on Action Research.

3. Current state-of-the-art and user requirement

This section provides a brief summary of the current state-of-the-art in use of technology in disaster management and the user requirements extracted from the stakeholders in the Living Lab to work towards innovative technology platforms that can overcome current challenges.

3.1. Intelligence-driven multi-agency decision making

Our focused group discussions and interviews revealed that many government organisations have developed risk information systems. For example, the Disaster Management Centre (DMC) has developed hazard profiles for 9 hazards (coastal erosion, drought, floods, landslides, lightning, sea-level rise, storm surge, tropical cyclone, and tsunami). In addition, DMC is providing access to risk information through websites such as riskinfo.lk and desinventar.lk. In addition, the National Building Research Organization (NBRO) has developed landslide hazard maps for several districts. NBRO maintains a landslide risk information portal with a legend describing the areas accordingly to landslide hazard risk. It provides landslide risk information for 14 districts including the eastern mountain slopes of the Colombo District. As the focal agency for hazard monitoring, the Department of Meteorology (DoM) issues its weather predictions, while the Department of Irrigation (DoI) reports the real-time water levels of major irrigation tanks. In addition, DOM, DOI, and the NBRO have established rain gauges, where they can obtain real-time rain data through their own systems to predict floods and landslides. It was observed that the exposure data is scattered across various government departments. For example, population data is maintained by Census and Statistics Department; building data, educational and health establishment, critical infrastructure, land use and road are maintained by the Surveying Department; and power stations and power lines are maintained by the Ceylon Electricity Board. Therefore, the current position in Sri Lanka is that the relevant hazard and exposure data are scattered across organisations, and as a result, it is difficult to establish an integrated risk view of a given local area for multiple hazards.

The interviews conducted with DOM, DOI, and NBRO showed that these organisations produce hazard information with the view that any interested parties can obtain and use those hazard information for decision making. However, it was identified that a system that brings those hazard information together with other exposure data, vulnerability data and planned development data that allow agencies to work together interactively and collaboratively to develop resilient communities and environments is missing. Such an integrated risk information system was considered a useful platform for identifying the communities at high risk and developing targeted programmes to work with such high-risk communities. Furthermore, the interviewees stated the need for having multiple hazard information simultaneously on a common platform. A sequence of events such as thunderstorms and floods, followed by landslides can occur within a short period of time and hence a holistic view of the risks is important for planning for such occurrences and issuing impact-based multi-hazard early warnings.

The senior officers at the Kalutara District Secretariat office stated that there isn't a method to observe collective risks in their district development plans for multiple hazards such as landslides and floods. Hence there is a need for a system where the officers at the District Secretariat can assess the impacts of multiple hazards in land use planning and socio-economic development. The senior staff from the Land Use Policy and Planning Department have observed that the Kalutara is being speedily urbanized and as a result, the land use is being challenged. At the same time, the flood and landslide impact on the district are escalating due to climate change. Therefore, they identified the need for a platform for settlement planning, larger infrastructure development planning, identifying economic risks as well as agricultural land use. Therefore, the stakeholders of this project identified the need for a multi-agency platform that can be used to capture and maintain local intelligence on exposure, vulnerability, and potential hazards and go beyond the current risk information management systems to build a collective understanding of local risks on communities and the local economy and support their land use and urban development planning.

3.2. Multi-hazard early warning system

It was apparent from our studies that there are several mobile apps for disseminating early warnings. As a result, communities need to deal with several apps to receive multiple hazard information. Therefore the availability of an integrated app for receiving multiple hazards specific to the local context was seen as a positive step toward communicating early warning systems to the community. Furthermore, the ability of the community to become an active participant in reporting hazard incidents was considered a useful feature.

Furthermore, due to the delays in structural mitigations and the relocation process, people are living in hazardous zones. The community living in Maragahadeniya stated that they are currently 'living with hazards' and are relying on landslide early warning. To survive during the rainy seasons, they need to be vigilant of their surroundings and must be well informed about potential landslide threats. During the community interviews, it was identified that the area-specific hazard information is helpful for them to make decisions such as removing their assets or evacuating the area. Moreover, the population in Margahadeniya is subjected to multiple hazards such as landslides, floods and thunderstorms, almost simultaneously during rainy seasons. Therefore, the community showed an interest in having one source for receiving early warning information in their multi-hazard context.

The community members Maragahadeniya area stated that at present, there is no efficient way of informing any hazard events such as landslide signs, increase in water level, or possible dike breach to the relevant authorities. The community members felt that the use of a mobile app for reporting potential hazards with evidence to the authorities by the community themselves can speed up the investigation process. Furthermore, they felt the mobile app can be used as a community tool to inform other members of the community of emerging hazards. Furthermore, the community are interested in knowing hazard events which have taken place upstream. This is because, from their past experience, the community is aware that such events can have a delayed impact on their locality. As a result, the community was interested in having the ability to listen to hazard warnings in their surrounding areas as well as monitor river levels through IoT sensors.

3.2.1. MOBILISE Platform

The MOBILISE 3.0, built on a micro-service architecture, offers a set of cloud-based digital services for local and national government agencies to collaborate in building local community resilience. At the heart of the MOBILISE 3.0 is a cloud-based risk information space, referred to as MOBILISE: Data Engine. It allows local councils or local disaster management committees to capture and maintain their local intelligence on exposure, vulnerability and potential hazards. In addition, the MOBILISE: Data Engine offers important data management functionality such as data cleansing, styling of data layers to enhance visual appearance, attaching of metadata such as origin of the data layers, year of data collection, star rating based on its quality, security level etc. The risk information within the MOBILISE: Data Engine is used by a range of other digital services available within the MOBILISE platform to perform activities such as evidence-based decision making, multi-agency collaboration, community engagement, real-time environmental data monitoring, early warning system and scenario planning through an easy-to-use visual interface. The following digital services are offered to the users by the MOBILISE platform:

MOBILISE: Risk Explorer: This tool allows the local stakeholders to explore the local risk information spaces in an interactive manner to establish a common understanding of the local risks (current and future risks due to climate change) in their area.

MOBILISE: Scenario Generator: This tool allows government agencies to consider possible future hazards due to climate change, and gain an in-depth understanding of the magnitude of the potentially affected population, impacted roads and critical infrastructure, damages and losses within different administrative boundaries.

MOBILISE: IoT Network Integrator: This tool offers functionalities for integrating disconnected sensor networks to establish better situational intelligence for issuing more accurate early warning messages to the community at risks, during disasters.

3.2.2. Case study Implementation using the MOBILISE platform

Following the focused group discussions and the interviews, this project identified and implemented a series of use case studies to demonstrate the potential of the MOBILISE platform for understanding the local risks and strengthening multi-agency collaboration for reducing them. This section briefly presents the outcome of two of the case studies.

3.2.2.1. Identifying communities at high risk

The purpose of this case study was to evaluate the ability of the MOBILISE platform to integrate various data sources to establish a common understanding of local risks and identify the communities at risk due to landslides. The following process was deployed in order to develop a complete local risk view and identify the communities at risk which then led to the establishment of 30 community-based programmes to work with the communities to build their resilience.

Step 1: The following data was collected from various agencies and uploaded to the MOBILISE Data Engine with the view to exploring local risks due to landslides.

Table 1: Project Stakeholders

Data Layers	Data Owner
Landslide Hazard maps	National Building Research Organisation
Landslide symptoms	National Building Research Organisation
Land use data	Land Use Policy and Planning Department
Building and Roads	Survey Department

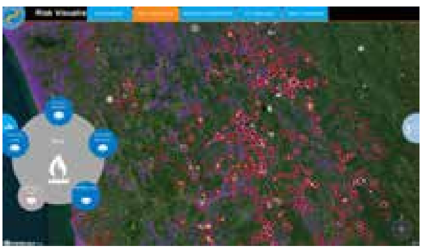
Step 2: Visualization of the Hazard and Exposure Layers for identifying pockets of risks.

a) Landslide Hazard Layer: The layer shows the landslide probability in four different classes as classified by the NBRO

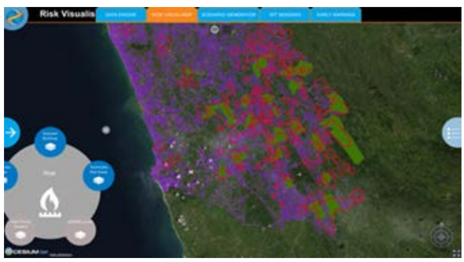
b) Landslide Symptoms Layer: This layer shows the recent landslide symptoms identified by communities & NBRO officers. The map shows the overlay between the landslide hazard layer and the landslide symptom layer

c) Residential building Layer and with landslide symptoms layer: This is overlapping the landslide symptom locations and building layer. Landslide symptom layer mark in red dots and buildings are represented in purple colour.

d) Landslide flow path simulation: The landslide flow path simulation was derived based on the Yellow/Red zoning concept. The yellow zone represents the low-impacted areas, and the red zone the high-impact areas.



e) Clustering of high-risk areas: The landslide clustering was conducted in the Kalutara district by considering the landslide symptom locations and landslide hazard zonation layer. Accordingly, 160 landslide high risk clusters were identified in the Kalutara District area. The red boundary shows the landslide high risk clusters in the Kalutara district



f) 30 Chosen High-risk communities for engagement: The results were communicated with the stakeholder agencies, and based on the feedback 30 communities were identified for further investigations.

Figure 1: Visualization of the Hazard and Exposure Layers

3.2.2.2. Land use assessment against landslide risks

This particular case study was proposed by the District Secretariat since uncontrolled human settlements are increasing the landslide risks on communities. The purpose of this case study was to explore how the MOBILISE platform can be used for establishing a detailed understanding of the local landslide risks and use that knowledge to guide risk-sensitive urban development and build the resilience of the communities already living in landslide-prone areas.

This case study selected Maragahdeniya and Diganna GN areas in the Baduraliya Division of the Kalutara District since they were identified as high-risk clusters during the first case study of this project.

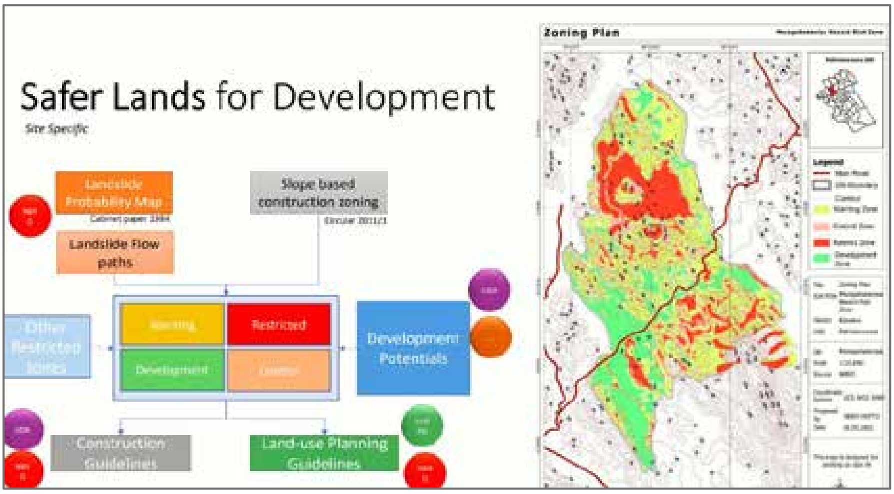


Figure 2: Hazard zonation maps

This case study was set out to answer the following questions:

1. What are the high landslide-risk areas that should be restricted for further human settlements? How many families are already living in this area and how can we ensure their safety?
2. Has the area development plan, developed by the Urban Development Authority (UDA), considered local risks to avoid further exacerbation of local risks?
3. What are the safer lands for future urban development?

In order to answer the above questions, a landslide hazard zonation map was developed with four types of hazard zones by analysing the slope angles of the terrain, landslide risk level and landslide flow path, as shown in Figure 2. In this map, the Red (Restricted) Zone marks the areas with critical risks and, therefore, they are restricted for any construction. The Amber (Control) Zone has high landslide risks and therefore landslide mitigation measures is required to control landslides. The Yellow (Warning) Zone is having comparatively less landslide risk, but the populations in the area can apply early warning measures for their safety while living in the area. The Green (Development) Zone areas are safe and therefore suitable for development. These hazard zone maps were loaded onto the MOBILISE platform to allow the District Secretariat to establish a better understanding of the hazard zones.

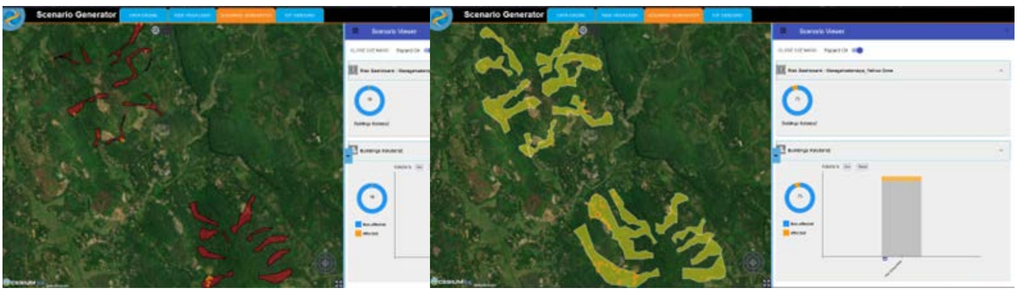
However, due to various historical reasons, people are still living and working in restricted, control, and warning zones. Therefore, the following guidelines were proposed as a way of creating a resilient environment for the community in the future:

- No new development should be allowed in the Restricted Zone and will be preserved for nature.
- No new housing should be allowed in the Control Zone due to high risks. Existing houses need to be relocated or countermeasures need to be taken to protect the property.
- New houses should be allowed in the Warning Zone, but after a thorough analysis of the surrounding for possible landsides and with good early warning system in place. No public facilities are allowed in this zone.

However, due to the delays in structural mitigations and the relocation process, people are living in restricted, controlled and warning zones. As a result, they are currently 'living with hazards' and relying on landslide early warnings for safety. In this case study, the MOBILISE platform was used to identify the families living in these Red, Amber and Yellow areas, following the following steps:

Step 1: First uploaded the landslide hazard digital layers to the MOBILISE Data Engine. The hazard map includes layers based on the potential and the possible flow directions of landslides. The Yellow-Red concept was used to analyse the landslide flow paths in the Maragahadeniya area. In the concept, red polygons indicate the high-impacted zones and yellow polygons indicates the low-impacted zones.

Step2: Scenario generator was used to calculate the buildings that will be impacted from each landslide flow path types.



a) Ten houses were identified in the Maragahadeniya GN division as high risk since they are on the flow path of high magnitude landslides.

b) Three houses were identified in the Maragahadeniya GN division as low risk since they are on the flow path of low magnitude landslides.

Figure 3: Scenario generator

With this enhanced understanding, it is important to establish a more effective early warning system for the community living in this high-risk area.

3.2.3. Community-based multi-hazard early warning system

3.2.3.1. System architecture of the multi-hazard early warning system

Figure 4 below shows the overall system architecture of the multi-hazard early warning system developed in collaboration with the THINKlab and the Tecxal Systems

Ltd. The overall architecture offered the following features, captured through the focused group discussions and interviews:

- Management of the authorisation process of early warning messages among government agencies
- Integrated app for receiving multiple hazard warnings through the same mobile app
- Facility for the community members to report incidents to government organisations. Offer officers and appointed digital volunteers to authorise the reported incidents. Offer community discussions and feedback around a reported disaster incident.
- Allow community members to monitor the river levels by themselves through IoT sensors
- Provide a dashboard for national and local organisations to collect, visualize and analyse reported incidents by the community, ECMWF weather information and real-time environment data (river level, pollution data etc), collected via IoT sensors.

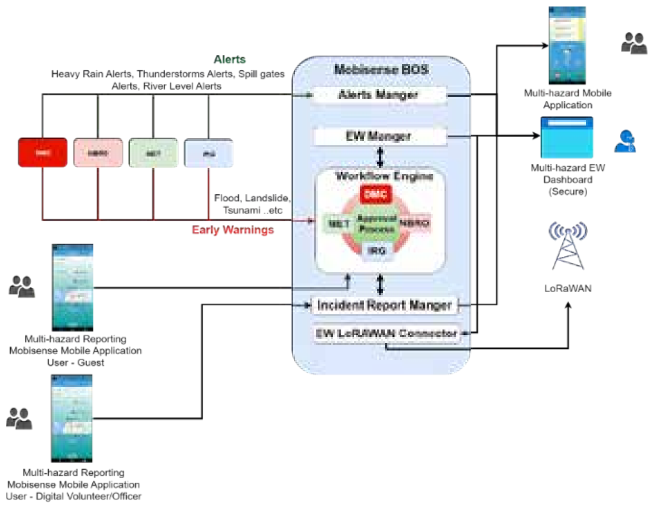


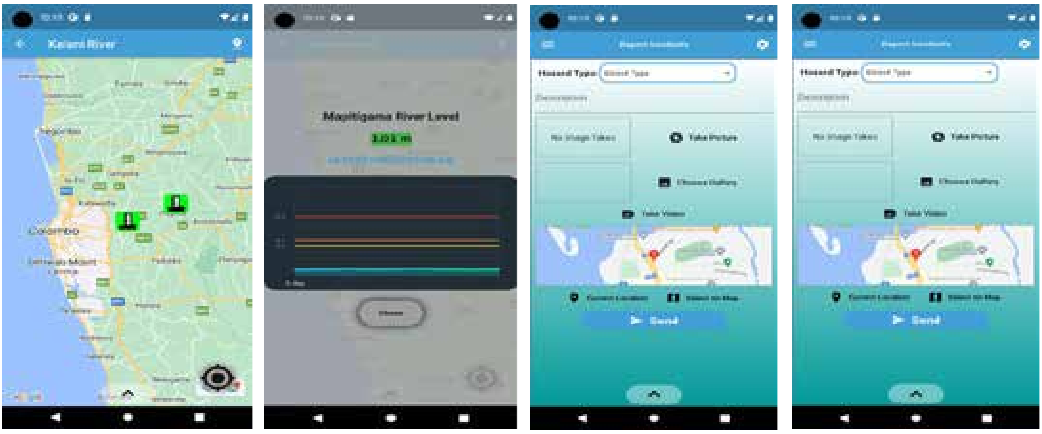
Figure 4: System Architecture of the Overall Multi-hazard Early Warning System

a) App Configuration page

b) App Interface once launched

c) Live Weather

d) Early Warnings



e) Monitoring of River Levels **f) Monitoring of River Level of a given location** **g) Community incident reporting** **h) Community reported Hazards in a map form**

Figure 5: MOBILISE Mobile App interface

4. Conclusions

This project has initiated a research programme to bring digital innovation for building community resilience in Sri Lanka by exploiting the potential of advanced digital technologies. Furthermore, it has enabled the research team to introduce the concept of Living Lab as an open innovation environment for the local stakeholders to come together to understand the risks within their local context and introduce digital solutions for reducing them. By working with international partners, the project has resulted in the implementation of two innovative digital solutions: MOBILISE (Multi-agency collaboration platform for building community resilience) and the Megha app as a community-centric early warning system. These technology platforms have been piloted through several case studies to illustrate their potential for revolutionising the current DRR activities.

The first case study on understanding local risks, by integrating various risk information, has enabled NBRO to identify 160 clusters of communities at high risk in the Kalutara District. After exploring these local risks with the divisional secretaries and Grama Niladharies in the Kalutara District, NBRO has initiated working with 30 communities to build their resilience against climate-induced hazards such as landslides. This particular case study was useful in validating the digital services and the user interfaces of the MOBILISE platform, for supporting stakeholders to understand local risks and then work with the communities to implement programmes for building their local resilience.

The second case study explored an approach for identifying the local lands subjected to potential hazard risks and developing a land use management policy to support risk-sensitive urban development policies. This particular case study illustrated the benefits of combining risk information and land use information to allow agencies to work together to develop sustainable and resilient environments for the community

The third case study allowed the team to work closely with the community members to establish a community-centric early warning system where the community members are empowered to become active participants in monitoring and reporting hazards to the relevant organisations and engaging in disseminating information to the rest of the community.

Due to the space limitations, this paper has only summarised the outcome of two case studies, but the project has deployed the MOBILISE platform for other scenarios such as: assessing economic losses; and predicting the impact of climate change in 2030, 2050 and 2080 in Kalutara District for different climate change pathways. Furthermore, the project has produced a comprehensive multi-hazard system that offers a workflow engine for managing early warning coordination among DMC and other technical organisations, and dashboards for the local and national partners to capture intelligence required for building situational awareness in responding to disasters. It is the intention of the researchers of this project to pilot these advanced features in the near future and seek opportunities for implementing them at both local and national levels:

Acknowledgment

The project was initiated under the Climate Innovation Challenge (2021) program conducted by the Asian Disaster Preparedness Centre (ADPC) with the support of World bank. The technical development was mainly handled by the University of Salford and Tecxal Systems Ltd in Sri Lanka. Implementation support was given by District Secretary Kalutara and the National Building Research Organisation. Additionally, different stakeholder agencies provide adequate support for driving the project into a successful milestone.

More information

Please visit the project website and MOBILISE system by following QR codes/websites.

Kalutara LIVING-lab
https://kalutara.mobilise-srilanka.org/

MOBILISE System
https://mobilise-project.org.uk/platform/

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3

REGULATING DEVELOPMENT FOR RESILIENCE

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Building Resilience amidst
Economic Challenges

Condition assessment of RC Structures-perspective on school buildings in Sri Lanka

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Abstract

Condition assessment of existing structures is promoted in Sri Lanka to fulfil scientific assessment requirements for existing defective structures. In some circumstances, renovation and rehabilitation options are feasible solutions other than new construction. Under the Building Assessment and Condition Reporting Project (PMD50M) program of NBRO, nearly 22 nos of school buildings were assessed by performing Non-destructive & Destructive (NDT/DT) testing. The investigations focus on two/three storied framed structures exposed in inland and coastal areas which were constructed 25 years ago. The NDT/DT test program includes combinations of laboratory and field tests namely core test, rebound hammer, ultrasonic pulse velocity, half-cell potential, resistivity, chloride content and carbonation depth. From the data analysis from a material perspective, it is encountered that both strength and durability factors were not satisfied in the most of School buildings. Embedded rebar corrosion due to carbonation and chloride ingress is the most common issue caused by insufficient cover concrete, deficient materials and lack of quality control. The poor construction practices are leads to a decline in the designed service life of school buildings.

Keywords: Concrete, NDT/DT testing, School buildings

1. Introduction

In general, the expected service life of a building structure is 50 years with a designed load-bearing capacity. However, in some instances without changing permanent or imposed actions, the further functioning of a building becomes uncertain within a few years of construction completion. It is essential to fulfilling the safety and serviceability requirements of RC structures to withstand short-term accidental events although long-term degradations due to the server exposure. Reinforced concrete is deteriorating due to several reasons such as corrosion, chemical attacks, accidental effects, adverse exposure, design issues, defective raw materials, poor workmanship, negligence in supervision & etc. The various assessment approaches exist for different purposes such as prevailing stability assessment, damage assessment, alternations and service life predictions. Comprehensive condition assessments are needed to ensure the structural stability and operational adequacy of a particular structure. The appropriate safety measures and retrofitting or repairing strategies implement in accordance with the assessment output.

NBRO was requested by many parties for assessment of different types of existing or partially constructed structures such as apartments, hospitals, schools, commercial buildings, heritage structures, warehouses, etc. Under the Building Assessment and Condition Reporting Project (PMD50M) program of NBRO, nearly 22 nos of school buildings were assessed by performing Non-destructive & Destructive (NDT/DT) testing. The findings of the PMD50M project indicated the number of school buildings recommended to demolish due to the damage severity of structures. For example, school buildings at Gampaha Bandaranayake College, Nivithigala Bharathi Tamil Vidyalaya, Dehiowita Ingiriyawatte Vidyalaya and Agulana Podujana Vidyalaya. Some of the buildings are partially or completely damaged and evident for structural distress, concrete deterioration and reduction of load-carrying capacities. Some buildings exist in a serviceable state but functioning terminated due to the susceptibility of sudden collapse. Most of the buildings were constructed 25 years earlier and are currently in an abandoned condition which makes heavy inconvenience to students and school staff.

Nowadays, in Sri Lanka, the construction of new buildings incurred high budgetary allocations. These premature failures of public-funded buildings in the education sector have a great impact on socio-economic development of the country. Accordingly, the intention of the present paper is an adequate technical insight into the deteriorated government school buildings to determine the most common defects and root causes from the material perspective.

2. Assessment approach

To establish school building condition assessment protocols, existing assessment standards, guidelines, manuals and related literature were reviewed. The standards such as BS EN 13791, BS6089, ISO 13822, ACI562-19 and Guidelines of condition assessments in ASCE; SEI/ASCE,1999 & Japan Concrete Institute,2014 indicates valuable information on the condition assessment of buildings.

Initially, a preliminary assessment was conducted comprised of a visual survey and documental reviews. However, design and other relevant details do not exist in most of the buildings. The dimensions of the buildings are typical; 27.0m x 7.8m floor area with two-storied/three-storied framed concrete structures filled by brickworks. The most common defects observed were cracking and spalling of columns, beams, slab areas and spalling of canopies. Figure 1 to Figure 6 show the defects in the front columns of school buildings.

Figure 1: Corroded G/F column School ID-D

Figure 2: Corroded G/F column School ID-N

Figure 3: Corroded G/F column School ID-N

Figure 4: Corroded G/F column School ID-C

Figure 5: Cracked G/F column School ID-B

Figure 6: Fig .6.Cracked G/F column School ID-I2

Poor compaction and insufficient cover thickness have caused carbonation-induced corrosion in beam locations as shown in Figure 7 to Figure 8.

Figure 7: Corroded beam rebar, School ID-A

Figure 8: Corroded beam rebar, School ID-O

The performance of structural elementals is important in framed buildings where decayed constituent materials mainly cause structural deterioration. There are many damages identification and modelling techniques such as chemical, electro-chemical, electro-magnetic and mechanical methods. According to the related literature, there were specified techniques for assessments do not exist and testing consists of advantages and limitations (Breysse, 2012; Conde, Ramos, Oliveira, Riveiro, & Solla, 2017). The present study mainly focussed on elemental residual strength for load bearing and durability for service life predictions. The NDT/DT testing programs were performed in accordance with its initial field data, existing condition and exposure environment such as inland and coastal zones.

It is difficult to obtain all material parameters by performing a single test assignment and need to conduct multiple NDT/DT testing for correlations. The test program includes combinations of laboratory and field tests namely core test, rebound hammer, ultrasonic pulse velocity (UPV), half-cell potential, resistivity, chloride content and carbonation depth. The list of conducted NDT/DT tests including related test parameters is given in Table 1. By visual observations and sounding tests on column, beam and slab areas, suitable locations were identified. The concrete cover delaminated points were examined to detect corrosion activity.

Table 1: List of conducted NDT/DT tests

Test Parameter	NDT/DT Test carried out	Test Standard
i). In-situ compressive strength	Core test	BS EN 12504-1:2009
ii). Relative compressive strength	Rebound Hammer test(Schmidt)	BSEN 12504-2: 2001
iii). Surface quality of concrete	Ultrasonic Pulse Velocity(UPV) test*	BSEN 12504-4: 2004
iv). Concrete cover to rebar	Cover meter test	BS 1881-204: 1988
v). Probability of corrosion	Half-cell potential test	ASTM C 876:1991
vi). Carbonation depth	Phenopthelene for freshly extracted cores or drilling*	BS1881-210:2013
vii). Conductivity	Resistivity; Wenner probe	Operating Instruction Manual, Proceq
viii). Chemical reactions Chloride concentrations	Water soluble chloride content	BS 1881-124: 1988

*Qualitative indications

A minimum of three nos. of cylindrical specimens (core samples) were extracted from each floor of the building to estimate cube compressive strength. It is the most reliable method for strength estimations and direct examination of the state of concrete. In compression members, beams & columns, mean strength values/relative compressive strength was derived from Schmidt hammer rebound values with correction for carbonations. The surface homogeneity and integrity quality of the column and beam concrete were determined by conducting UPV testing which emphasized qualitative implications. The rebar corrosion potential was measured by open circuit corrosion potential methods such as half-cell potential testing. The four-point Wenner probe was used to measure concrete resistivity. The depth of carbonation was observed by spraying a 1% phenolphthalein solution on freshly extracted core samples or drilled points to observe possible colour change. Cl concentrations were determined from dust samples taken from the core samples or drilling. The cover meter test was conducted to detect the cover thickness and rebar arrangements of each type of concrete element in buildings.

3. Summary of test results

Estimated in-situ cube compressive strength of core samples, mean strength of rebound values and interpretations of UPV readings (in accordance with IS 13311: 1992) of tested concrete elements of school buildings are given in Table 2.

Table 2: Summary of test results; Compressive strength & UPV testing

School ID	Compressive strength(N/mm^2)			UPV test interpretations	
	Slab	*Column*	*Beam*	*Column*	*Beam*
a). Schools –Urban/ Inland Zone					
School A	5.3	<10	11	Doubtful	Doubtful
School B	12.5	13	12	Medium	Doubtful
School C	18.0	<10	<10	Medium	Medium
School D	16.5	17	21	Good	Medium
School E	13.0	24	22	Medium	Medium
School F	18.2	14	18	Good	Medium
b).Schools – Rural/ Inland Zone					
School G	8.6	13	16	Medium	Medium
School H	18.2	25	22	Medium	Medium
School I-1 to 3	21.5,18.0 18.5	18,23,24	21,22,23	Medium	Medium
School J	23.0	12	13	Medium	Medium
School K	16.2	21	18	Good	Good
School L	12.1	<10	<10	Doubtful	Doubtful
c).Schools - Coastal Zone					
School M	22.5	26	18	Good	Medium
School N	17.3	13	12	Doubtful	Medium
School O	16.5	19	17	Medium	Medium
School P (1 to 5)	11.3,14.1,14.5 18.2,26.5	<10,<10 12,14,14	14,12,18 18,17	Medium	Doubtful(1) Medium(3) Good (1)

Half-cell potential and resistivity readings, observed carbonated depth and level of surface Cl concentrations are given in Table 3.

Table 3: Summary of test results; Half-cell potential, resistivity, Avg. carbonation & Cl content

School ID	Level	Corrosion state			Resistivity			Avg Carb. Depth(mm)	Cl content wt% by concrete
		C	B	S	C	B	S		
a). Schools –Urban/ Inland Zone									
A	G/F	●	●	●	*			60	0.02
	F/F	◒	-	-				55	
B	G/F	●	◒	●		*		35	0.04
	F/F	◒	◒	◒	M	M	M	25	
	S/F	◒	-	-	M	-	-	25	
C	G/F	●	◒	●	*			50	0.01
	F/F	◒	○	●	*			45	
	S/F	○	-	-	N	N	N	12	
D	G/F	●	◒	●	*			55	0.02
	F/F	●	◒	○				45	

	S/F	○	-	-				45	
E	G/F	●	●	●	M	M	M	25	0.04
	F/F	●	◒	◒	M	M	M	20	
	S/F	◒	-	-	N	-	-	10	
F	G/F	◒	◒	◒	M	M	M	15	0.02
	F/F	○	○	○	L	L	L	10	
b). Schools – Rural/ Inland Zone									
G	G/F	●	●	●	M	M	M	20	0.01
	F/F	●	-	-	M	-	-	15	
H	G/F	●	●	●	H	H	H	15	0.02
	F/F	○	-	-	M	-	-	15	
I(1-3)	G/F	●	○	○	L	L	L	40	0.04
	F/F	●	○	○	L	L	L	35	
	S/F	●	-	-	L	-	-	30	
J	G/F	●	◒	◒	M	M	M	25	0.02
	F/F	◒	○	○	L	L	L	20	
	S/F	○	-	-	L	-	-		
K	G/F	●	◒	◒	M	M	M	20	0.01
	F/F	○	-	-	M	-	-	15	
L	G/F	●	◒	◒	*			45	0.01
	F/F	◒	-	-				40	
c). Schools - Coastal Zone									
M	G/F	●	●	○	H	H	M	15	0.18
	F/F	◒	○	○	H	M	M	10	
N	G/F	●	●	◒	H	H	H	35	0.05
	F/F	◒	○	◒	H	M	M	35	
	S/F	◒	-	-	M	-	-		
O	G/F	●	●	◒	H	H	H	10	0.2
	F/F	●	◒	●	H	H	H	8	
	S/F	●	-	-	H	-	-	12	
P-1-2	G/F	●	●	●	H	H	H	30	0.06
	F/F	◒	○	◒	M	M	M	25	
P-3-4	G/F	●	○	◒	M	M	M	10/40	0.04
	F/F	◒	○	◒	M	M	M	12	
P5	G/F	◒	○	○	M	M	M	10	0.04
	F/F	◒	○	○	M	M	M	8	

● Corrosion ◒ uncertain ○ No Corrosion C- column B-Beam S-Slab

4. Analysis & discussion

4.1. Strength & quality of concrete

The estimated in-situ cube compressive strength of core samples extracted from the slab areas of each school building was mostly in the 16-20N/mm^2 range and the second most range was 10-15N/mm^2. The estimated cube compressive strength was below 10MPa in 02nos. of school buildings. In most cases, the mean strength values of tested column concrete are in the range of 10-15N/mm^2. In some school buildings, the column concrete strength is less than 10N/mm^2. In beam concrete, major portion of strengths is in the 16 to 20N/mm^2 strength range and 02nos. of buildings, the mean strength of beam concrete is below 10N/mm^2. The carbonation depth correction was considered when estimating the mean strength from the rebound values. The graphical interpretations of computed in situ cube compressive strength values of the tested slab, columns and beam locations of each building are shown in Figure 9.

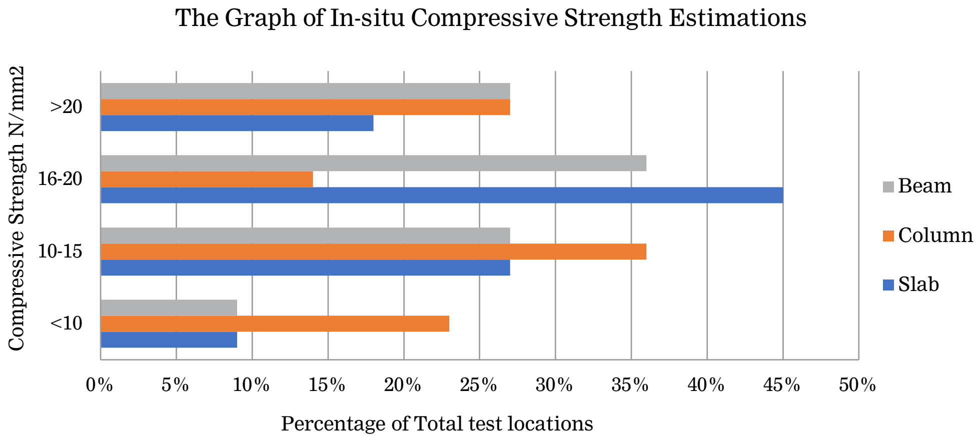

Figure 9: The graph of In-situ compressive strength estimations of slab, column & beams

The voids, cavities and larger coarse aggregate particles (Particle size>20mm) existed in extracted core samples. The excessive voidage of some of the core samples was more than 3 as per visual identification given in BSEN 12450-1:2009. Field data indicated that typical concrete thickness was 100mm and some section thickness varies between 75-85mm. The surface appearance and failures after the compressive test of core samples are shown in Figure 10 & Figure 11 respectively. The designed grade of slab concrete is assumed as Grade 20. Poor site mixed practices and manual compaction methods could have affected the reduction of the compressive strength of core specimens.

Figure 10: Surface appearance of extracted core samples, School ID-N

Figure 11: Failure after compressive strength test, School ID-K

Heavy carbonations resulted in high rebound values in column and beam concrete. After the correction for carbonation, mean strength values were reduced significantly. The concrete strength is important for compression members nonetheless recorded strength values were below >10N/mm^2 in some of the columns and beams locations. The quality of column & beam concrete in terms of uniformity, incidence or absence of internal flaws, cracks, and segregation were detected by UPV testing. The graphical interpretations of total UPV test results on columns and beam locations are given in Figure 12. In general, column concrete fell in the "Medium" quality category and school IDs A,N & L were in 'Doubtful' quality. Beam concrete is also mainly categorized in the "Medium" quality category. The surface quality of the material is uttermost important to protect the concrete from the penetration of deleterious materials. The construction issues such as lack of quality control in the mixing to curing process weakened the concrete quality

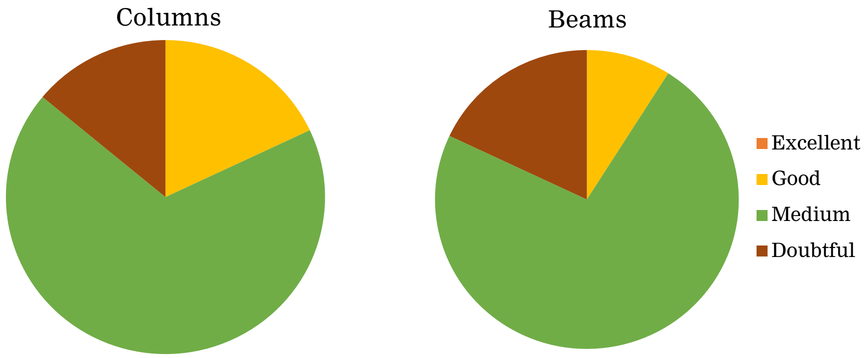

Figure 12: The graphical representation of total UPV results; column & beams

4.2. Concrete durability

As per the guidance given in ASTM C876:1991 standard, the probability of corrosion activity was interpreted in selected column, beam & slab locations. A 90% probability of corrosion was detected in the G/F columns of most of the school buildings which were located in both inland and coastal zones. Corrosion was propagating in column concrete and initiated in slab areas. In the coastal zone, a 90% probability of rebar corrosion was detected in some beam concrete.

The heavy carbonation presented in extracted core samples and drilled locations; mostly in urban/inland and secondly in the rural/inland areas. The alkalinity reduction of concrete is significant in urban/inland areas and concrete has carbonated beyond embedded rebar. The carbonation-induced corrosion is prominent in rural and urban areas of inland zones. In wet rural areas, carbonation is not progressive but wetting and drying could be favourable for corrosion. The most important factor that affects the carbonation of concrete is the relative humidity and water/cement (w/c) ratio of the concrete mix (Elsalamawy, Mohamed, & Kamal, 2019). The resistivity of concrete which indicates the likelihood of corrosion was a predominantly medium risk in buildings located in an urban and rural inland zone even in wet conditions. High resistivity values were recorded in some of the areas where heavy carbonations were experienced in urban/inland buildings. Concrete pore solution refinement and permeability and porosity reductions were significant due to heavy carbonation (Song & Kwon, 2007). In coastal region school buildings, high risk of corrosion resistivity values were observed in column, beam & slab locations.

Coastal area buildings' carbonation is not decisive but corrosion initiated due to the chloride attack. The Cl concentrations of inland areas fall within the permissible limit as per the guidance given in Concrete Society Publication (1984) which is below 0.05%. However, in coastal zones, Cl content was in the high risk range where Cl concentrations to the weight of concrete were above 0.15%. In some of the school buildings, the Cl profile revealed that Cl ions existed in concrete mix constituents. The obtained Cl contents are beyond the threshold levels and promote severe corrosion in rebar. The detected cover readings from the cover meter testing are less than 25mm in all zones which is not sufficient for relevant exposure conditions.

5. Conclusion

Based on laboratory and field test results neither in-situ compressive strength nor durability of concrete elements is satisfied in most of the school buildings in both coastal and inland regions. The school buildings are vulnerable to corrosion activity, cracking & spalling of G/F columns, balcony canopies and signs of corrosion initiation in beam and slab locations are the most common defects which were caused to premature failures. In urban and rural inland areas carbonation is higher and corrosion was initiated in the wetted areas while in coastal areas carbonation is not significant. In coastal areas, macro-cell corrosion was occurring and it is further propagated due to the severe exposure condition.

Furthermore, considerable variations were observed in compressive strength, surface quality, homogeneity and durability of a single structure. It is evident that insufficient durability requirements such as nominal cover concrete, w/c ratio, compaction and curing have contributed to the deterioration of the structures. The poor workmanship, deviations from standard practices and lack of quality control greatly influenced to decline of the designed service life of structures. School building construction, attentiveness in stage-wise constructions and proper record-keeping of design details and other related documents are important. It is recommended to implement adequate quality control measures and performance-based durability tests in public-funded school building construction projects.

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Building Resilience amidst
Economic Challenges

Integrating landslide mitigation with economic development - special reference to risk mitigation integrated re-development design for Ohiya railway station

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Abstract

Landslides have become one of the most devastating disaster occurrences in the country, regularly causing human deaths, property losses, and damage to infrastructure and lifelines. Hence Landslide risk mitigation is becoming an exigency in the Sri Lankan context to sustain development gains. Realizing the above need, the National Building Research Organization (NBRO) as the focal point for landslide risk management is embarking on a program for undertaking structural engineering measures to mitigate landslide risk, associated with infrastructure such as roads and highways, critical buildings of importance such as schools, hospitals etc. The Government of Sri Lanka (GOSL) has planned for an estimated total investment of USD 104 million for such landslide risk mitigation interventions within a duration of three years. The estimated budget for the same is around USD 97 Million, covering the cost of civil engineering construction works, associated engineering designs, construction supervision, management etc. GOSL plans to receive a financial support from Asian Infrastructure Investment Bank (AIIB) towards this. Basically, the structural mitigation of landslide risk is executed through expensive engineering solutions. Sri Lanka being a developing country, when implementing such risk mitigation projects, wish to incorporate additional practices to provide multiple benefits, in addition to achieving the cost benefits and cost effectiveness. Through this paper, it is expected to examine the cost effectiveness of proposed landslide risk mitigation interventions at Ohiya Railway Station, and to derive the additional benefits including the socioeconomic benefits to the society in addition to landslide risk reduction in the area.

Keywords: Landslide mitigation, Integrate potential development

1. Introduction

As evident from the previous occurrences of natural disasters, Sri Lanka is rapidly becoming a hotspot for natural disasters within the South Asian sub-region. Among them Landslides are one of the prominent occurrences annually, which can be described as a phenomenon associated with the movement of masses of earth, rock, or debris, down the slope under the gravitational force. It can happen as a natural phenomenon and also result due to manmade interventions. It is known that over 12,000 km^2 of Sri Lanka's 65,610 km^2 land area, spread over 14 administrative districts, is highly prone to landslides. Hence the landslide occurrences have become one of the most devastating annual events in the country, regularly causing human deaths, property losses, and damages to infrastructure and lifelines. It has become the third most impacted natural hazard in the country, in terms of number of events, area and extent of the impact, affected people etc. annually (ADPC, 2020).

Risk management can be associated with several concepts such as preparedness for response, structural and non-structural mitigation, and resettlement to avoid exposure. Structural and non-structural Mitigation interventions can be defined as "long-term actions that reduce or minimize the long-term risk to people and property and their consequences". Since structural mitigation is basically carried out through engineering solutions, they are also quite expensive. Hence, they are mainly being proposed to reduce the landslide risk associated with strategic locations, such as urban infrastructure, roads & highways, railways, and critical buildings, such as schools and hospitals. During Implementation of structural mitigation measures it is essential to consider aspects of cost recovery and cost effectiveness of the investment. It is essential and important utilizing such mitigated locations to a productive socio-economic purpose (Ekanayake & Rathnasiri, 2021).

The National Building Research Organization (NBRO) as the focal point for landslide risk management is currently undertaking a program to mitigate landslide risk, associated with infrastructure: such as railways, highways, roads, water & electricity supply and communication system etc. The proposed project will be implemented covering all the landslide vulnerable districts of Sri Lanka; that include, 14 districts in 6 provinces. Government of Sri Lanka (GOSL) planned for an estimated total investment of USD 104 million towards this initiative during three years and has dispensed a budget for USD 97 Million for Civil works, associated engineering designs ,construction supervision, management . Funding support for this initiative is received from the Asian Infrastructure Investment Bank (AIIB).

Accordingly, about 147 critically important locations have been identified as the locations with potential landslide risk, where undertaking mitigation solutions is essential for risk reduction. NBRO as the project execution agency is expected to provide technical resource inputs throughout the project, which include designing mitigation measures, procurement of services for construction, and construction management, where construction supposed to be undertaken by private sector agencies, selected through an open bidding process.

Usually when risk mitigation projects are designed, usual practice is to consider only benefits associated with risk management. As per the service delivery conditions such mitigation projects shall harness the development potentials associated with each location but it is rarely done or evaluated during project feasibility studies. Risk mitigation projects can offer additional benefits, when such projects could facilitate, or create additional space for new development or expansion of existing development.

Some of such development proposals can integrate risk mitigation while extending scope for expansion of urban facilities, services, creating safer urban built up areas, providing spaces for market facilities, service centers, or recreational facilities. As well such projects can be utilized as opportunities for creating new places that provide avenues for people to get engaged in other socioeconomic activities (Sugathapala & Rathnasiri, 2012).

This research study is expected to investigate the development prospects and socioeconomic benefits created through the landslide risk mitigation work undertaken at Ohiya Railway Station. Through the research study, the authors have made an attempt in showcasing other potential economic and social benefits to vulnerable communities, while analyzing the cost effectiveness of landslide mitigation measures undertaken to minimize the risk to infrastructure. Thereby It is also expected to introduce improvements to the current landslide risk management practice.

This project is targeting at.

- Analyzing the effectiveness of mitigating the risk due to potential landslides and slope instability
- Enhancing the capacity of NBRO to deal with landslide risk mitigation efforts effectively in future
- Introducing appropriate land use practices to regulate future land use and development in landslide prone urban areas
- Introducing guidelines for utilization of landslide prone urban areas effectively

2. Case Study

Ohiya railway station is located in Badulla District, Uva Province, at Ohiya GN division of Welimada DS division. It is one of the most popular tourist destinations among the 147 locations, identified as important tourist attractions within the area. It is located between Pattipola Railway Station and Idalgashinna Railway Station as the 67th station in the main Colombo-Badulla railway line. It has a significant architectural and historical importance as it was established around 1883 during the British era. Since this station is surrounded by major tourist attractions such as Nuwara Eliya, Horton Plains, Devil's Staircase, Ambewela, Bambarakanda Falls, Kirigalpoththa, etc, it is a popular destination for both local and foreign tourists in addition to regular commuters. Therefore, it is essential to develop this railway station further to enhance its development potential to become one of the highest tourist attractions as well as to become a central hub for tourists and railway commuters. It is also important to pay attention to its landscape for enhancing its most picturesque view and upgrading infrastructure facilities within the station to ensure better service delivery to its users.

Figure 1: Ohiya Railway Station & Surrounding Area

3. Methodology

People should be one of the main focuses during any physical planning intervention. Hence, during the participatory planning process, the planning team kept an eye on the above aspects, while following a few essential steps in generating the final outputs under the project. Basically, there were 7 steps involved in this project design and each step mutually supported in achieving the project objectives.

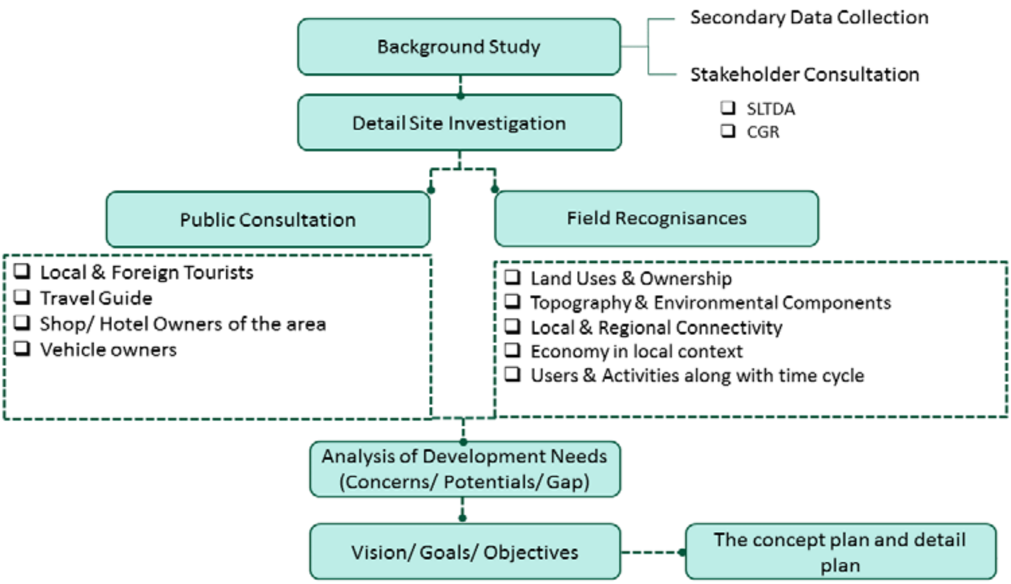


Figure 2: Methodology

4. Data collection methods

Several key Stakeholders were consulted during the various stages of data collection and throughout the process of preparation of the Post Mitigation Redevelopment Plan for Ohiya Railway Station. These stakeholders cooperated with the team at key stages such as data collection, analysis, problem identification, formulation of strategies etc. The planning team has utilized two major data collection methods such as remotely conducted telephone survey method and face to face interviews during field visits. Sri Lanka Tourism Development Authority & Sri Lanka Railway Department are the two main Stakeholders of the project, who have provided valuable inputs during data collection. As well Grama Niladhari-Ohiya GN division, Local & Foreign Tourists, Travel Guides, Shop/ Hotel Owners of the area, Vehicle owners etc. were the others who have provided useful inputs during the design process.

Figure 3: Public Consultation-Ohiya Railway Station

5. Results

The field visits, interviews, and drone surveys have helped the team to get some idea about the perceptions of individuals towards Ohiya railway station development and their thought process. From the perceptions and expectations expressed by the stakeholders, the team has derived a few key concerns. While fostering proposals, the team has made an attempt to address a few key concerns: such as lack of food venders and shops that could provide refreshments, low quality standard of available shops, no price control in such shops, inadequacy of sanitary facilities, exorbitant charges imposed by those who work as local tour guides to show around and the places of importance within the vicinity to tourists and foreign travelers, inadequate parking facilities, poor landscaping within the station and around, poor Internet & network coverage, etc.

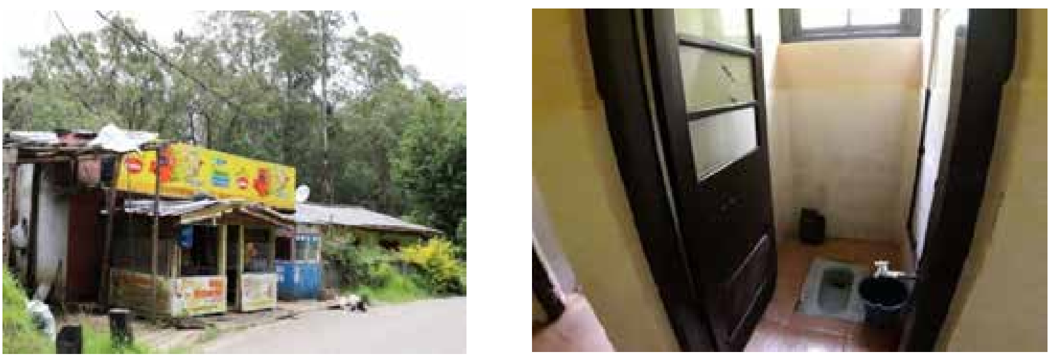


Figure 4: Current Status of the Area

Furthermore, it is worthwhile to mention the valuable contributions, which have been made by town planners, civil engineers, and architects from the area, about the soil conditions, risk mitigation designs, provision of view corridors, socio-economic and geographical characteristics of the surrounding area. Such important information has been utilized in proposing the improvements that can be undertaken for upgrading and enhancing the functionality of the station and for improving the landscape of its surrounding. It was felt helpful in summarizing all the gathered data into a SWAT analysis and hence a detailed SWOT analysis was carried out Summarizing the key findings which is provided in Figure 5. The planning team has come up with the directions towards the overall future development plan of the Ohiya Railway Station, considering the findings of the SWOT analysis.

Travelers for instance have several expectations when visiting a particular place and are related to several features of the chosen destination such as culture & heritage, architecture & landscape, infrastructure, food and accommodation facilities, amenities that could ensure better health & sanitation facilities, variety of local products such as cut flowers, fruits such as strawberries, etc. These features not only attract people to the destination and contribute to their overall experience but also offer them value for money. On the other hand, the income generated will contribute to local economy and socio-economic upliftment of people living in the areas. Based on this, the planning team recognized issues that will become limiting factors for the development and key concerns that needs to pay more attention while setting up the plan for regeneration of Ohiya. Consequently, to utilize its potential while addressing the landslide risk mitigation in the area, planning team proposes addressing some of the key limitations. The planning team has taken steps to incorporate the recognized issues of importance to capture in to a legitimate planning intervention for Ohiya carried out under the project.

When consider above factors, Ohiya can become a very strategic location not only as a tourist destination for both local and foreign tourists but also as a location which could offer several other benefits to the population of the area. It is of importance in preserving the railway heritage in the upcountry railways and also offer great potential for developing livelihood related ventures for the residents of the area. The Ohiya railway station could be regenerated to have several positive socio-economic benefits to the local community and to the neighborhood. With such possible improvements to the connectivity to other strategic locations within the area, it could offer greater socio-economic benefits. The full potential of the geographic area of Ohiya and its great scenic beauty could be made known to more investors to enable them to convert the area in to a better multi-purpose urban center with higher development prospects in future. Then those who will be visiting the location in future will have more opportunities for appreciating the value of their visit to Ohiya. Hence taking into account each and every possibility mentioned above, the authorities should take initiative for integrating development plans and designs for regenerating the area for harnessing its true potential, while undertaking the landslide risk mitigation measures.

1. Sceneric beauty of the surrounding area with natural elements
2. Historical & architectural value of the station
3. Serving as a transit point
4. Already prefers tourists
5. Availability of developable lands

1. No cafeteria inside the railway station
2. Low quality of the available refreshment facilities
3. Low quality Sanitary facilities with poor maintenance
4. Unavailability of resting places for its users
5. Low Internet & network coverage
6. Incomplete landscaping

SWOT

1. Higher Connectivity with the tourists' hotspots
2. Located in a Prominent Tourist route which has been identified by Sri Lanka Tourism Strategic Plan (2017-2020)
3. Proposed tele-communication tower installation project by Dialog Axiata
4. People engaged in farming as their livelihood and provide cut-flowers, floral arrangements, strawberries and vegetables
5. NBRO has proposed to mitigate landslide risk, with the funding available from the AIIB.

1. Located in High-Risk Landslide hazard area which is identified by NBRO

Figure 5: SWOT analysis

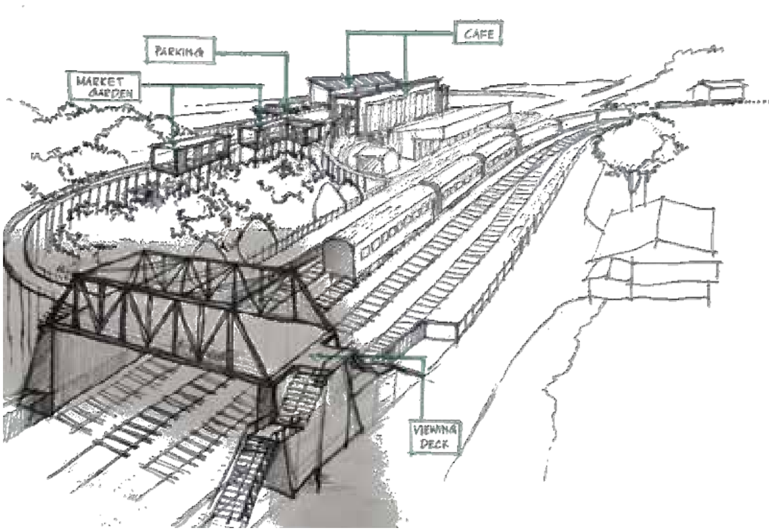
Accordingly, the vision was to develop the Ohiya Railway station as a "Tourism Integrated safe Railway Paradise in Hill Country". It has three main goals such as

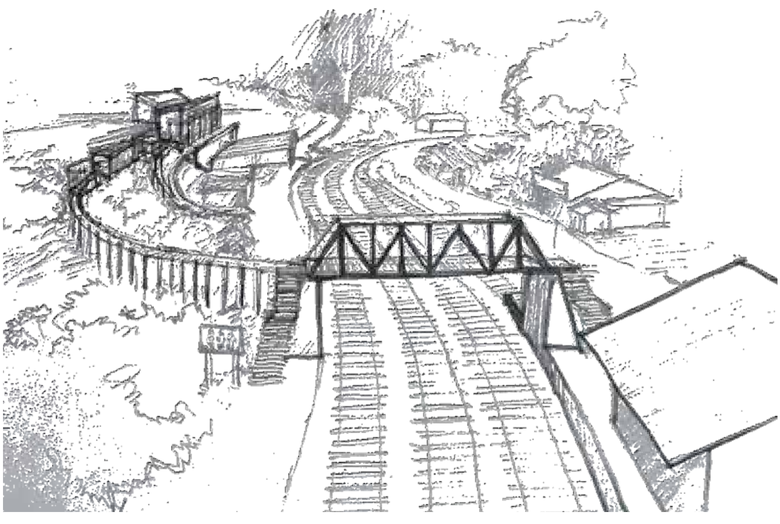
a) A disaster-free environment with an integrated natural ecosystem
b) A Comfortable spot with historical & cultural importance with significant architectural heritage", and
c) A location full of diverse economic functions with efficient facilities".

Figure 6: Proposed Concept Plan

In view of that, a conceptual plan was proposed based on growth potential covering aspects such as spatial form, functionality, and sustainability of the site outlining ‘where' and 'how' the land use development could take place. Considering the prerequisite and time availability, it was recognized that the proposal has to be implemented in two phases, giving priority to the first phase, which is predicted to be accomplished within 5 years. It includes development of the area as a multi-purpose urban center, with a market garden, viewing deck, sanitary facilities, and parking spaces. The second phase is expected to be implemented within next 10 years to provide vehicles renting services, accommodation facilities and free Wi-Fi-zone with mobile charging facilities. The proposed development projects will be executed in complementary with the landslide risk mitigation solutions.

Concurrently, the planning team engaged in the final stage of the planning process and finalized the detailed plan with a technical feasibility report. Here, the detailed architectural drawings were attached for further information as Figure 7.





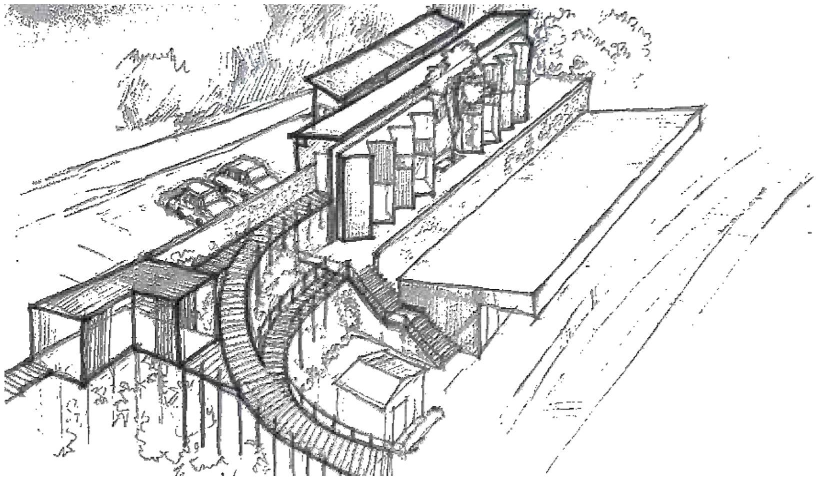


Figure 7: Detailed Project Drawings

In order to assess the financial feasibility, cost components for project implementation were identified including construction cost for multipurpose area, parking area, market garden and viewing deck, as well as the labor and material cost for the 1st phrase. Average construction cost per square foot as per the current market prices was used to calculate construction costs of each element and the total cost of the project is estimated to be around LKR. 18,342,500. Among the cost components highest share for construction was assigned to the construction of multipurpose area.

In addition to that, the income figures also were generated based on realistic assumptions. For example, average number of tourist arrivals for Ohiya per day (assuming that the annual tourist arrivals to Sri Lanka per year remain unchanged in the future) can be assumed as around 520 persons, average number of customers who may use at least one shop per day is around 32,average net profit from business in shopping area per person per day is assumed as around Rs. 150.00, average number of vehicles which may use temporary parking area per day could be around 10 (2 cars/ vans, 2 safari jeeps and 6 three wheelers). Such figures were used in calculating the revenue from Vehicle Renting area and Market Garden, assuming that those areas will be rented using a fixed rate for generating an annual income. The assumed income generation for each component is as follows:

Table 1: Income Generation

Description	First Five Years		Next Five Years	
	Monthly Net Income (LKR)	Annual Income (LKR)	Monthly Net Income (LKR)	Annual Income (LKR)
Multi-Purpose Area	144,000.00	1,728,000.00	158,400.00	1,900,800.00
Temporary Parking	87,000.00	1,044,000.00	95,700.00	1,148,400.00
Vehicle Renting	50,000.00	600,000.00	55,000.00	660,000.00
Market Garden	30,000.00	360,000.00	33,000.00	396,000.00

As per the feasibility analysis, calculated IRR value for this project is around 16.3946% considering the Discounted rate of 10%. Since the Net Present Value of this project can become a positive figure (Rs. 207,828.46) at the end of eleventh year and the

IRR rate is around 16.39% (>10%), it can be said that this project can be a viable venture to implement in future.

6. Conclusion

After completion of the phase 01 of the projects, the initial developments may result in an economic agglomeration in the area, while expanding the services to a great extent. Therefore, during the feasibility analysis, the potential income that could be generated through the project is calculated only for the 1st 10 years. However, after completion of the project, it can assume that the income generation could continue for a longer period while further expansion of income from business, services, tourism etc. can be expected. Possibility of utilization of the space in a productive manner can be one of the significant achievements of the project. In addition, there is a great potential for recovering the investment cost of structural mitigation in the long run, while ensuring the socio-economic benefits and wellbeing for the public.

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Building Resilience amidst
Economic Challenges

Application of resilient planning concept to reduce disaster risk in landslide-prone areas - A case study in Kothmale DSD, Sri Lanka

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Abstract

In the past few decades, landslides can be considered one of the most serious disasters in Sri Lanka due to heavy rainfall and human intervention. Approximately 80% of the landslide hazard zones in Sri Lanka are located in the Central Highlands. The landslide disasters have caused extensive damage to property and claimed the lives of people. Therefore, the National Building Research Organisation (NBRO) is preparing hazard maps to identify landslide hazard prone areas in Sri Lanka. However, the establishment and improvement of the legal arrangement for land use planning and development standards have become an urgent issue in Sri Lanka at present.

Accordingly, this study aimed to reduce landslide disaster risk in Sri Lanka through land use zoning with disaster resilience guidelines. Kothmale DSD, Sri Lanka, which is a landslide-prone area, was selected as the study area. A combination of the yellow/ red zoning concept and the landslide hazard zonation concepts were used in this study. The result indicated that the land use zone was classified into four categories: Restrict Zone, Control Zone, Warning Zone, and Development Zone. In addition, the fundamental strategies of each land use zoning are discussed. Furthermore, the land use zoning plan can be used as a comprehensive site-specific plan that focuses on the local level to minimize the impact of sediment disasters.

Keywords: Land use, Land use zoning, Non-structural mitigation measures, Landslide hazard zoning maps

1. Introduction

Landslide is one of the most severe natural disasters in Sri Lanka (Ekanayake & Rathnasiri, 2021; Jayaweera, 2008; Sugathapala & Prasanna, 2012). In recent years, landslides triggered by excessive rainfall during the spring monsoon season have become intense. Furthermore, increasing exposure to the hazards due to rapid reclamation and development has been raising landslide disaster risks in urban and rural areas. Landslides have caused major socioeconomic impacts on people, their properties, and lifelines, such as highways, railways, and communication systems. Similarly, nowadays, landslides in Sri Lanka have caused significant challenges in development and land use planning. Accordingly, there is a need for preparing legal arrangements for land use planning and development standards to reduce risk from the hazard and enhance sustainability and resilience (Roccati, Paliaga, Luino, Faccini, & Turconi, 2021; Saunders & Kilvington, 2016).

National Building Research Organisation develops landslide susceptibility maps for landslide-prone areas in Sri Lanka, under the Landslide Hazard Zonation Mapping Programme. The hazard levels in these maps are simply an indication of the possibility of landslides in a particular area. The Landslide Hazard Zonation maps were intended to be used as a decision-making tool for the development of the central highlands in Sri Lanka. However, less attention has been paid to the Landslide Hazard Zonation maps in the implementation process of land use planning and land management practices in the landslide-prone area. On the other hand, the lack of standard procedures restricts the use of susceptibility and hazard-zoning maps. Therefore, unplanned human settlements have increased in the landslide-prone area thereby increasing hazards and risks (Jayaweera, 2008). Furthermore, NBRO has identified that poor governance and lack of awareness are the main problems faced by the authorities and decision-makers in settlement planning in the central highlands. Hence, there is an increasing need to introduce a proper land use zoning mechanism for a landslide to regulate the existing settlements and future development.

In a such a situation, this research attempts to make a significant contribution to the land use planning and development guideline in landslide-prone area of Sri Lanka. Therefore, main objective of the study is to reduce landslide disaster risk in Sri Lanka through land use zoning with disaster resilience guidelines.

The paper is organized as follows: the next section presents the literature review, discussion and results of the study are presented in the section three followed by the conclusion and recommendation in section four.

2. Literature review

The study closes the existing information gap by expansion of the scientific literature available on the planning process in the land use plans in Sri Lanka. Specifically, the relevant legal system related to land use planning in Japan was reviewed, and the basic concepts on the method of setting Yellow and Red Zone to be applied in high disaster risk areas are addressed. Finally, the section includes zoning plans as non-structure measures derived from the past literature.

2.1. Legal background of landslide mitigation in Japan

Land use planning is the process of regulating the use of land to promote prioritization of required social and environmental outcomes and improve the efficient use of resources (Nha, 2017). In the context of Japan, four main types of legislation have been enacted for the provision of powers necessary for landslide mitigation.

a. The Sabo Law (1897, Law No. 29)

In 1897, the "Sabo Law" was enacted for water and sediment control viewpoint, with the purpose of controlling harmful acts in sabo-designated areas and executing construction or maintenance of the “sabo” facility. “Sabo” is a Japanese term which means sediment control and prevention. Although the law addresses both structural measures and non-structural measures, more emphasis is placed on structural measures.

b. Landslide Prevention Law (1958, Law No.30)

The Landslide Prevention Act of 1958 provides the legal definition of a landslide as "sliding phenomena of a part of land due to groundwater and/or other factors, or moving phenomena involved to the sliding phenomena". The objective of the law is to “to prevent landslide and collapse of slagheap, with an aim to eliminate or mitigate the disaster caused by landslide and collapse of slagheap, and thereby to contribute to land conservation and stabilization of people's life.” The law prescribes drainage facilities, retaining walls, dams and other construction facilities as structure measures to prevent landslides.

c. Law for Prevention of Disasters due to Collapse of Steep Slopes (1969, Law No. 57)

In 1969, the Prevention of Disasters due to Collapse of Steep Slopes law was enacted “to take necessary measures for prevention of steep slope failure with an aim to protect people's lives from disaster caused by steep slope failure, and thereby to contribute to the stabilization of people's life and land conservation”. The law prescribes drainage facilities, retaining walls, dams and other construction facilities as structure measures to prevent of steep slope failure.

d. Sediment Disaster Prevention Law (2000, Law No. 57)

Due to rapid urbanization and intrusion of residential areas into the mountain foot area especially in Hiroshima in 1999, many residents were affected by the heavy rainfall. It was noticed that only structural measures prescribed under the above three acts were not sufficient in the current situation. Therefore, the government established a team of experts for comprehensive sediment disaster prevention, and after 1 year, the act was established. As a result, the Sediment Disaster Prevention Act was established in 2000 to promote non-structural measures. The purpose of the law is to design of sediment disaster warning areas based on the basic investigation, establishment of warning and evacuation systems, and land use and house-building regulation in the sediment disaster warning area. However, the law has been further strengthened by amendments in 2005, 2010, 2014 and 2017. Table 1 summarizes the amendments to the Sediment Disaster Prevention Act.

Table 1: Enactment and amendments of the Sediment Disaster Prevention Act

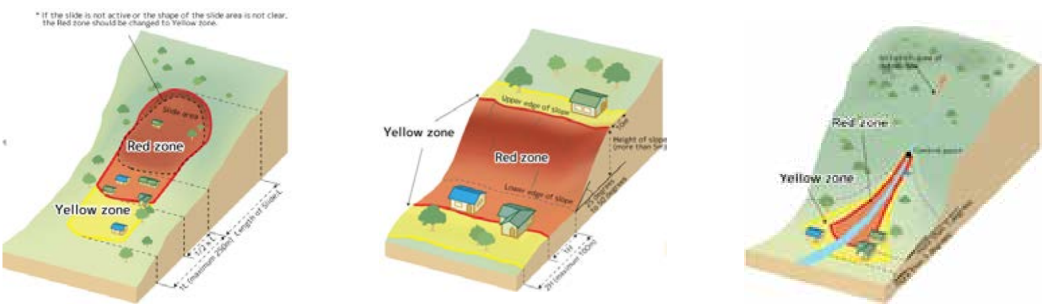
Time period and nature of amendment	Description of the requirement
May, 2005 Partial amendment	Distribution of the sediment-related disaster hazard map

November, 2010 Partial amendment	Operation of emergency investigation when a large-scale sediment-related disaster is about to happen
November, 2014 Partial amendment	Publication of the basic survey results, even before official designation by the Governor
	Announcement of sediment-related disaster alerts to the municipalities and residents
May, 2017 Partial amendment	Operation of evacuation drills and preparation of evacuation schemes at facilities used by people who need assistance

The Act specified the process of designating sediment-related Disaster Hazard Area (Yellow Zone) and Special Hazard Area (Red Zone). Figure 1 shows the process of designating of Sediment-related Hazard Areas.

Figure 1: Process of Designation of Sediment related Disaster Hazard Area (Kunitomo, 2003)

Under the Sediment Disaster Prevention Act, an area prone to sediment disaster is designated as a Sediment Disaster Risk Area (Yellow Zone), and an area where there is a higher risk of damage to residential houses and threat to residents is designated as a Special Sediment Disaster Risk Area (Red Zone). The primary purpose of designation of the two zones is to identify the affected area (flow path) when landslide occur in upper slope as well as to assess and manage the risk. The sediment disasters under the Act include three types of landslides, namely, a) Debris flow, b) Steep slope failure and c) Slide. Each sediment disaster type has its own definitions of the Yellow and Red Zones, which were based on the actual state of past sediment disasters and their damage situations. Figure 2 shows the Yellow and Red Zones of different types of sediment disasters.



a) Slide b) Slope failure c) Debris flows

Figure 2: Sediment Disaster types that predict from the Yellow/Red zoning concept (Sabo Publicity Center, 2001)

If an area is classified as a Yellow Zone, early warning systems should be established, and steps to raise the awareness of local people about sediment disasters should be taken. Furthermore, if the area is classified as a red zone, there is a severe risk of damage to the buildings and a threat to residents, thus, non-structural measures including development regulation should be applied based on the appropriate land use planning.

2.2. Non-structural mitigation measures

As mentioned above, more attention has been paid to non-structural mitigation measures at present, as it helps the community more effectively. "The main significance of landslide hazard management and mitigation has been largely identified due to adverse impacts on human lives and properties" (Ekanayake & Rathnasiri, 2021). Under the non – structural mitigation measures, development of hazard maps and land use zoning, establishment of early warning systems, conduct awareness programme, development of guidelines and regulations for steep slopes and cultivation of special plant species such as grass, bamboo, etc. on unstable slopes have been implemented (Sugathapala & Prasanna, 2012). Accordingly, land use management is a major part of the non-structural disaster mitigation measures.

"Hazard maps can be presented in a form that is fully understandable, with all affected populated areas, facilities and structures indicated and marked. Hazard zoning maps present hazard levels together with the probable intensity of magnitude in each hazard zone" (Andjelkovic, 2001). Many countries and municipalities have developed specific regulations that apply to landslides by overlaying hazard maps (Department of Natural Resource, 2014; Fell, et al., 2008). Therefore, land use zoning takes the outcome of the landslide susceptibility mapping and land use zoning regulation provides a direct advantage by restricting development for most hazardous in high-risk zones and confining other development activities to conditions depending on the degree of risk in the area (Australian Geomechanics Society, 2007). Presently, most of the local authorities do not have land use zoning plans or spatially deny any disaster risk reduction by law. Therefore, it is necessary for each local authority to have declared risk areas that should be developed according to the land use zoning plan (Jayaweera, 2008).

3. Results and discussion

Based on the above consideration, a proper zoning mechanism essentially used for landslide-prone areas in Sri Lanka to reduce the risk and enhance sustainability and resilience.

The Landslide Hazard Zonation Map (LHZ maps) developed by NBRO has main six categories, "Landslide occurred in the past", "Rock falls and subsidence", "Landslides are most likely to occur", "Landslides are to be expected", "Modest level of landslide hazard exists" and "Landslides not likely to occur". Out of these six zones, development should be taken place only in the safe areas that are demarcated as "Landslides not likely to occur". At present, due to the haphazard land use planning activities prevailing in the country, a majority of the high landslide hazard categories contains settlements. However, because the existing LHZ maps neither identify different types of landslides nor consider the affected area of various types of landslides, they cannot be used to properly assess the local, site-specific risk of an individual or different type of landslides. Due to the insufficient attention on these factors, the failure in implementation of land use planning guideline and related practices in landslide-prone areas have increased landslide hazard and vulnerability. Consequently, identification of different types of landslides and subsequent site-specific assessment of landslide risk including both initial and runout or affected areas of a landslide are increasingly becoming essential in landslide risk reduction. Therefore, the incorporation of Yellow/Red zoning concept is crucial to identify detailed and site-specific landslide hazard risk levels that can assist in promoting appropriate land use development at a community scale in the hilly areas. The Yellow/Red zoning is also utilized for understanding the flow paths and slope failure of each landslide type and identifying the possible land development type. Due to the hilly geomorphology and active rainy seasons, Kothmale Divisional Secretarial Division (DSD) is considered as one of the critical landslide-prone areas in Nuwaraeliya District, Sri Lanka. Therefore, Kothmale DSD was considered as a case study in this study.

Accordingly, the area was categorized into main four zones based on the Yellow/Red concept and Landslide Hazard Zonation Map, namely, “Restrict Zone”, “Control Zone”, “Warning Zone” and “Development Zone”. Table 2 indicates the four zones.

Table 2: Relevance with LHM and Yellow/Red zone categories

	Yellow/Red Zoning (Applied for the Y/R zoning prepared area)	Landslide Hazard Map (Applied for the remaining area)
Restrict Zone	Red Zone (Special Sediment Disaster Hazard Area)	Landslide have been occurred in the past
		Rock falls and subsidence
		Landslides most likely to occur
Control Zone		Landslides are to be expected
Warning Zone	Yellow Zone (Sediment Disaster Hazard Area)	Modest level of landslide hazard exists
Development Zone	Else	Landslide not likely occur

Since most of the Restrict Zone and Control Zone is placed in Red Zone, criteria/conditions should be developed to distinguish areas to be defined as Restrict Zone or Control Zone. The boundaries of these two zones can be decided based on the exposure at the sites, mainly the distribution of the existing houses and the topography. Where the existing houses are distributed and the slope is mild, the area is designated as a Control Zone.

3.1. Land use zoning plan

Land use planning is conducted by the planning agencies like Urban Development Authority (UDA), National Physical Planning Department (NPPD), Land Use Policy Planning Department (LUPPD), and Local Authorities. The descriptive land use plan is developed to enhance the future benefits of the area under the relevant Local Authority and to maximize the land utilization in the Local Authority. However, disasters will affect the area, either due to natural or man-made causes. Therefore, it is required to conduct planning in mitigating existing and future risk situations. A new land use zoning plan was developed for the Kothmale DSD area, overlapping the new Yellow Red zoning and the LHZ maps. Land Use Zoning Plan for Kothmale DSD is shown Figure 3. The four zones; Restrict Zone, Control Zone, Warning Zone and Development Zone are shown in the map. Accordingly, 40.06%, 12.19%, 27.18%, and 20.55% of land areas belong to restrict zone, control zone, warning zone and development zone, respectively. Also, the basic strategies to reduce landslide hazard/ risk of each land use zone are mentioned below.

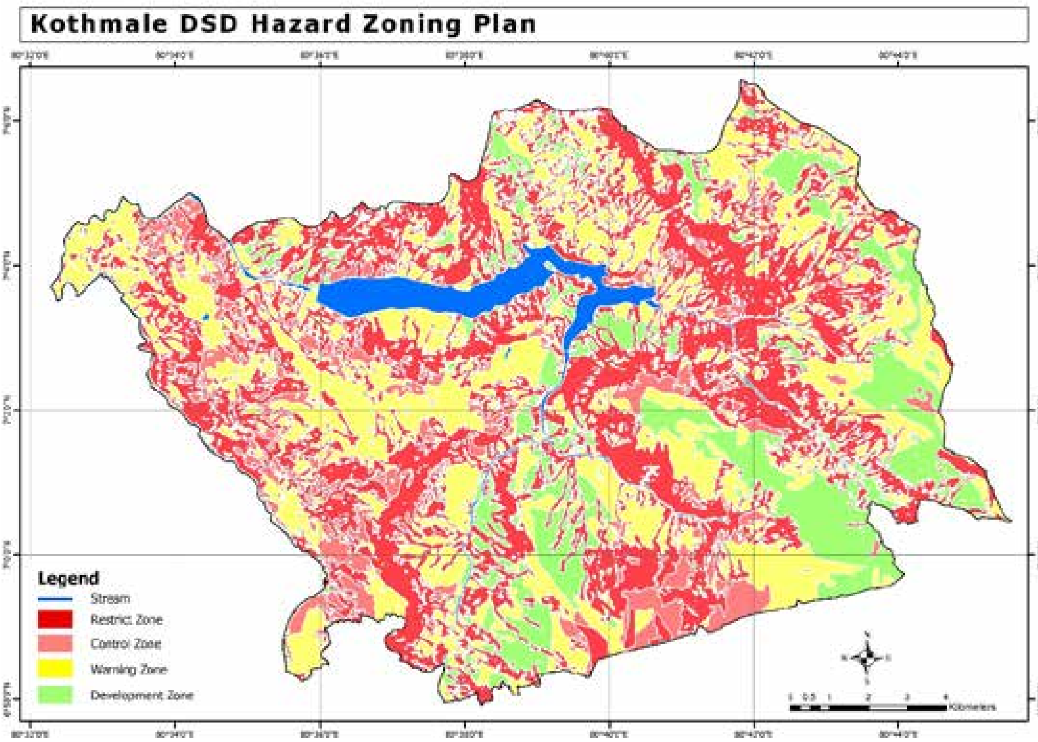


Figure 3: The Land use zoning plan

Any construction or development activity shall be prohibited in the Restrict zone as this zone has high probability of occurring landslide events. Any construction which is already in the Restrict zone should be relocated with proper investigations. This land area should be kept as a natural area and required to monitor the environmental conditions such as water flow and the hazard situation should be monitored in-detail. In the future, this area will be designated as a sensitive area to control all kinds of man-made influences. It is required to conduct detailed investigations and proper early warning systems for the upper catchments before converting the areas a green area.

The Control zone is considered as a high-risk zone due to the landslide events. Therefore, new developments such as residential, retail, office, and industry, should not be allowed in this zone. Existing developments are encouraged to resettle to Development Zone as the one in Restrict Zone. Where resettlement is difficult, the disaster risk reduction measures such as establishment of a proper early warning system will be applied. On the other hand, it is also possible to set a Buffer Zone between Restrict Zone and the Control Zone. One of the other uses of a buffer zone is to introduce tree lines as a debris barrier. It may assist in controlling debris flow to the

Control Zone to a certain extent and to create visual boundaries between the Restrict Zone and Control Zone at the sites.

Development activities are allowed in the "Warning zone" but they are required to follow the resilient construction guideline which was published by the NBRO (Hazard Resilient Housing Construction Manual, 2015). This zone can have different building densities depending on the risk levels. However, the entire zone should have a proper early warning system and continuous awareness programmes should be conducted for commuters and residents.

The Development zone is demarcated by considering the importance of the development activity and the existing hazard levels. This zone can be used to develop any kind of construction but should adhere to the guidelines which are provided by the planning agencies like UDA, NPPD, etc. Resilient construction techniques are not mandatory for this zone, unless the disaster management professionals identify the area as a disaster-impacted area. If so, the any construction should be adhered to the resilient construction guideline.

3.2. Possible land uses for the zones

The four zones can be used for planning existing human settlements and future development activities. The possible land types for each zone are considered, and Table 2 shows the allowed and prohibited land use activities in each zone. If any construction is located in the Yellow Zone (Warning Zone), it should follow the hazard-resilient housing construction guideline which was published by NBRO. According to this guideline, no construction is permitted on lands with ground slope is higher than 31^{o}, unless a risk assessment is obtained from NBRO and the construction is conducted based on the recommendations and conditions given in the risk assessment report. Further, depending on the slope angle of the ground, less than 11^{0}, 11^{0}-17^{0}, 17^{0}-31^{0}, and > 31^{0}, the site can be broadly categorized as no risk, low risk, medium risk and high risk, respectively (Hazard Resilient Housing Construction Manual, 2015).

Table 3: Proposed Land Use Category

	Proposed land use category			
	Development Zone	Warning Zone	Controlled Zone	Restricted Zone
Residential	Suitable for Use	Detailed Investigation	Not Suitable	Not Suitable
Retail & Commercial	Suitable for Use	Detailed Investigation	Not Suitable	Not Suitable
Office	Suitable for Use	Detailed Investigation	Not Suitable	Not Suitable
Industrial	Suitable for Use	Detailed Investigation	Not Suitable	Not Suitable
Parks/ Playgrounds	Suitable for Use	Suitable for Use	Detailed Investigation	Not Suitable
Agricultural	Suitable for Use	Suitable for Use	Suitable for Use	Detailed Investigation

4. Conclusion and recommendation

This study attempts to reduce landslide disaster risk in Sri Lanka through proposing a suitable land use zoning with disaster resilience guidelines. The Zoning Plan was categorized into main four zones, Restrict Zone, Control Zone, Warning zone, and Development Zone, based on the Yellow Red concept and Landslide Hazard Zonation Map. The four zones are indicated in the Kothmale DSD map and specific guidelines and possible land use are given for each zone. Restricted zone and Control zone should be free from the settlements as it has a high risk due for sediment disaster. The settlements in the yellow zone area should be strengthened by introducing resilient construction guidelines, and new developments should be encouraged in the development zones. The development of this land use zoning plan assists in reducing the risk of landslides by regulating the construction activities in the landslide-prone areas.

As this study is applied research, the findings of this study benefit the communities living in the landslide-prone areas and relevant decision makers. Therefore, it is recommended to refer this guideline and to implement the Land Use Zone Plan for local government with the cooperation of relevant central government agencies.

Acknowledgement

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Building Resilience amidst Economic Challenges

Analysis of the insurance process to compensate the damages to adjacent structures due to high-rise building construction in Sri Lanka

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Abstract

High-rise building construction is popular in Sri Lanka due to the lack of horizontal space in urban and semi-urban areas and the increasing demand for space in those areas. Hence the developers focus on vertical development and therefore, high-rise building development has become common nowadays. The construction process is complex and advanced and therefore various precautions are taken to avoid any adverse impacts on the surrounding built environment. This is becoming more complex due to the high density of built environment closer to the high-rise building development sites and structural instability of the existing construction. In this case, an insurance scheme is introduced and in case of any damage has taken place, a compensation process is followed for further assurance. Yet, there are many drawbacks and gaps in the process including claiming the insurance payment. Those gaps and drawbacks need to be properly addressed to smoothen the process and ensure the safety of the community living in the vicinity. Two case studies are discussed in this study to identify major gaps in the insurance process in Sri Lanka. The research findings indicated that there are major issues in (1) identifying the effective area for the pre-construction survey, (2) failing to follow a proper technical methodology in making decisions and, (3) faulty understanding of the process in the insurance and claiming procedure.

Keywords: Built environment, High-rise, Insurance scheme, Vicinity

1. Introduction

The damages to foundations and structures occur due to natural reasons including poor soil conditions, soil moisture, wind and earthquake effects, and tree routes. Similar to natural occurrences endangering structures, various man-made causes also contribute to drastic damages due to vibrational effects and other variations (groundwater table) to the natural environment. These activities include vibrations, demolition, dewatering, and excavations. When considering vibrational effects, specifically, using equipment for constructions that generate high vibrations such as blasting, drilling, and compaction of soil, etc. (Roberts, 2011). Moreover, activities related to piling, demolition, and the use of jackhammers may also contribute to the generation of the force and repetitive nature of vibration to the surrounding built environment (Blumenshine Law Group, n.d.). On contrary, excavations for basements also provide responses that are hard to predict and depend on several factors including soil type, water level, and the nature of neighboring structures. The surface settlement and lateral ground movement are the main excavation-related damages which are followed by the impacts to adjacent properties and the extent and severity of the impacts are critical for establishing proper earth retaining structure (Bryson & Kotheimer, 2011). Due to these damages and claims, irreversible effects could occur such as monetary damages and complaints, losing the development permit by the contractor, and destroying the contractor's and developer's reputation (Bailey & Levy, 2020).

Risks in construction projects including damages to the adjacent built environment are important to be mitigated or avoided due to the cost and time consumption it generates with the incident. Also, adopting safe construction practices is a timely requirement. But risks are not entirely mitigated as there can be unforeseen risks and therefore the general practice is to transfer the risk to an insurance scheme (Perera, Rathnayake, & Rameezdeen, 2008) and the widely used scheme is Contractors' All Risks (CAR) policy.

2. Research problem

The damages that can occur due to vibrational impacts during the construction of high-rise buildings include cracking, settling, and failing of foundations, structural failures, cracking of floors and walls (interior and exterior) and facades (interior), and roof damages (Yala, Bowers, & Lovenstein, 2022). These damages occur due to magnifying of some factors through vibrational impacts, such as inadequate water tightness, voids or cavities within the soil, defects in materials, ground settlement, and less monitoring and maintenance (Roberts, 2011).

To evaluate the extent and verify the damage, technical methodologies are followed on the construction site, by the management staff and technical staff.

a) Follow CEA pollution control guidelines to maintain the values at acceptable limits
b) Preconstruction survey (Crack survey)
c) Monitoring of water table during dewatering
d) Distance from the construction activity to damaged structure/ property
e) Method statements and monitoring plans and monitoring results of considered parameters

The main contractor appointed for the project owns the highest responsibility related to the completion of construction activities of the site, which are mentioned and assigned to them via construction contracts, laws and regulations in the country, and other local authority guidelines. In the normal scenario, the main contractor has a liability insurance policy to cover up damages that have taken place by mistake or negligence (Blumenshine Law Group, n.d.).

As a regulatory body of assessing the possible impacts to adjacent built environment due to construction of piling and basements, the National Building Research Organisation has received many complaints from neighboring communities on structural damages and issues of claiming for the damages. Further, it was observed that there is a controversy in of considering criteria for the insurance policy and claiming process. Hence, this research aims to identify the insurance policy for construction of high-rise buildings of the country and evaluate the compensation process if damage occurs. The main objectives of this research are;

- To analyze current insurance policy framework applicable for the construction of high-rise buildings in Sri Lanka
- To analyze the claiming process in case any damage takes place in the adjacent built environment due to the construction project
- To identify the gaps in the current procedure and provide recommendations to overcome the issues

3. Literature survey

3.1 Preconstruction survey

Preconstruction surveys are documenting the condition of the built environment located around the proposed construction site, before any construction activity commencement. For a development project with complex foundations and structural constructions such as basements, pile foundations, and permanent/ temporary earth retaining structures, especially when the construction is going on in a congested and high-dense area, the owners of the adjacent structures could complain that pre-existing cracks and damages were also occurred due to the effects of the construction activities in the development site. Therefore, the preconstruction survey is conducted as an assuring method for the developers to restrain from compensating for false claims (Bailey & Levy, 2020), and for minimizing any disputes and uncertainties that could occur if any damage has taken place to the existing built environment due to the project (Ben Engineering, 2022). Another objective of carrying out this survey is to assess the feasibility of the development project on its impact on the adjacent environment.

When a construction activity is going on in a site, which creates vibrations, either continuous or intermittent, the vibration waves could travel passing adjoining soil layers, through voids and cavities in soil strata, and cause damage to the surrounding built environment (Blumenshine Law Group, n.d.). Therefore, all possible impacts need to be addressed during the site evaluation stage of a development project and if any risk could be identified, construction methodologies to minimize or avoid the impact, monitoring process and necessary modifications need to be proposed and adopted for the development project.

3.2. Post-construction surveys

Post-construction Survey is not a mandatory document for a construction project and is done either after the completion of sub-structure construction or the project completion (Ben Engineering, 2022). This report is prepared to check for the condition of the adjacent built environment of the site after major structural work and compare the situation before and after construction and determine if there are any considerable changes occurred due to the construction activities. These changes include the expansion of existing cracks, formation of new cracks, deformations or settling of structures, etc.

3.3. Insurance process and claiming

In the Standard Bidding Documents (SBDs) by Construction Industry Development Authority (CIDA), required policies regarding insurance are mentioned (Nandasena, Hanifa, Zavahir, & De Seram, 2021). There are insurance policies that are compulsory and non-compulsory and the required policies vary as per the type of construction. Normally, as compulsory policies, public sector contracts include insurance for the assets of the project and third-party liability insurance, also.

As per the previous records, more than 85% of claims of the construction industry have been paid as third-party liability claims in Sri Lanka (Perera, Rathnayake, & Rameezdeen, 2008) and most frequent damages of third-party claims were due to damaging houses and boundary walls and the percentage is 94% of total third-party liability claims.

There can be 3 actions that are possibly processed when the insurance company received a submission for a claim, which are accepting and fully claimed, partial payment, and rejection.

Not only the completion of relevant documents accurately does not result in a full claim payment, but the process needs to be accurately followed and supplementary data need to be submitted accordingly to receive the whole amount depicted in the claim form. However, as per the records, rejected claim applications in third-party liability claims were more than 55%, both based on the damage and based on the source of risk categories (Perera, Rathnayake, & Rameezdeen, 2008).

For partial settlement of a claim, the most effective cause was the estimation by the insuring company to a lower value than that of the estimate by the claimant. Then, the wordings stated in the insurance policy need to be thoroughly referred to and followed before the request for a claim otherwise misunderstanding of the words in the agreement can lead to a reduction of the claim payment by the insurance company.

To obtain the total settlement of the claim, several methods have been followed by the contractor or the developer in the considered cases and considered previous studies. First, the estimated amount needs to be accurate as per prevailing market conditions and supplementary documents. Second, the developer or the contractor should consult the insurance company for the accurate method for submitting a claim document. Then, the corporation between the contractor and the insurance company needs to be responsive. Further, all details and information regarding the project and incident need to be informed to the insurance company by the contractor. Finally, if any negotiation has been done and a settlement was agreed upon, it should also inform to the insurer in due course (Perera, Rathnayake, & Rameezdeen, 2008).

4. Methodology

4.1. Research methodology

National Building Research Organization (NBRO) receives requests from developers for their building construction activities through Project Approving Agencies such as Urban Development Authority (UDA), Department of Coast Conservation and Coastal Resource Management (CCD), Central Environmental

Authority (CEA) and Sri Lanka Tourism Development Authority (SLTDA) for obtaining a Geotechnical Clearance from NBRO for the proposed development activities including pilling and/or deep excavation. The requirement is enacted by the UDA as per their newly published Gazette Clause No. 57 (3) c. of the Urban Development Authority Planning & Development Regulations 2021 Gazette No. 2235/54 published on July 08, 2021. The main objective of this Geotechnical Clearance is to assess impacts of a particular proposed development to adjacent properties and surrounding built environment especially during the construction of the substructure of the building.

The clearance projects received by NBRO in the year 2022 were considered for the study, and initial screening was done for projects which have already paid compensation for the damages to the adjacent built environment of the construction site. There were 4 projects which have followed the compensation process which were different from each other. After going through all required documents, respective officers who were involved in the compensation process were contacted, and required details were obtained as a "Question and Answering form". The questions directed to the responsive officers covered the following areas.

- Crack survey details obtained by the insurance company for the insurance process
- Claiming process
- Follow-up of the renovation of damaged structural components

In addition, the property owners of the adjacent structures of the same projects were also interviewed to identify their knowledge and awareness on possible damages that could take place and claiming process if an incident take place. The questions directed to them were designed to cover following areas.

- Knowledge of adverse impacts that could occur due to construction activities in the vicinity
- Alert on any structural changes due to vibrations induced by constructions
- Knowledge on advantages and effects of Crack Survey
- Claiming process

Further, previous studies with a similar analysis were reviewed to identify any related trends or methods within the process which have considered third-party damage claims.

4.2. Analysis of results

The focused result is to identify the current procedure followed by Sri Lankan developers, contractors, and insurance companies regarding the claim for damages in the adjacent built environment of a construction site. Then, possible rejections to the claims and their reasons were also discussed along with the suggestions to avoid those circumstances. In addition, information was collected to identify the existing gaps in the current practice.

5. Results and discussion

5.1. Current insurance policy framework

According to the previous literature and information gathered from the interviews, the following routine was identified as the current procedure followed in the insurance process for construction projects in Sri Lanka.

Contractors all Risks (CAR) Insurance is the insurance scheme that is applied and used in the construction industry in Sri Lanka to provide the required protection for work mentioned in the contract document, construction equipment, plant and machinery, and also third-party claims, which means risks associated since consignment are brought to the site until the project is completed are covered by this insurance scheme (Continental Insurance, 2022). Other than the provided coverage for construction work and related perils, the insurance covers third-party liability and related perils including bodily injury, property damages, vibration, removal or weakening of support and underground cables.

The insurance needs to be applied and taken by the developer, or main contractor including all subcontractors, and as per the companies providing the overage, this scheme covers "all risks" in a site, which includes unforeseen, unseen, accidental damage or loss except any damage excluded in the policy. When the main contractor is appointed for a construction project, the contractor applies for an "All risk policy" from an insurance company for the contract period, by submitting a set of documents including a contingency plan, a pre-crack survey from a reputed organization, and project contract. In most construction companies, the pre-crack survey is a mandatory document. The effective area to be considered for the survey is 40 m radius from the site boundary, but some insurance companies require 70 m radius, and some are not specified. After the submission of the required documents properly, the insurance company visits the site with its engineers and makes references to the location and adjacent properties. when there are house owners who did not provide any permission to perform the crack survey within their premises and did not let officers from the insurance company access the premises, then they take photographs of the external view of the house (with permission from the owner) and note down the situation.

In case a complaint is filed, or damage took place, the insurance company first checks whether the particular house was covered in the crack survey. If the house is covered, the damage is estimated by a reputed organization and the payment is done. If the homeowner has not given permission to do the crack survey on their house, and now it is cracked, then the officers from the insurance company compare the photographs they have taken before and after the complaint. If any change has taken place as per the photographs, partial payment is done (as proper inspection was not conducted for the property).

Most importantly, the insurance covers the damages that take place only within the area covered by the crack survey. Also, the payment is done as a third-party liability payment.

5.2. Claiming

First case study is a proposed housing scheme in Makumbura area. The apartment building is G+19 floors and the parking block is G+6 stories. As per the records, a crack survey has been conducted for an area covered by a radius of 50 m. When the

Geotechnical Clearance application was submitted to NBRO by the developer, a site visit was organized by NBRO officials, and as per the information received, one complaint has been received from a house owner of a nearby house. During the visit to the house, information received that this house was not covered by the crack survey, although it was situated within 50 m distance from the site. After the appearance of cracks, an estimation of the damages was done by the house owner and has submitted to the insurer for a claim. However, later it was informed that the claim was not paid by the insurer mentioning that the house was not within the considered crack survey area.

The second case study is a proposed apartment complex at Thalawathugoda. The apartment complex is having G+12 stories with no basement levels, and as per the records, the developer and the contractor have been changed from substructure construction to present condition. Previous developer has carried out a crack survey prior to commence substructure construction, but when the new developer has bought the land, piling has been completed and cracks have been appeared in two houses. However, the new developer had to compensate the damaged houses as there was no information available regarding the previous insurer, and no insurance scheme was yet applied for the project by the new developer.

Considering these two case studies, it can be clearly identified that there are considerable gaps in the insurance process, which brings losses not only to the developer but also to the neighboring property owners.

5.3. Gaps identified in the current procedure and recommendations to overcome the issues

Table 1: Identified gaps in the current procedure and recommendation

Identified Gap	Recommendations to overcome the issues
The crack survey area is not always decided depending on a technical criterion or an analysis and is normally conducted based on the experience and practice. Some insurance companies mention a minimum crack survey radius, but the majority accept a report which is done by a reputed organization. Further, no claim could be obtained for a property that is situated beyond the considered crack survey area.	Decision regarding the area required to undergo the crack survey needs to be taken upon a sound technical basis. Technical decisions based on a technical analysis or a study need to be prioritized during the whole process, even from the site surveying and design for the proposed development. In this scenario, either the project consultant or the specialists' team of the insurer needs to decide. The feasibility study should be made compulsory and after recognizing the surrounding built environment through the study, the design can be completed to comply with the existing condition.
The property owners of the adjacent built environment are not informed about the possible circumstances resulting of not granting permission to carry out the crack survey in their premises. Also, if a high-rise construction work is proposed to be initiated in the vicinity, people do not consider adverse impacts it could bring such as settlements and displacements.	The involvement of the property owners of the vicinity needs to be improved, they should be properly informed on the reason for conducting the crack survey and the consequences if the permission is not granted to enter their premises. Also, some people are not aware about the possible accidents which might occur even after slight damages take place in their houses. It was observed that they tend to be attentive and take necessary actions only after a severe incident

	occurs. Further, they should be informed to check on any damage that has taken place due to the construction and inform the developer, or a relevant body immediately, before the situation escalate into any serious damage.
Several contractors are involved in the different phases of construction of a project therefore when a damage has taken place due to initial construction work, there is no clear responsible party or process to evaluate damages and request claims for damages.	The identification of damages occurred due to a certain phase need to be identified at the same phase, and request of the claim also need to be completed prior to handing over the project to the next contractor. It is recommended to complete a post-construction survey after each construction phase which are having high possibilities of damaging adjacent built environment (Eg.: Piling and Excavation), to ensure any adverse impact was not taken place due to the construction and proceed with any claims for further actions.
Developers and contractors are not fully aware of the insurance process and application of claims. Therefore, the possibility of receiving a full claim is reduced and the highest possibility is either receiving a partial payment or a rejection for the claim.	Proper awareness should be provided for the developers and contractors regarding the entire process followed by the insurance company, and regulations of the company regarding requesting claims. The wordings stated in the insurance policy need to be thoroughly referred to and followed before the request for a claim is forwarded to the insurance company.
Preparation of false estimates, and/or preparation of estimates of the damage which does not comply with the requirements of the insurer.	
The hidden problem is that although a full claim or a partial claim is paid to the damaged property, there is no proper way of monitoring the renovations, and quality of renovations. When the payment is done as a one-time payment by the insurer, no responsibility is borne by the insuring company to check on the status of repairing the damages.	When a claim is paid to the damaged structure, there should be a proper mechanism to monitor the progress and quality of the renovation process. Therefore, any future confusions and unnecessary financial losses would not take place, and safety of the occupants could be ensured and maintained.

6. Conclusion and recommendations

The main problem associated with the process is taking decisions based on the practice or previous experiences while not considering site- specific technical aspects in the decision-making process and lack of awareness about the whole process. Further, the developer focuses only on profit and development, but not on the surrounding area. Therefore, the use of machinery and designs may not comply with the surrounding built environment. On the other hand, the involvement of the neighbors in the process is not at satisfactory level. Certain individuals in the neighboring areas do not permit to conduct the crack survey on their premises and later when an incident takes place, request claims via complaints.

Technical decisions based on a technical analysis or a study need to be prioritized during the whole process. However, the outcome of any development should benefit the country, and it should be satisfactorily ensured that the health and safety of the general public are met, along with less or no environmental pollution. Therefore, successful achievement of an equilibrium between development goals and environmental and public considerations needs to be highlighted throughout the construction process. For that, the formation of new regulations by the government and providing amendments to existing regulations should be done after conducting proper studies. The feasibility study should be made compulsory and after recognizing the surrounding built environment through the study, the design can be finalized and comply with the existing condition. Even the selection of safety precautions, machinery, and equipment could be selected to minimize and avoid any possible harm to the existing condition of the vicinity.

According to the previous studies, the prevailing regulations are providing the right to the developers to damage the vicinity and request claims afterward. However, a suitable mechanism needs to be implemented to avoid possible causes of damage. The process may include a design for the development which complies with the adjacent built environment, machinery and equipment to match with the surrounding condition, and precautions such as monitoring to avoid each slight damage that could occur due to any activity done in the construction site. Preparation of a site-specific contingency plan to address and rectify any abnormal conditions in the ground, water level, and any other aspect, and damages to any adjacent structures need to be done before commencing any activity on the proposed site. Further, Alert, Alarm, and Action limits for each monitoring parameter relevant to each construction stage should be specified together with proposed actions for rectification, and readiness of any required resources and machinery should be ensured on the site.

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Building Resilience amidst Economic Challenges

A framework for evaluating disaster resilience of code-based building designs in Sri Lanka

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Abstract

Sri Lanka has prioritized designing disaster-resilient buildings to withstand more intense and frequent cyclones triggered by future climate change and disastrous earthquakes generated by continuous tectonic plate movements. However, the current design practice in Sri Lanka faces a grandiose challenge in designing disaster-resilient buildings. To date, the degree of disaster resilience of the code-based building designs in Sri Lanka has not been subjected to critical evaluation. Therefore, it is a timely need to investigate the effectiveness of design codes in designing disaster-resilient buildings in Sri Lanka. This paper proposes a novel framework to evaluate the degree of disaster resilience of code-based building designs. The workflow of the framework is demonstrated through an analysis of a three-story school building designed according to Eurocodes. The wind performance of the school building was evaluated using Non-linear Static Pushover Analysis and using a wind performance objective matrix. The seismic performance was evaluated by conducting Non-linear Dynamic Time History Analysis, Incremental Dynamic Analysis, and combined with fragility assessment based on a seismic performance objective matrix. The results revealed that the Eurocode-based design of the school building has a significantly larger base shear capacity than that induced by the wind with the 1700-year return period. Compared to the wind load, the expected base shear of a seismic loading with a 949-year return period is considerably larger but still does not exceed any performance criteria. This study, therefore, indicates the adequacy of Eurocodes to design low-rise buildings similar to the school building in this study with disaster resilience qualities.

Keywords: Disaster resilience, Code-based design, Pushover analysis, Time-history analysis, Fragility assessment

1. Introduction

Disaster-resilient buildings are an ultimate challenge for design codes and standards because these buildings must be stood against extreme external loadings without exceeding the load capacity of critical structural members. Designing disaster-resilient buildings in Sri Lanka has become a priority because the relentless process of climate change increases the frequency and intensity of cyclones, and the continuous tectonic plate movements impose a great threat of disastrous earthquakes – two natural disasters likely to occur in Sri Lanka. However, to date, building design codes have not been subjected to critical evaluation for their degree of disaster resilience in the Sri Lankan context. As a result, the degree of disaster resilience of special-category buildings such as school, university, and hospital buildings, designed according to codes and standards is unknown to designers, and researchers. Therefore, it is a timely need for a framework that critically evaluates the degree of disaster resilience of buildings that were designed following building design codes and standards.

2. Proposed framework for evaluation of disaster resilience of code-based buildings

This study proposes a novel framework to evaluate the degree of disaster resilience of code-based building designs. In this framework, lateral loading on buildings is considered as the major loading. Lateral loads are assumed to be induced by cyclones and earthquakes. When a building is subjected to extreme lateral loadings due to a disastrous cyclone or earthquake, buildings might sustain structural and non-structural damages, undergo prolonged downtime, and incur massive repair costs. Given the significant impacts of these three factors on building operation, safety, and maintenance, they have been used as the main measurements in estimating the degree of disaster resilience of buildings. In other words, a building with satisfactory disaster resilience should sustain minimum structural and non-structural damages, quickly return to normal operation, and incur small recovery costs after a natural disaster. Despite many facets of disaster resilience, the proposed framework limits its scope to evaluate the performance of the structural frame of buildings in an event of a cyclone or earthquake as an indicator of the degree of disaster resilience. Figure 1. summarizes the major steps of the proposed framework.

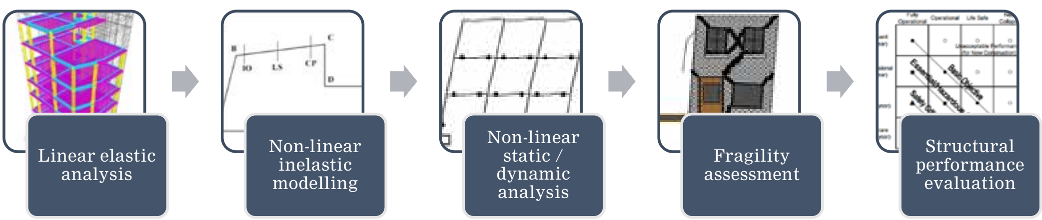

Figure 1: Main steps of the proposed framework

The succeeding sections provide a detailed explanation of the framework and illustrate the outcomes of each main task for the case study.

3. Case study

A school building, assumed to be designed with disaster-resilient features, is taken as a case study for demonstrating the workflow of the proposed framework. Table 1 shows the location, dimensions, and basic design parameters of the school building.

Table 1: Basic details of the school building

A) Building Description	
A.1) Location	Colombo
A.2) Type of structure	Multi-story reinforced concrete frame
A.3) Type of roof	Reinforced concrete slab
A.4) No. of stories	Three (Ground floor + two upper floors)
A.5) Story height	3.0 m
A.6) Plan dimensions	31.0 m × 7.5 m

3.1. Linear elastic analysis

The linear analysis evaluates linear relationships between applied forces and structure responses. In this framework, linear elastic modeling and code-based design are employed to determine structural member sizes and the reinforcement requirement of the building of interest. In this study, the structural analysis of the school building was conducted using SAP2000 software, and the structural design was carried out using the relevant provisions given in the Eurocodes and Sri Lankan National Annexes. Figure 2. shows the three-dimensional finite element model simulated in SAP2000.

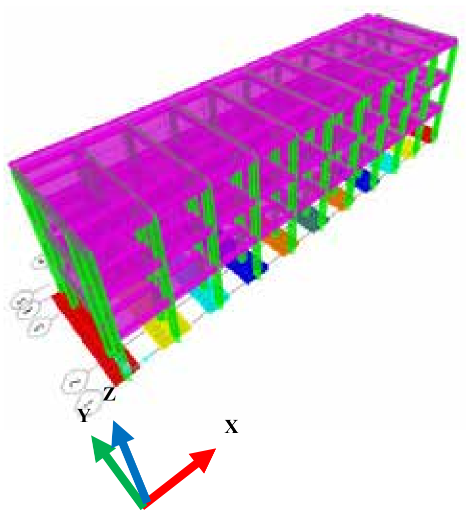

Figure 2: Three-dimensional (3D) finite element building model in SAP2000

3.2. Non-linear inelastic modeling

The non-linear analysis assesses how building non-linearly responds to applied forces. In this framework, non-linear analysis is proposed to test the building responses under extreme lateral loading. This study simulated a non-linear model of the school building in PERFORM3D software. The non-linear properties: moment-curvature curves and P-M-M (Axial force – Major axis bending moment – Minor axis bending moment) interaction curves of the members were computed as specified by the American Society of Civil Engineers (ASCE) in ASCE 41 – 13 (ASCE, 2014) code provisions and cross-sectional analyses in the SAP2000 section designer. Figure 3. (a) and (b) show a moment-curvature curve, and a P-M-M interaction curve developed for a beam and a column in this school building.

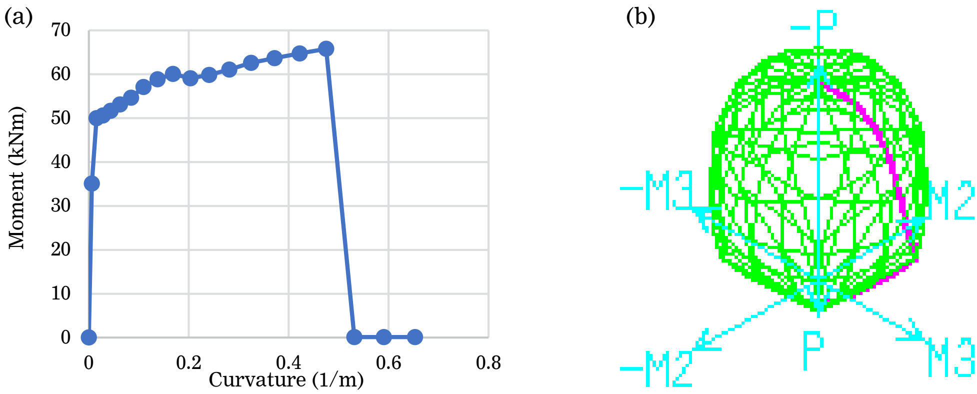

Figure 3: (a) Moment curvature curve of 225 mm × 375 mm beam; (b) P-M-M interaction curve of 350 mm × 350 mm column

3.3. Non-linear static pushover analysis

Non-linear Static Pushover Analysis (NSPA) estimates the structural performance of buildings under static lateral loading. In the pushover analysis, the school building was subjected to a monotonically increasing lateral load, which was vertically distributed along the building height as recommended by the Eurocodes. The pushover curves were developed based on the relationship between the base shear-induced due to the monotonically increasing lateral load, and the roof displacement. In this framework, NSPA was employed to evaluate the performance of the school building under wind loading. Figure 4. (a) and (b) show the pushover capacity curves obtained for wind loads applied in the *x*-direction and *y*-direction of the school building.

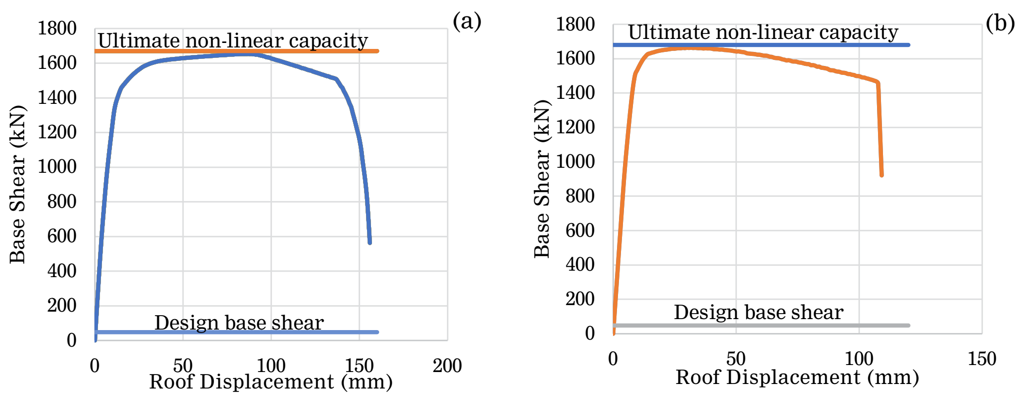

Figure 4: (a) Pushover capacity curve for x-direction response; (b) Pushover capacity curve for y-direction response

3.4. Non-linear dynamic time history analysis and incremental dynamic analysis

The Non-linear Dynamic Time History Analysis (NTDHA) combined with Incremental Dynamic Analysis (IDA) provides more reliable structural performance predictions under seismic loading compared to Non-linear Static Pushover Analysis (NSPA). The IDA curves can be developed based on the relationship between the intensity measurements and the engineering demand parameter. In this study, pre-recorded earthquake time histories were scaled to match the seismicity in Sri Lanka by using a ground motion scaling software.

NDTHA and IDA are employed in this framework to examine the probable structural response of the designed model against ground motions with different intensities. The framework chose Peak Ground Acceleration (PGA) and roof displacement as the intensity measurements, and the engineering demand parameter, respectively. A set of 20 ground motions was selected from the Pacific Earthquake Engineering Research (PEER) Centre database (PEER Ground Motion Database - PEER Centre, 2013) based on the criteria specified in FEMA P - 695 (FEMA, 2009) by the Federal Emergency Management Agency (FEMA). Then, the selected ground motions were matched with the target response spectrum of Sri Lanka by using SeismoMatch software. Figure 5, and 6 show the target response spectrum, original acceleration time histories, and matched acceleration time histories, respectively.

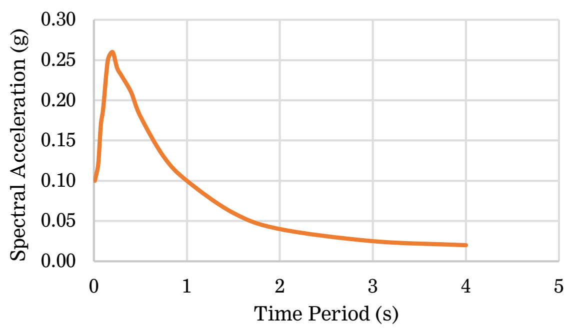

Figure 5: Target response spectrum of Sri Lanka

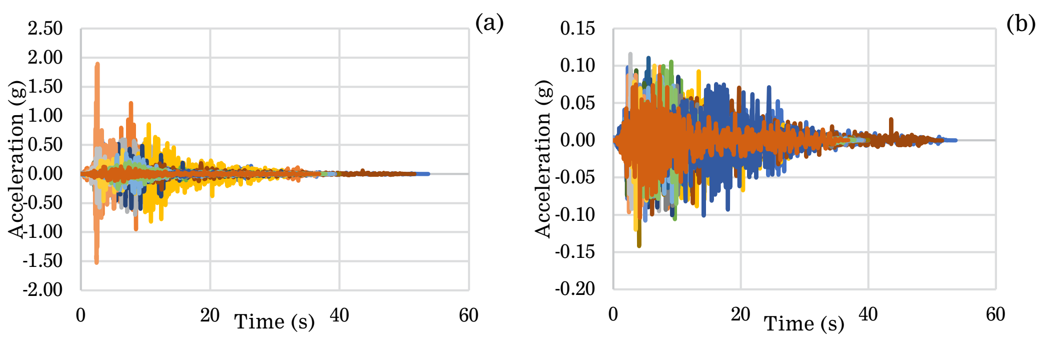

Figure 6: (a) Original acceleration time histories; (b) Matched acceleration time-histories

After that, matched acceleration time histories were scaled to different PGA and the IDA curves were obtained through the NDTHA carried out in PERFORM3D software. Figure 7 (a) and (b) show the IDA curves for the *x*- and *y*-direction response of the designed model.

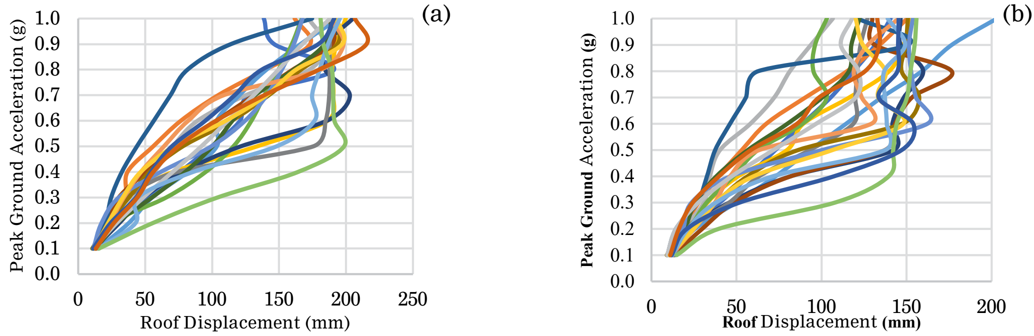

Figure 7: (a) IDA curves for X-direction response; (b) IDA curves for Y-direction response

3.5. Fragility assessment

The fragility assessment shows the exceeding probability of structural damage levels due to external loading. Fragility curves, the output of the fragility assessment, can, therefore, assess building performance against external forces. In this study, three damage limits: operational, life safety, and near collapse associated roof drifts as a measurement of structural damage were considered for developing fragility curves as recommended by the Structural Engineers Association of California (SEAOC, 1995). The corresponding roof drifts at the operational, life safety, and near-collapse damage limit states are 0.5%, 1.5%, and 2.5%, respectively. Figure 8 (a) and (b) show the fragility curves for the *x*- and the *y*-direction response of the school building developed by using the IDA curves derived in the previous stage of the framework.

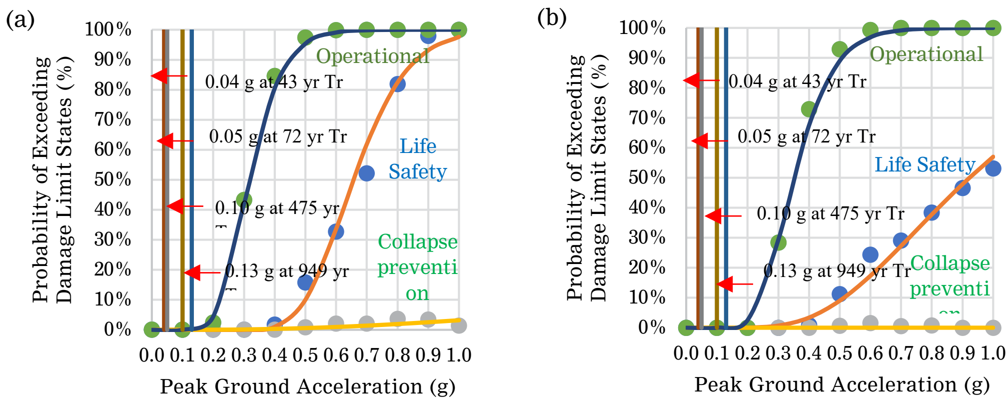

Figure 8: (a) Fragility curves for X-direction response; (b) Fragility curves for Y-direction response

3.6. Disaster resilience evaluation

The degree of disaster resilience of a code-based design can be evaluated with reference to the resilience rating systems, which are independent of building design codes. In this study, the wind performance objective matrix proposed by Griffis et al. (2013), and the recommended seismic performance objectives specified by the Structural Engineers Association of California (SEAOC, 2000) were chosen to evaluate the degree of disaster resilience of the school building. Figure 9 (a) and (b) show the performance objective matrices employed in this study.

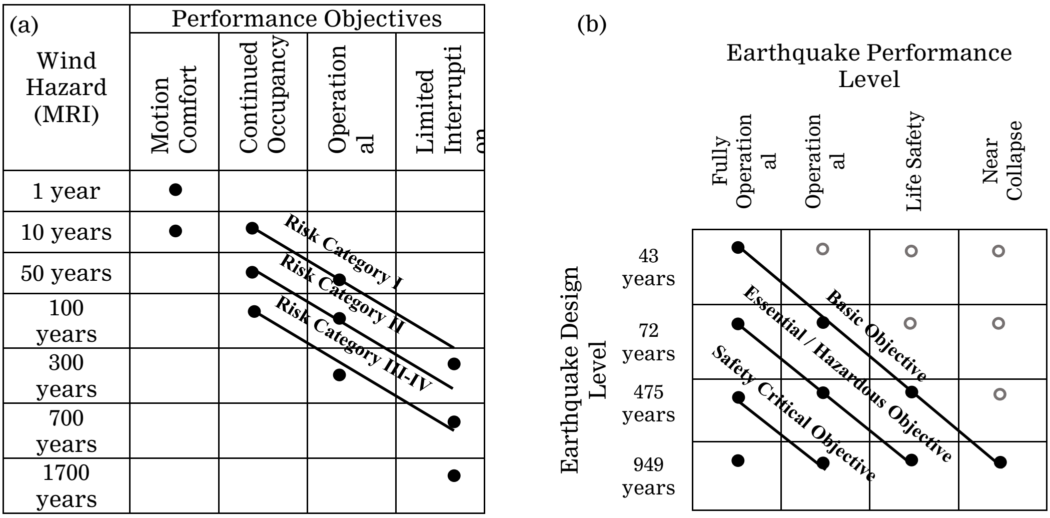

Figure 9: (a) Wind performance objective matrix (Adapted from Griffis et al., 2013); (b) Recommended seismic performance objectives (Adapted from SEAOC, 2000)

Accordingly, it is mandatory for a disaster-resilient building to achieve the performance objectives; continued occupancy, operational, and limited interruption in the presence of cyclones with return periods of 100 years, 300 years, and 1700 years, respectively. In a catastrophic earthquake, a disaster-resilient building should stay within the performance objectives; fully operational, and operational after it exposed to earthquake with return periods of 475 years, and 949 years.

4. Discussion

According to the pushover capacity curves obtained in this study, it is evident that the ultimate non-linear capacity of the school building designed according to the Eurocodes is significantly higher than the design base shear at a 1700-year return period. In fact, the building has a linear elastic behavior even against a wind with a significantly large return period of 1700 years, which is the maximum return period considered for the wind performance objective matrix. According to the fragility curves derived in this study, the school building does not exceed any performance objective; operational, life safety, and near collapse during an earthquake event with a 949-year return period, which is the maximum return period considered in the chosen seismic performance objective matrix for this study.

5. Conclusion

This study proposes a novel framework by combining linear elastic analysis, non-linear inelastic modeling, non-linear static/dynamic analysis, fragility assessment, and structural performance evaluation. The effectiveness of this framework was demonstrated by evaluating a three-story frame building, which was designed according to the Eurocodes and assumed to be with some disaster resilience qualities.

The proposed framework confirmed the building's disaster resilience, which did not exceed any performance objective for wind and earthquakes with the maximum return periods recommended in the resilience rating systems. Although the findings of this study indicate the adequacy of the Eurocodes to design buildings with disaster resilience qualities, it should be confirmed by analyzing high-rise buildings and using other performance objectives such as the life-cycle cost.

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Building Resilience amidst
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Development of test methods and specification for coir geotextiles

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Abstract

Coir fibre is a widely available bio-degradable material in Sri Lanka which is used to produce biodegradable products for local and international markets. Coir geotextile is the main coir product, manufactured using hand-twisted yarn and machine-spun twine. It is used as a blanket to prevent soil erosion. Nevertheless, there is an issue of local manufacturers being unaware of applicable test methods for coir geotextiles and the unavailability of standardized methods for determining physical and mechanical test parameters. Further, it was found that the Indian Standard IS 15868 (Parts 1 to 6) specifies test methods for six test parameters, but considering the locally manufactured geotextiles, these do not cover the requirements. Therefore developing test methods for physical and mechanical test parameters and observing the performance of coir geotextiles would be beneficial for the coir base industries. The main application of coir geotextile in Sri Lanka is used as a soil erosion blanket and media for plant growth at landslide mitigation projects. In this study, identifying the factors that affect plant growth and the inter-relation with coir is essential. All the test methods developed to determine tensile strength, eye size, thickness, electrical conductivity and unit weight of the coir geotextile are reported. As the main consultant of the landslide mitigation projects in Sri Lanka, the National Building Research Organization has developed a guideline for the testing and application of coir geotextile based on the findings of this study.

Keywords: Coir geotextile, Tensile strength, Electrical conductivity

1. Introduction

With a coconut crop of over 3 billion nuts per year, Sri Lanka has produced coir fibre and a wide range of coir fibre products. The coir fibre industry is one of the most celebrated traditional crafts of Sri Lanka. It is a unique and significant cottage industry, particularly in the southern coastal belt of the traditional home of coir products in Sri Lanka (H.S. Rohitha Rosairo, 2004). Sri Lanka produces two kinds of coir fibre, identified as "brown fibre" and "white fibre," extracted from coconut husks. This differentiation is linked with the raw material and processing techniques applied to achieve the required physical qualities. Brown fibre is extracted from the mature brown-coloured coconut husks using the traditional "Ceylon drum", in which the long and coarse bristle fibres are separated. Bristle fibre is cut into required lengths to satisfy buyers' needs and is exported in natural, dyed, or bleached form.

Considering the application of the coir fibre, the use of coir in erosion control became a major innovation; the fibres mesh well with the soil and prevent the topsoil from washing away during storms. While being used in industrial and domestic applications, coir is widely used for woven geotextile, stitched erosion control blankets, vegetation fascines, roof greening, and sediment control drainage.

1.1. Background and Significance

The local manufacturers are unaware of applicable test methods for coir geotextiles, and standardized methods could not be found for testing Tensile Strength, Electrical conductivity, and other test parameters. Due to this reason, they are not able to improve the quality of their manufacturing process. The unavailability of required specifications and test reports for the material adversely affects the coir industry in export markets.

1.2. Literature review

Coir geotextile is a prominent geotextile with natural mainly applied to temporary soil reinforcement and control of erosion. It is a biodegradable natural material with a structure that is highly crystalline. Compared to other natural fibres, the high lignin content leads to higher, more durable, and slow bio-degradation. Coir has the highest tensile strength in any natural fibre and retains much of its tensile strength when wet. It is also long-lasting, with a service life of 4 to 10 years in the field. In its capacity to absorb solar radiation, Coir resembles natural soil. This means that, as often happens in the case of synthetics, there is no chance of excessive heating. The advantages of coir geotextiles for hill slope stabilization are analyzed by evaluating different parameters such as retention of soil moisture, organic carbon, vegetative growth, etc. Installed in the soil, coir fibre helps to increase the soil's organic content and thus can promote vegetal development. Geo-mechanical and soil-hydrological effects are discussed as two major beneficial effects of vegetation on slope stability. Coir geotextiles help to shield the seeds and surface soil from flooding away in the initial stage as erosion control is applied and the final stabilization of the slope is accomplished by the roots of vegetation and soil consolidation. (Hao Wu, 2020)

Considering available test standards, Indian standards IS 15868 specify test methods for natural fibre geotextiles, including common parameters such as mass per meter run, thickness and mesh size. However, it does not cover important parameters such as tensile strength and electrical conductivity (EC). Also could not be found other international standards as well. The electrical conductivity (EC) is an index of salt concentration and an indicator of the electrolyte concentration of the solution. The EC of the nutrient solution is related to the ion concentration in the root zone available to plants. The optimal EC is specific to crops and depends on the conditions of the environment. Electrical conductivity due to moisture absorption of natural fibre is one major concern in outdoor applications. There is no measurable electrical conductivity in the dry natural fibre composite. After absorbing moisture from the atmosphere or any other means, natural fibres impart electrical conductivity, which is undesirable even though it is deficient. This conductivity increases with the amount of loading of the fibre and does not depend on the orientation of the fibre matrix. Growing substrate or medium serves as an environment for a plant's root system to grow and function. The chemical properties of the substrate, such as pH and conductivity, must be suitable for the crop you expect to grow. Good quality coir is essential for crops to achieve optimal growth. So, before using it, it is necessary to measure the conductivity to determine if the geotextile of coconut coir fibre selected is suitable for growing crops.

2. Methodology

Since this matter is directly related to the coir manufacturing industry, it was decided to identify their actual requirement as an initial step. Apart from that, the design requirements of the coir geotextile for the landslide mitigation works were studied by the NBRO geotechnical engineers. Accordingly, a priority list of tests and studies was identified. The sampling of material is a key factor in testing. Therefore, material purchasing for the trial testing was done from the selected three manufacturers. During the process of purchasing, three types of samples were purchased from all three manufacturers based on their unit weight. Those samples were tested with available and developed test methods, and the most suitable methods were selected as the standard test method.

2.1. Determination of mass per unit area

The mass per unit area is a key test parameter of the coir geotextile because all the properties of the product and practical applications of the products are based on this parameter. There are three different unit weights available in the market, i.e. 400 gsm, 700 gsm and 900 gsm. The principle of calculating the mass per unit area is dividing the measured weight in grams by the calculated area of the sample. The specimens should be cut in such a way that they represent all the material to be tested. Three specimens were cut to a nominal size of 400×400 mm^2 from randomly selected locations of the sample. The area of each specimen was determined to an accuracy of 0.5 per cent. Each specimen was weighted to an accuracy of 0.1 per cent. The mass per unit area of each specimen was calculated and expressed in gm^{-2}.

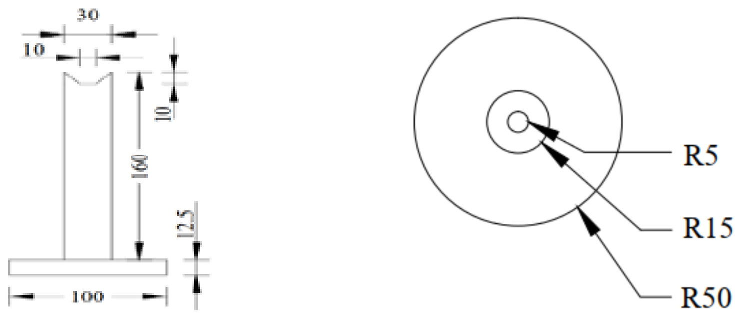
2.2. Determination of thickness

The thickness of the geotextile is measured under pressure for the synthetic geotextile. The recommended pressures are 2 kPa, 20 kPa and 200 kPa, given by a pressure foot. First, the test method used for synthetic geotextiles was tried for coir geotextiles. But the area of the pressure foot was not sufficient for the coir geotextile. Then, new pressure feet were designed with 100 mm, 110 mm and 120 mm diameters for the bottom area (see Figure 1 and Table 1). However, a 100 mm diameter foot was selected due to the easy handling of testing. Using this foot, 2 kPa pressure was applied to the sample.

Table 1: Calculation of foot pressure and comparison with the available foot pressure

Physical parameter of the pressure foot	Designed			Available
Suggested diameter for the pressure foot (mm)	100	110	120	56.5
Weight of the foot (kg)	1.600	1.936	2.305	0.511
Total volume of materials(cm^3)	203.87	246.69	293.58	65.08
Steel Bar Height (mm)	150	150	150	76.25
Steel bar diameter (mm)	30	30	30	24
Steel bar volume (cm^3)	105.98	105.98	105.98	34.48
The volume of pressure foot (cm^3)	97.90	140.71	187.60	30.60
Height of pressure foot (mm)	12.47	14.81	16.60	12.21

Ten specimens were cut from a sample, which covers the whole area of the sample. The specimen size is 200×200 mm^2. Then the specimens were tested by applying pressure for 30 seconds and measuring the thickness using a dial gauge (Minimum reading of 0.01mm) that measures the difference between the zero-plate and the pressure foot.



(a) (b)

Figure 1: (a) Designed pressure foot – Side view; (b) Designed pressure foot – Plan view

2.3. Determination of electrical conductivity of coir fibres

As a principle for this test, the 1:2 (V/V) Dilution Method was used. The electrical conductivity measurement of coir fibres was taken by using the electrical conductivity meter. The sample preparation was done by hand, and small pieces of coir fibre samples were cut manually to get accurate readings. Then distilled water was added to these coir geotextile samples, sufficient to cover the samples with extra distilled water (see Fig.2). After the 30 min time, the sample solution was extracted using filter paper and measured the electrical conductivity using a conductivity meter.

(a) (b) (c) (d)

Figure 2: (a) coir particle ; (b) dilution with distilled water; (c) Filtering; (d) measure EC

2.4. Determination of tensile strength

ASTM D4595 specifies tensile strength for woven fabrics, nonwoven fabrics, layered fabrics, knit fabrics, and felts geotextiles; hence it cannot be adopted for coir geotextiles due to larger mesh size. Most geotextiles can be tested by this test method. Some modification of clamping techniques may be necessary for a given geotextile depending upon its structure. Accordingly, two different clamping attachments were used during testing. The test specimens were prepared and tested according to different clamping techniques and sample sizes (see Fig. 3). By using trial and error, the most suitable clamping technique was selected to measure the tensile strength of the coir fibre geotextile sample collected. Five modified test methods were tested to select the most suitable Clamping method, and the sample size to measure the tensile strength of Coir fibre geotextiles is as follows.

a) Sample size of 200 mm×200 mm; Crossing edges bound with thread or wire and measuring the tensile strength.
b) Sample size of 500 mm×500 mm; without edge binding
c) Sample size of 400mm×400mm sample size without edge binding
d) 200mm×200 mm Sample size and tie up with own rope of the sample
e) 300mm×200 mm Sample size and tie up with own rope of the sample

However, the 200 mm×200 mm sample size was identified as the most suitable method for tensile testing during the trial and error testing session. If it is difficult to keep the shape of the sample until the testing, either the method of tying with thread/wire or tying up with the rope itself is accepted. Then all the samples were tested using one of the above-selected methods. Ten numbers of specimens were tested per sample for both machine direction and cross-machine direction. Tensile strength is calculated by dividing the maximum load obtained during the test by the width of the specimen.


Figure 3: Two clamping methods used

2.5. Determination of eye size

Eye size is an important test parameter for erosion control and vegetation application. However, many variations were observed during the testing, which will highly affect other physical test parameters. To obtain a better result, ten different locations covering the whole sample were tested and took the average of them.

3. Test results and discussion

This study mainly focuses on one special coir product, coir geotextile. According to the developed test method, many issues were identified in the production process and the quality of the end product of coir geotextile. The summary of test results obtained for samples from three manufacturers is given in this section.

3.1. Eye size and Mass per unit area test parameters

Table 2: Average test results of eye size and mass per unit area

Manufacture	Sample type based on gsm value	Average results of mass per unit area test (gm^{-2})	Average results of eye size test (mm×mm)
Manufacture 1	400gsm	348.71	38×35
	700gsm	606.56	26×25
	900gsm	905.62	19×19
Manufacture 2	400gsm	372.42	40×34
	700gsm	624.22	24×24
	900gsm	908.21	19×17
Manufacture 3	400gsm	351.24	39×36
	700gsm	614.25	26×26
	900gsm	895.24	19×20

Both eye size and mass per unit area properties depend on each other. Therefore, varying one parameter will affect the other. The main issues identified in the above parameters were noncompliance of test results with the manufactures data sheets. Some of them have significant variations. Most of these issues are due to the uncontrolled manufacturing processes of coir geotextile. These parameters affect the final quality of the product considerably. When the tensile strength of the coir geotextile is considered, it directly depends on the eye size and mass per unit area. Therefore, the above parameters must be controlled during the manufacturing for the quality final product.

The test method used to determine the eye size and Mass per unit area of the coir geotextile during the above study can be finalized because it gives enough accuracy and a clear idea about the test parameter. Detailed test methods for the above test parameters with sampling criteria are included in the guideline developed by NBRO.

3.2. Thickness of coir geotextile

The first trial for this test was done with a geotextile thickness tester for normal geotextiles. The pressure foot of this tester is small, and the above foot cannot cover the sample properly. However, the thickness can be measured with the bigger pressure foot. Therefore, a new pressure foot was designed and manufactured with a 100 mm diameter. This method was successful and the results obtained are given in Table 3.

Table 3: Average test results of coir geotextile thickness

Manufacture	Thickness (mm)		
	400gsm	700gsm	900gsm
Manufacture 1	7.95	8.24	8.55
Manufacture 2	8.27	8.47	8.23
Manufacture 3	9.07	8.99	9.27

This test parameter is not the main requirement for landslide mitigation applications. However, thickness is important to improve the manufacturing quality of coir geotextile.

3.3. Tensile Strength of coir geotextile

Table 4: Average test results of Tensile strength

Manufacture	Sample type based on gsm value	Average results of tensile strength machine direction (kN/m)	Average results of tensile strength cross machine direction(kN/m)
Manufacture 1	400gsm	8.46	9.14
	700gsm	10.26	11.11
	900gsm	18.44	17.35
Manufacture 2	400gsm	6.71	9.16
	700gsm	11.33	11.66
	900gsm	18.15	17.82
Manufacture 3	400gsm	7.71	8.63
	700gsm	11.91	10.35
	900gsm	19.87	19.91

During the determination of tensile strength, five different sample preparation methods and two different clamping attachments were used. By trial and error, the most suitable sample was selected out of five samples. 200mm*200mm sample size was selected as the most suitable method, and test results given in Table 4 are obtained for the selected size.

The major issue faced during the sample preparation is the inability to keep the sample's shape after cutting them to the required dimension. Five methods are discussed here with their issues when considering the possibility of using them as a standard test sample. The first method is the tensile strength of a sample sized 200mm×200 mm and the crossing edges tied with thread/wire. Here a normal geotextile clamping attachment which has a width of 220mm, was used to attach the sample to the universal testing machine. As this method's sample preparation time is much longer, it was not selected as the most suitable test method. Then 500mm×500 mm sample without binding crossing edges of the sample was used. A specially designed clamping attachment was used for this method. However, it was unable to achieve the maximum load due to the higher elongation of the sample. The 400mm×400mm size samples were used as the third testing method with the same clamping attachment used for the 500mm×500 mm sample. Attaching the sample was difficult, and not enough gauge length to test it after attaching them to the machine. Therefore, this method is not suitable for testing of tensile strength of the coir geotextile. The geotextile, sized to

200mm×200 mm and tied up with itself, was used for the tensile testing as the fourth sample. The sample preparation time of the fourth sample is shorter than the first sample. In addition, easy to clamp the sample into the machine and can easily achieve maximum tensile force. Therefore, this method was selected as the most suitable scientific method to determine the tensile strength of coir geotextile. However, another sample size with a dimension of 300mm×200 mm was also used. The same clamping attachment was used for this sample size as well. Elongation of some samples is higher and unable to achieve maximum tensile force. Therefore, this method was also not selected as a suitable method to test the tensile strength and the 200 mm×200 mm sample size was selected as the most suitable method, as mentioned above.

3.4. Electrical conductivity of coir geotextile

The test method used during this study is the 1:2 (V/V) Dilution Method. The test results of electrical conductivity do not vary with the unit weight. Therefore, average test results are taken based on the manufacturer.

Table 5: Average test results of electrical conductivity

Manufacturer	Average EC Value (µs/cm)
Manufacturer 1	875.5
Manufacturer 2	1035.0
Manufacturer 3	910.1

The Electrical Conductivity (EC) value of coir geotextile is not generally considered an important factor since it is not used for agricultural purposes in Sri Lanka. But in the case of other countries, they consider EC value as a major factor. EC value affects plant growth. Therefore, the coir geotextile EC value would be an important test parameter during exporting.

During the application of coir geotextile to the landslide mitigation project as an erosion control blanket, some selected plants are introduced in the field to develop a natural blanket with roots. Higher EC values will affect the growth of these plants. Therefore, it is recommended to use washed coir geotextiles for landslide mitigation applications.

4. Conclusion

This study mainly focuses on developing test methods for coir geotextile, an extensively manufactured biodegradable product in Sri Lanka. Accordingly, the following test parameters were selected based on the requirement of manufacturers, exporters and geotechnical engineers involved in the design of landslide mitigation projects, viz. tensile strength, eye size, unit weight, thickness and electrical conductivity. The selection of the appropriate sample size to test each parameter was studied, and a suitable sample size and testing procedure were proposed for each test parameter. The electrical conductivity test method developed in this study is sufficient to obtain an approximate EC value since the proposed method gives the electrical conductivity of water extracted by submerging coir in water. Considering the national need for coir geotextile test methods and specifications, a document of guidelines was developed based on the findings of this study focused on testing and applications of coir geotextile.

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Building Resilience amidst
Economic Challenges

Improvement of Kelani River water quality with the COVID-19 lockdown

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Abstract

Anthropogenic activities are known to be one of the primary drivers of pollution within various spheres of the environment. Since the lockdown implemented due to COVID-19 in various countries and seized industrial activities and vehicle movement, a decrease in environmental pollution across the globe has been reported. Sri Lanka imposed an island-wide curfew from mid-March to 11th May to combat the outbreak of the coronavirus pandemic. Water quality of the lower basin of the Kelani River, which has the highest industrial density was tested on 2nd June 2020 immediately after restarting institutions after a prolonged curfew period and the transport sector, state and private sector institutions, schools, and industries were not in 100% operation. Samples were tested for pH, EC, BOD, COD, FC, and TC, and resulted data were checked against National Environmental (Ambient water quality) standards, 2019, and results of the Pavithra Ganga program for the studied section for 2019 and 2020. The BOD and COD values are well below for most stringent water uses; Category A: water requires simple treatment for drinking and therefore unquestionably complies with other uses. The recorded COD value (4 mg/L) is the lowest recorded compared to the Pavithra Ganga program 5- 54 mg/L. FC and TC vary from 90-970 and 100- 2900 organisms/ 100 mL respectively and levels are lower than that of the Pavithra Ganga study for the river section. The water quality levels analyzed show an improvement during the study period, implying a positive response to COVID-19 imposed a lockdown on the environmental fronts.

Keywords: Anthropogenic activities, Covid-19, Lockdown, Water quality

1. Introduction

The 2019 novel coronavirus disease ("COVID-19") was first identified in December 2019 in Wuhan, the capital of Hubei Province in China. Since then, the outbreak has significantly expanded across borders, leading the World Health Organization (WHO) to declare COVID-19 a pandemic on 11th March 2020 (COVID-19 pandemic, 2022). The novel Coronavirus (COVID-19) infected several thousands of people around the globe and affected the world economy severely in the first half of 2020. The worst affected countries in terms of population are the United States, United Kingdom, Brazil, and India, which account for more than 5.5 million cases of virus infection. As the outbreak continued to spread, governments across the world have adapted to varying levels of public health measures, including movement restrictions, nationwide curfews, travel bans, and border closures to tackle the pandemic. These measures are having a huge impact on people's lives, families, and communities whilst having significant consequences on national economies and global trade.

Sri Lanka got the first confirmed case of coronavirus on 27th January 2020, it was a 44-year-old Chinese woman from Hubei province in China. On 10th March the first Sri Lankan local national tested positive for covid-19. With this, there were several COVID-19 patients were detected in some districts. Consequently, the Government of Sri Lanka initiated several endeavors to help the country to prevent, detect, and respond to the COVID-19 pandemic and strengthen its public health preparedness. Sri Lanka's COVID-19 response has focused on community quarantine efforts by declaring curfews, closure of some public facilities, and declaration of an extended national public holiday that urged the public to work from home. In parallel, the ministry of health released a series of guidelines and circulars to aid health facilities and local health programs in COVID-19 preparedness and response. Sri Lanka imposed an island-wide curfew to combat the outbreak of the coronavirus pandemic, with the total cases of in the country has reached to 100. The Sri Lankan government announced that it lifted the curfew on 11 May which was in effect for over two months and meaning that the public can start going to the workplace by maintaining social distancing but public gatherings, festivals, and celebrations are banned.

Several studies state and prove that anthropogenic activities are considered one of the key drivers of pollution in all spheres of the environment. Since people's movements and industrial activities are closed for months during the first COVID-19 outbreak, pollution loads to the environment are expected to decrease.

The improvement of the environment was noticed all over the world due to imposed curfew in various countries almost which has seized industrial activities and vehicle movement. The lockdown of one-third of its cities in China, which strictly curtailed personal mobility and economic activities caused a decrease in air pollutants (He et.al,2020). Similarly, exception enrichment in the air quality environment was also observed in Sri Lanka. The NBRO monitoring station in the heart of Colombo recorded a 75% drop in PM 2.5 and 65% in PM10 levels, including the lowest 24-hour average within 20 years aligning with the mobility restrictions and curfews that came into force (ESSD, NBRO).

Improvement in the water quality of the Yamuna River in Delhi, which has been one of the burst polluted rivers has also been observed. The concentrations of pH, EC, DO, BOD, and COD has been measured which showed a reduction of 1-10%, 33-66%, 51%, 45-90%, and 33-82% respectively during the lockdown phase in comparison to the pre-lockdown phase (Arif et al.2020). The Grand Canal in Italy became clear, and some aquatic species reappeared with the COVID-19 lockdown (Daly 2020). Improvement in surface water quality in terms of suspended particulate matter (SPM) in the Vembanad Lake, the longest freshwater lake in India was also noticed in a study by Yunas et al.2020.

Therefore, the Covid-19 restrictions provided an ideal situation to assess the impact of human activities on the water quality in Sri Lanka as a nationwide curfew was in place since 20 March 2020. The research aimed to detect the physical, chemical, and bacteriological quality of water with the COVID-19 restrictions to develop insights into the link between human activities and impacts on water.

2. Study area

The Lower basin of the Kelani River is selected to study water quality before and during the COVID-19 lockdown period. The total river catchment area is 2,292 km^2, the third largest watershed. Topographically, the river comprises distinct topographies dividing the basin into the steep mountainous upper catchment, the middle catchment with relatively gentle slopes, and the almost flat lower catchment with flood plains. The middle (starts from Hanwella) and lower basin of the Kelani River flows through the Colombo and Gampaha districts, which have the highest population density and the highest density of industries. The river section in the lower basin is under the pressure of major sources of urban and industrial pollution. The highly populated cities of Colombo and Gampaha districts too fall within the lower basin.

The river is the primary source of drinking water for over 4 million people living in Greater Colombo and over 10,000 industries and businesses depend on the natural resources and services provided by the basin. For these 2 supply locations are located in the lower basin of the Kelani River; Ambatale and Pattiwila. Water intakes of water bottle industries are also located in the Kelani River (Mallawaarachchi et al,2016)

Three major industrial estates are located in the Kelani Basin; Seethawaka Industrial Estate, Lindell Industrial Estate at Sapugaskanda, and Biyagama Industrial Estate. All three industrial estates, and Ceylon Petroleum Corporation, Ceylon Tyre Corporation, depend on Kelani River water for their industrial water needs. All estates and industries mentioned above except Seethawaka Industrial Estate are located in the lower Kelani basin.

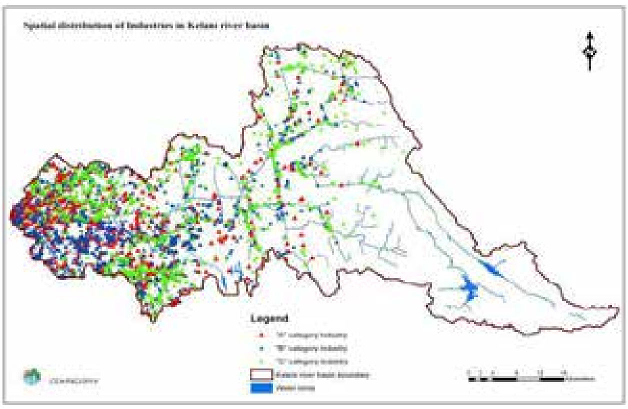

Figure 1: Spatial Distribution of Type A, B, and C industries in the Kelani River, CEA

According to CEA database, about 2,840 industries are recorded in the Kelani basin with different pollution potentials, 30%, 43%, and 27% of type A, B, and C type of industries, respectively (Mallawatantri et al, 2016).

3. Methodology

3.1. Sampling locations

Eight samples (Table 1 and Figure 2) from the lower basin of Kelani River were collected on 02nd June 2020, immediately after restarting institutions after a prolonged curfew period. However, the transport sector, state and private sector institutions, schools, and industries were not in 100% operation.

3.2. Parameters

Each sample was tested for the following parameters pH, Temperature, Electrical Conductivity (EC), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Faecal coliforms (FC), and Total coliforms (TC).

3.3. Sample collection, transportation, and analysis

Samples for Physio- chemical parameters, were collected, transported, preserved, and analyzed as per the Standard methods for examining water and wastewater, APHA AWWA WEF 2017, 23rd Edition. for bacteriological parameters were collected, transported, preserved, and analyzed as per SLS 614: 2013 -Specification for potable water.

Table 1: Location reference & Description

Location Reference	Location Description
L1	Pusseli Oya -Close to Atigala Ranala
L2	Kelani River close to Jalthara Ranala
L3	Kelani River close to Embugama-Ranala
L4	Kelani River close to Ranala
L5	Kelani River close to Pahala Mapitigama bridge
L6	Kelani River downstream to Ambatale water intake
L7	Kelani River at Mulleriyawa North
L8	Kelani River at Sedawatta

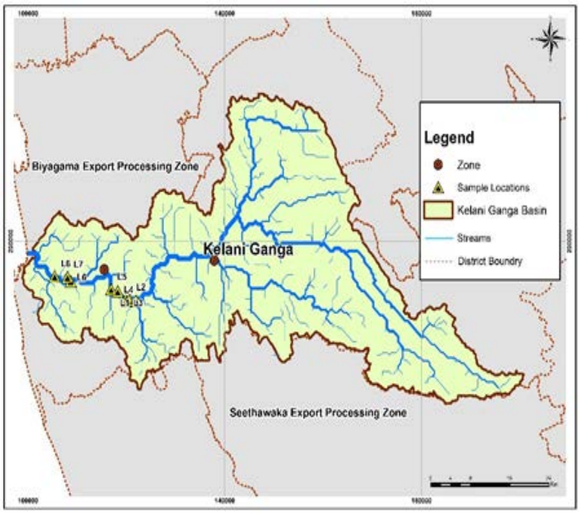

Figure 2: Kelani River watershed showing Sampling locations

3.4. Interpretation

The water quality results were compared to determine the compliance status of categories (Table 2) with National Environmental (Ambient water quality) standards, No.1 2019 In addition, the water quality status was also considered against the studied section with the data of Pavithra Ganga program for the previous two years (2019 and 2020).

Pavithra Ganga program: The Ministry of Environment in collaboration with the CEA and the National Water Supply and Drainage Board monitors the water quality at 18 main locations in the main river and tributaries in mainly the lower and a part of the middle basin above Hanwella for 12 major water quality parameters including pH, EC, DO, BOD, COD, FC, and TC biweekly since 1998.

Table 2: Categories of ambient water quality standards

A	Water that requires, simple treatment for drinking
B	Bathing and contact recreational water
C	Water suitable for aquatic life
D	Water sources that require to undergo general treatment process, for drinking
E	Water suitable for Irrigation and Agriculture activities
F	Water with minimum quality but does not fall into categories A to E

4. Results and discussion

Figure 3a- 3f present the spatial distribution of pH, EC, BOD and COD, FC, and TC at each location and their compliance status with ambient water quality standards.

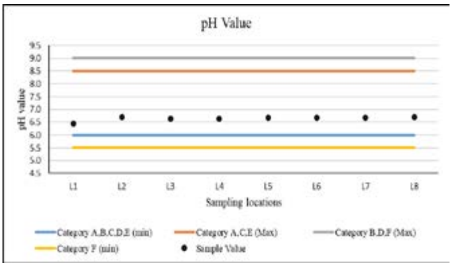

Figure 3a: Spatial distribution and Compliance of pH with Ambient water quality standards

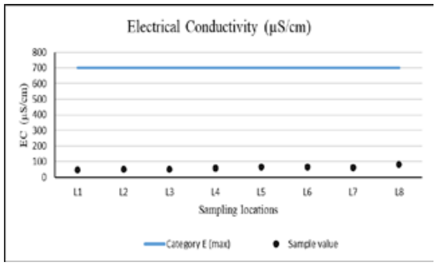

Figure 3b: Spatial distribution and Compliance of EC with Ambient water quality standards

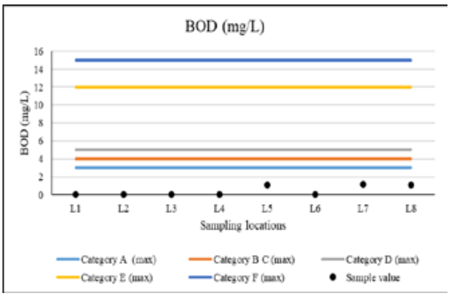

Figure 3c: Spatial distribution and Compliance of BOD with Ambient water quality standards

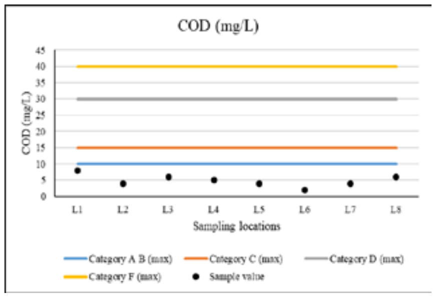

Figure 3d: Spatial distribution and Compliance of COD with Ambient water quality standards

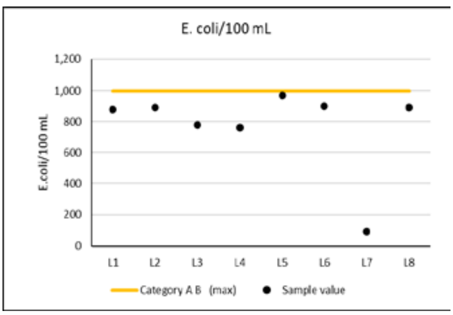

Figure 3e: Spatial distribution and Compliance of FC with Ambient water quality standards

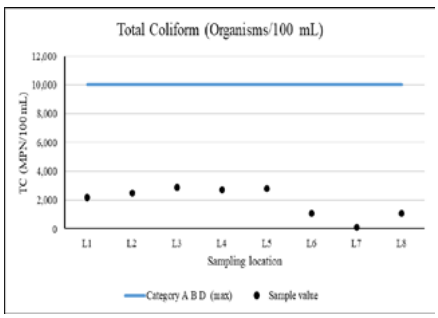

Figure 3f: Spatial distribution and Compliance of TC with Ambient water quality standards

4.1. pH

The pH of the river section studied varied from pH 6.4 to 6.7 indicating that the water quality is within the natural range and the pH values at all locations comply with National Environmental (Ambient water quality) standards, No.1 2019.

4.2. Electrical Conductivity

In the study section, EC varied from 50 and 82 µs/cm. The ambient water quality standards are available only for one water use: maximum allowable for irrigation and agricultural purposes; 700µS/cm. All EC measurements comply with this category (Figure 3b).

Conductivity in water is affected by the presence of inorganic dissolved solids. Therefore, the resulting EC values reflect a reduction of inputs of inorganic dissolved solids, possibly due to the lowering of industrial wastewater inputs. However, a substantial reduction was not observed with the EC values of 2019 and 2020.

4.3. BOD & COD

The BOD values are well below for most stringent water uses; Category A. water that requires simple treatment for drinking (3 mg/L), and therefore the water unquestionably complies with other uses, Category B- bathing and contact recreational water, Category C -water suitable for aquatic life; Category D -water source that requires to undergo general treatment process, for drinking; Category E - water suitable for irrigation and agricultural activities as shown in Figure 3c.

The COD concentrations of water samples fluctuate between a minimum of 2 mg/L at location L6 and a maximum of 8 mg/L at location L1. These results satisfy all categories' ambient water quality standards (Figure 3d).

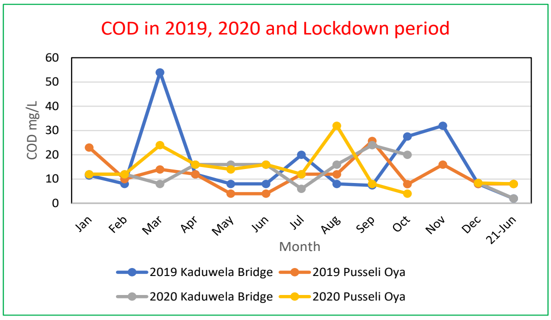

Figure 4: COD in 2019, 2020 and during lockdown period

Comparing the results of the Pavithra Ganga study, the observed COD values at L6 (Kelani River downstream to Ambatale water intake) and L1 Pusseli Oya are the lowest reported values for 2019 and 2020 (Figure 4). Further, many measurements at this location (Pusseli Oya, Kaduwela bridge) in 2019 and 2020 exceed the stringent water quality requirements; Category A: water that requires simple treatment, for drinking, Category 2: bathing and contact recreational water. The lower COD levels during the lockdown period indicate a low level of pollution. The wide usage of chemicals and organic fertilizer and the discharge of sewage affect COD levels, while the low COD pointing to an increase in the water quality is attributed to reducing the discharge of industrial effluent.

4.4. Bacteriological quality; FC and TC

FC and TC vary from 90-970 and 100- 2900 organisms/ 100 mL respectively and are well below the standards for Category A, and B, and total coliform counts are well below category D. The levels are lower than that of the Pavithra Ganga study for the river section for previous 2 years implying reducing wastewater from sewage treatment plants. The studied section of the Pavithra Ganga study reported 1000-180,000 counts/mL for FC and 2000-180,000 for TC during the period of 2019 and 2020. The levels exceed the Ambient water quality standards for category A, B, and D for most of the months.

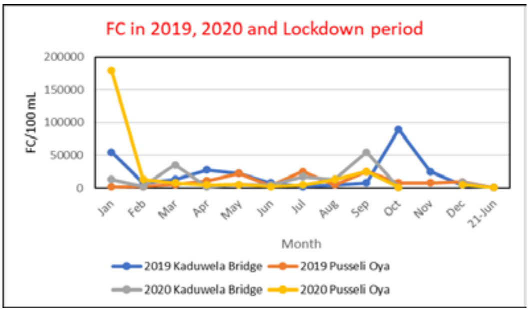

Figure 5: FC in 2019, 2020 and during lockdown period

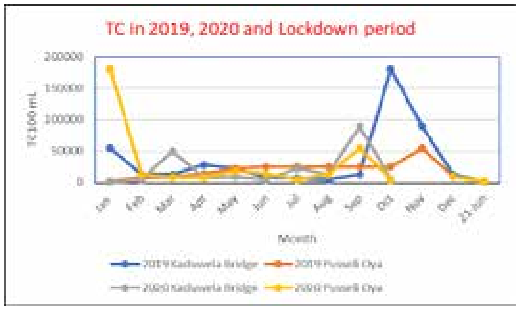

Figure 6: TC in 2019, 2020 and during lockdown period

5. Conclusion

The curfew period in all Covid-affected countries has been unique. No such event occurred over the recorded history where all the anthropogenic activities have been reduced to the minimum levels. This has led to a decline in emissions and restricted the production of industrial waste and other pollutants in urban centers worldwide during the lockdown. The improvement of the water quality of the Kelani River in this study signifies this transformation.

It has been fascinating to note that the behavioral changes in nature are highly positive, and the atmosphere, hydrosphere, and biosphere are rejuvenating which gives an appearance that the earth is under lockdown for its repairing work.

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Building Resilience amidst
Economic Challenges

Systematic methodology for the assessment of risk associated with chemical related incidents of industrial facilities in Sri Lanka

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Abstract

Industrial facilities that store, transport or process chemicals are prone to chemical-related incidents leading to disasters which results losses and damages to life, property and the environment. In order to prevent and reduce the losses and damages caused by industrial related chemical disasters, timely issue of warnings and emergency rescue mobilization is essential. To facilitate this, it is necessary to conduct a systematic assessment of the case-specific information along with identification of risk zone or area, determination of exposure levels, etc. In Sri Lanka, there are no such criteria or methodology developed for risk assessment related to chemical disasters. As a result, number and intensity of chemical related incidents are increasing over time. Realizing the significance of closing this gap, our study focused on developing a chemical disaster risk assessment method suitable for the Sri Lanka. The assessment adopts a simple logical stepwise methodology to assess the chemical disaster risk of chemical related industrial facilities in Sri Lanka which includes source identification, hazard identification/prioritisation, vulnerability assessment, risk assessment, issue warning & instructions and rescue operations and risk management, treatment & mitigation. This method was developed for assessing chemical disaster risk in a proactive, participatory, well-structured, multi-disciplinary and multi-sectorial approach which facilitates involvement of all stakeholder groups associated with chemical disaster management in Sri Lanka.

Keywords: Chemical disaster, Chemical hazard, Systematic risk assessment

1. Introduction

Continued increase of population and economic growth coupled with the climate change impacts are the driving forces of the rapid increase of the disasters, both natural and man-made, and this exponential increase have devastating impacts on human and environmental wellbeing at global, national and local scales (Jiang et al., 2020; Olawuni et al., 2020). Past data indicate chemical incidents, man-made disasters, occur relatively frequent with the increase in number, size and variety of chemical used (Chen at al., 2021; Wood and Fabbri, 2019). With the recent development of initiatives such as Sendai Framework for Disaster Risk Reduction and Better Regulation Agenda of the EU, developed countries have been stimulated to focus their attention on measuring the impacts of chemical disasters and the effectiveness of the methodologies and regulations in reducing these risks (Wood and Fabbri, 2019). The effectiveness of these methodologies in controlling the chemical disaster risks is indicated by the associated significant low human casualties in developed countries compared to developing countries (Wood and Fabbri, 2019). Due to limited capacities to manage disasters and complex nature disasters, developing countries are more susceptible to adverse consequences, therefore, systematic assessment of disaster risk is essential in prioritising and targeting problematic sectors (Olawuni, et al., 2020; Wood and Fabbri, 2019). In addition, unlike other types of disasters, chemical disasters are associated with a range of industries not limited to one industry type, chemical substance or process (Wood and Fabbri, 2019). Further, chemical industry premises are often congested with storage tanks, complex pipe networks, high-pressure compressors, etc. where an unintended chemical release can lead to multiple hazards (Chen at al., 2021). Hence, determining chemical disaster risk is critical to develop effective chemical disaster risk management initiatives.

In Sri Lanka, currently there are more than 20,000 chemical related industries located as industrial clusters or as individually and during the past decades there is an increase in chemical accidents (Kaushalya et al., 2016). Even though these incidents have been less prioritised historically, with the increase of the number and intensity coupled with the intense of the impacts imposed on neighbouring communities and environment, mitigation of chemical disaster risk has become a national priority. Although the importance of managing chemical disaster risks have been realised, there is a serious gap in available policies, legal instruments, customised updated databases and tools to efficiently manage chemical disaster risk in Sri Lanka. Further, due to the complex nature of the chemical disasters and their diverse consequences, to assess the risk and damages of chemical disasters, a multi-tiered system with appropriate lateral institutional links should be established in Sri Lanka. Hence, the main objective of the paper is to propose a customised systematic methodology, required database frameworks and recommend policy directives to assess the chemical disaster risk in Sri Lanka.

2. Methodology

After investigating past chemical disaster incidents in Sri Lanka, the major drawbacks encountered in handling and managing the chemical risks were identified. These results, international standards and previous literature were used to develop a methodology to systematically assess the chemical disaster risk in Sri Lanka. The primary and secondary data required were obtained from relevant regulating and administrative authorities and a stakeholder meeting was held in March 2022. Representatives from Disaster Management Center, Ministry of Industries, Board of Investments of Sri Lanka, Central Environmental Authority, Sri Lanka Customs, National Institute of Occupational Safety and Health, Ministry of Environment, National Authority for the implementation of Chemical weapons convention, academia, etc. participated the stakeholder meeting. With the suggestions received at the stakeholder meeting proposed methodology was further refined.

3. Systematic assessment methodology

3.1. Main steps in the proposed methodology

The proposed method adopts a simple logical stepwise methodology to assess the chemical disaster risk of chemical related industrial facilities which process, stores and transport chemicals. The assessment method has six sequential steps illustrated in Figure 1. The methodology is specially devised to be used in estimating the chemical disaster risk in potential situations and immediately after the initiation of causes which might lead to chemical disasters for example a chemical leak.

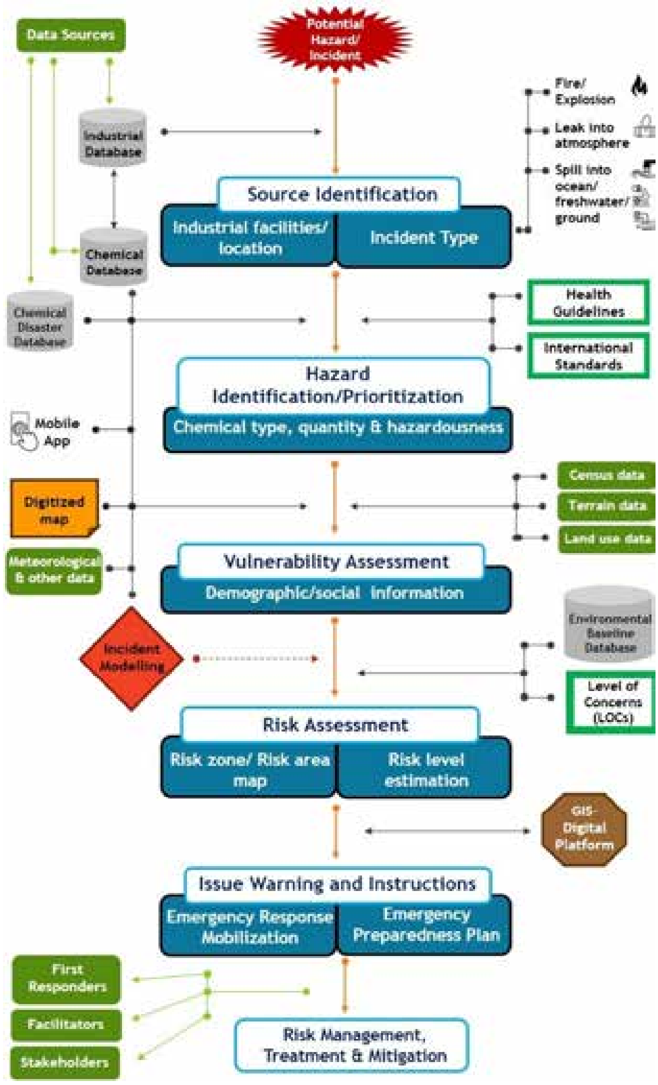

Figure 1: Proposed stepwise methodology for chemical disaster risk assessment in Sri Lanka

3.2. Step 1: Source identification

The initial step of the proposed methodology involves identifying properly identifying the industries using, processing, storing and transporting chemicals in Sri Lanka using following criteria.

a) Specific industrial facility

Location of the industrial facility subjected to the incident and the industrial process type will be identified first. To perform this task, a detailed database having information about industries, their locations, types of chemicals used is essential. However, there is no central database which satisfies this requirement. Hence a database framework was developed to facilitate collection of data such as industry type, GPS locations, emergency contact numbers, etc.

b) Type of the incident

Identification of the incident type is significant in the risk assessment process as certain types of incidents such as fires are more frequent. Fires accounting to 44% from all the major chemical related accidents in the world and was the causative factor of 60% of total chemical disasters recorded during 2006-2016 in Sri Lanka (Chen et al., 2021; Kaushalya et al., 2016). Therefore, the incident type was distinguished as either fire or explosion, chemical spillage into ocean/marine environment, surface/groundwater body/land or chemical leaks into atmosphere (Kaushalya et al., 2016).

c) Hazard (Source of the chemical)

Since handling of chemicals are the hazard agent responsible for the chemical disaster and various facilities/industries use numerous types of chemicals for different processes, the source of chemical associated in the incident will be identified. During this step, characteristics, behaviors and properties of the chemical needs to be recognized. To successfully accomplish this task, availability of the suitable chemical data is a crucial. In Sri Lanka, information on chemicals in industrial context is currently available with different entities in various forms and updated at different time frames. Therefore, a chemical data platform with vital information on the possible chemicals imports to the country was developed. The database includes chemical name, physical state, potential hazards, exposure limits, etc.

3.2. Step 2: Hazard identification and prioritization

Chemical hazard identification involves identifying whether the chemical associated with the incident or subjected to the assessment can cause an adverse effect or not (Perkins et al., 2019). Hazard prioritization entails relative ranking of hazard sources of at a given concentration or a particular area for a specific risk factor which are likely to cause adverse outcomes and helps determining the levels of attention and focus of disaster management resources (Perkins et al., 2019; Wood and Fabbri, 2019). This study used following three criteria to prioritise the chemical related industrial facilities and associated chemicals after the identification of the hazard point of source.

d) Specific hazardousness for the identified incident type or chemical hazard possessed by the chemicals.

Based on the hazardousness, industries and the chemicals within an industry have a tendency of being subjected to chemical disaster incidents. An industry or a chemical within an industry with a higher hazardousness can be considered as a facility/substance with a risk of potential chemical disaster. NFPA Rating Standard System for the Identification of the Hazards of Materials for Emergency Response (NFPA 704) will be used for the estimation of the hazardousness of the chemicals in an industrial facility.

e) Previous incidents/accident history of the industrial facility

Industries associated with a chemical disaster incident/s in the past has shown a comparative high potential for chemical hazards as occurrence of a chemical accident indicates the existence of an actual risk and the number of accidents occur in the same time period is a strong indication of the presence of high-risk initiatives (Wood and Fabbri, 2019). Often media reports and figures from insurance companies, hospitals, etc. are few of informal sources available related to chemical accident data. However a routinely updated database of past chemical incidents is important as the details of past incidents provide a) inputs on the range and scale of impacts that different chemical accident scenarios can potentially produce, and b) helpful in diagnosing the potential risk (relative hazard exposure levels, etc.) and where the incidents have common features and the commonalities among incidents may indicate a signs of failure (Wood and Fabbri, 2019).

f) Storage quantity and conditions of the chemicals

In hazard identification and prioritization, type and quantity of chemicals are crucial factors. Industries which do not use hazardous chemicals can also be sources of chemical accident risk. Some chemicals can be non-hazardous in small quantities but potentially hazardous in large quantities while certain chemicals can be hazardous even in minute quantities. Therefore, processing and storage amounts of chemicals need to be well managed. The dangerous storage limit should be decided depending on the usability and the hazardousness of the chemical with relevant safe storage practices.

3.4. Step 3: Vulnerability assessment

Chemical disasters have the potential to damage not only to employees of the industry or the individuals lives in the surrounding areas but also can cause damages to the adjacent ecological and built environment (Chen et al., 2021; Jiang et al., 2020; Tahmid et al., 2020). Having densely populated areas close to chemical industries has been identified as one of the main factors contributing extensive human exposure and death in 43% of chemical disasters in USA and in Sri Lanka the highest number of chemical disasters have been reported in the densely populated Western Province (Kaushalya et al., 2016; Tahmid et al., 2020). Even though many industrial accidents in Sri Lanka are reportedly managed within the factory premises, several have propagated beyond and released hazardous substances to the environment through exposure pathways such as air, to surface water, soil, groundwater, sea, thermal waves, kinetic energy (Kaushalya et al., 2016). However, the socio-economic impacts are often neglected or entirely left out due to the lack of precise data on range and severity of the impact required for quantification of the impact exert, at least estimates should be drawn from the available information.

Since vulnerability is influenced by many external factors access to demographic, land use, terrain, meteorological, social and environmental data is essential. These data should include population density, household density, locations of sensitive entities such as schools, hospitals, etc., topographical data such as rivers, land cover and elevation, groundwater level, closest water sources used for drinking and other purposes, etc. A working and updateable prototype of mobile app to collect real time data on the chemical hazards directly from the field and a digitized map which has the facility of displaying the outputs of the vulnerability assessment was developed under this step. Even though, outputs of the vulnerability assessment provide substantial insights on risk drivers and case-specific vulnerability which may not necessarily be generalized without logical assumptions. Therefore, it is essential to conduct vulnerability assessment in each case to understand the specific vulnerabilities of the each incident. Also, apart from mapping socio-environmental vulnerability to the chemical hazards, identification of available resources and institutional capacities are also vital in this process (Fatemi et al., 2019).

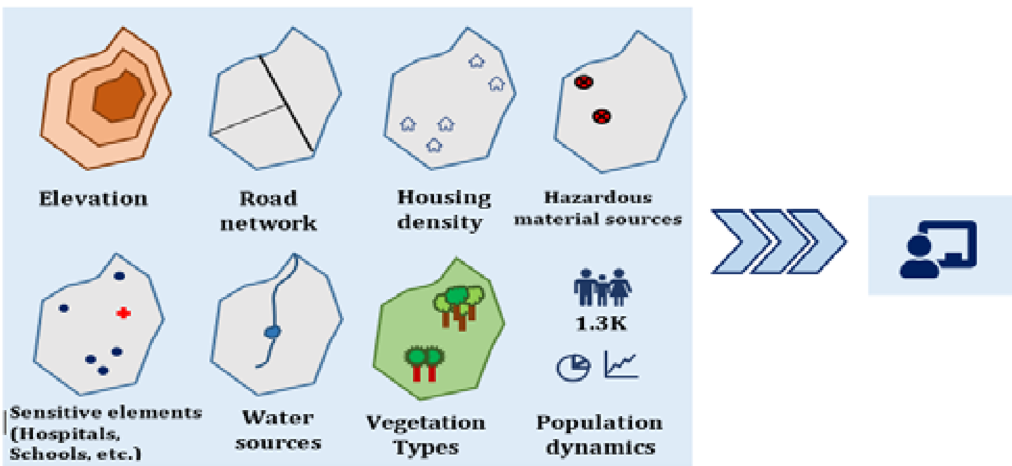

Figure 2: Process of vulnerability assessment

3.5. Step 4: Risk assessment

Due to unpredictable and disproportionate consequences, effective risk management initiatives through assessing the spatial and temporal dispersion from the point of release is essential for protecting staff, neighbouring communities and first responders (Chen et al., 2021). The method of calculating the risk level varies depending on the incident type, availability of data, etc. Also, the risk assessment tools such as dispersion models (Breeze Incident Analyst Software Package, ALOHA software and AIRMOD) intended to use for decision making should be scientifically sound, robust and should tested to make sure their prediction validity (Perkins et al., 2019). Depending on the tool, the requirement of the types and quality of data varies greatly. In general, simple models require fewer data types and depending on the model complexity the data requirement can be higher than the data already available.

In such instances assessment tools can be selected based on the available data or where necessary developing theoretical relationships or extrapolations relying on expert judgment might be necessary to improve the model outputs (Perkins et al., 2019).

Hazard and exposure bands are usually used to visualize the corresponding risk levels which enable identification of high-risk areas and facilitate efficient use in planning emergency response and evacuation. To categorize risk, internationally accepted standard guidelines such as Acute Exposure Guideline Level (AEGL), Emergency Response Planning Guideline (ERPG), and Protective Action Criteria for Chemicals (PAC) can be used. In addition, baseline environmental data is important in defining the risk levels. For example, atmospheric temperature, wind direction and wind speed have shown to have an impact on evaporation of liquid chemical substances and dispersion of vapour and aerosols (Chen et al., 2021; Jiang et al., 2020). Hence, it is important to have a central updated environmental quality databases.

3.6. Step 5: Issue warning & instructions and rescue operation

The objective of issuing warning, instructions related to chemical disasters is to inform the hazard or risk level to the relevant individuals or communities and help them to take appropriate actions or decisions in order to protect them from the forthcoming hazards. It is one form of risk communication, which is an interactive multilevel exchange of information between risk communicators and vulnerable groups (Adella et al., 2019; Fatemi et al., 2019). Two-way communication among the stakeholders are crucial as it easier to deploy support and resources in a more flexible, reliable and coordinated manner in times of crisis (Booth et al, 2020; Fatemi et al., 2019). Hence, there ought to be greater synergies between regulation bodies, chemical industries and all other relevant stakeholders of chemical disasters. Thus, development of timely, robust and symmetrical institutional communication channels is essential in avoiding mismatches in issuing warning, response and rescue (Booth et al, 2020; Fatemi et al., 2019). Population living in the vicinity should have information about the hazard levels of the area and the protective action they need to take in case of an incident occurs (Fatemi et al., 2019). Therefore, it is also important that the right stakeholders receive the information they need in a way that they can understand and act upon it. Visualization and mapping were identified as useful tools in this regard (Booth et al, 2020). Therefore, a GIS-digital data platform was developed to facilitate displaying and sharing information on chemical disasters risks.

3.7. Step 6: Risk management through risk treatment & mitigation

Risk management consists of a coordinated approach in preventing, preparing, responding and recovering from chemical accidents which includes risk treatment and risk mitigation (Fatemi et al., 2019). Risk treatment one form of risk management, is the process of modifying risk which contains selection and application of one or more risk reduction measures for a risk level to reduce from unacceptable to a reasonably acceptable and practicable level (Lyon and Popov, 2019). Common risk treatment options include, avoiding the risk by deciding not to start or continue the activity associated with the risk, removal of the source of the risk, change the likelihood of the risk, changing the consequences, risk financing and retain risk through informed decision making (Lyon and Popov, 2019). It is important not to introduce new risks unintentionally while treating the risks therefore evaluation of the evaluation of the residual risk after treatment is crucial. Risk mitigation is taking actions to reduce severity of the risk by making a condition or consequence less severe or the effort to reduce loss of life and property by reducing the disasters (Lyon and Popov, 2019).

4. Conclusion

Due to the complexity of managing chemical disasters, many parallel measures should be implemented which requires substantial coordination among stakeholders. In Sri Lanka, lack of available adequate data, institutional barriers in sharing expertise and data, lack of lateral multi-sectoral networking hinders efficient respond to chemical disasters. Realizing this, the paper proposes systematic assessment method for chemical disaster risks in Sri Lanka.

Furthermore, the existing vacuum of regulations indicates the pressing need of drafting an inclusive policy streamlining the preparation, response and recovery of chemical disasters considering following elements.

Regulation of installation and functioning of chemical industrial facilities in Sri Lanka

- Seveso Directive II which indicate land use planning must consider appropriate distances between hazardous establishments and residential areas should be adopted in installing chemical industrial facilities including small and medium scale ones in Sri Lanka.
- Introduction of obligatory chemical risk certification to identify chemical hazards associated with each industrial facility which will also help local authorities to focus more into potential chemical risks in their local jurisdictions.
- Introduction of development of chemical hazard profiles and ranking hazards according to the hazard source for individual industries and specific geographic and administrative areas with high concentration of chemical related industries to minimizing the associated negative impacts of probable future extreme events.

Capacity development in risk assessment, handling health emergency and rescue

- Required facilities, equipment and trained staff should be provided to the hospitals in the areas where the chemical hazard level is high to manage chemical health emergencies and specific training courses on chemical induced injuries should be introduced in the public health system.
- Establishment of a specific unit with field investigation teams responsible in rapid assessment of the situation and controlling the emergency operations and appropriate distribution of such teams/individuals is needed for readily availability in the case of an emergency.

Data availability, data sharing and effective stakeholder involvement

- Development of centralized databases (with appropriately restricted access) should tailored to address local requirements (chemical industry database, chemical database, chemical incident database and baseline environmental quality databases, etc.) and collection and sharing of data with combined effort involving both government institutions, industries and other stakeholders.

- Establishment of a special task force encompassing all stakeholders such as policy makers, regulation bodies, professional experts and regional authorities having indispensable information regarding local situation, etc.
- Conduct regular national level dialogues to understand the resource allocation and investment needs and sharing knowledge and experience among stakeholders to motivate active engagement in managing chemical disasters in Sri Lanka.

Acknowledgement

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Building Resilience amidst
Economic Challenges

Identification of actions for effective urban air pollution risk management for short term high exposure situation

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Abstract

Air pollution will intensify with increasing urbanization and the rapid pace of motorization. In recent decades, air pollution has become one of the most important environmental problems in urban areas of Sri Lanka. According to the air quality monitoring data, Colombo, Kandy, Kurunegala, Jaffna, Vavuniya, Kegalle and Puttalam urban areas recorded high air pollution that exceeds WHO annual guideline levels and closer to annual standard levels of National Ambient Air Quality Regulations in Sri Lanka with respect to $PM_{2.5}$.

The pollutant levels in all urban areas were significant during the period of November to March (North-East monsoon period) which could be due to the contribution of trans-boundary pollutants. In some days during this period, the air pollution condition with respect to $PM_{2.5}$ exceeded the 24-hour average national standard levels. The short-term high exposure levels of Particulate Matter during this period cause unhealthy conditions for city dwellers, especially for sensitive groups. Therefore, more concern should be drawn to managing urban air quality during this period. The development of an action plan can effectively address these situations through measures such as the limitation of pollution emissions by local pollutant sources. The main objective of this paper is to highlight an effective action plan for the short-term high $PM_{2.5}$ exposure situation in the Colombo area as risk management during this period. Public and private sector participation and adherence would be successful approaches for the effective implementation of this plan.

Keywords: Air pollution, $PM_{2.5}$, Preparedness planning, Transboundary pollution, Urbanization

1. Introduction

Ambient air pollution is a growing problem in Sri Lanka mainly due to the rapid growth of urbanization and use of motor vehicles. According to past air quality monitoring data, urban areas such as Colombo, Kandy, Kurunegala, Jaffna, Vavuniya, Kegalle and Puttalam have recorded high air pollution levels that exceed WHO annual guidelines [1] and also closer to annual standard levels of National Ambient Air Quality Regulations [2] of Sri Lanka with respect to $PM_{2.5}$. Accordingly, thousands of city dwellers in these cities are exposed to relatively higher levels of pollutants in long term.

Since Colombo is the most urbanized, commercialized and industrialized city in the country, it is the highest polluted city in Sri Lanka. The population density of Colombo has reached a level of 3417 Persons/km^2 [3] and they are exposed to the annual average level of 28 g/m^3 [4] with respect to $PM_{2.5}$ in 2019 which exceeded the WHO annual guideline values as well as national ambient air quality standards. Also, the daily concentrations of $PM_{2.5}$ exceeded the national ambient air quality standard levels in most of the days during the period of November to March (North-East monsoon period) each year.

It is assumed that, this high level of daily PM levels during the North-East monsoon period is by trans-boundary pollution from neighboring countries due to the prevailing wind pattern clearly shown in the international predictions [5]. The formation of "Asian Brown Cloud" over Asian cities during this period could be the reason for this trans-boundary pollution [6]. Accordingly, the pollutant levels, especially $PM_{2.5}$ levels were significantly high during the period and some days it reached unhealthy conditions depending on the wind direction and speed.

Exposure to high Air Quality Index (AQI) [7] values above 100 with respect to $PM_{2.5}$ contributed by trans-boundary effect may carry substantial amount of high health risk materials. These could cause health impacts, particularly for sensitive groups, younger children (0-10 years) and elderly persons, who are susceptible to air pollution and at high risk. [8] Not only sensitive groups but individuals may also be affected by this short-term condition mainly causing respiratory diseases such as changes in lung function, types of Asthma symptoms and frequent occurrence of wheezing etc. In addition, there are many adverse effects of exposure to high $PM_{2.5}$ during pregnancy which includes preterm birth, low birth weight, intrauterine growth restriction and congenital anomalies, etc. [9]

Therefore, the management of air quality especially $PM_{2.5}$ during the period of North-East monsoon is essential and should be a prime concern on air quality management programs in Sri Lanka. However, it is difficult to control any trans-boundary contribution, but can manage local contribution at a manageable level. This paper summarizes the possible actions which can be taken to control the high level of $PM_{2.5}$ by reducing emissions from local pollution sources during any critical days as a preparedness plan for the management of air quality.

2. Methodology

Air Quality data on $PM_{2.5}$ for the study was obtained from the Automated Air Quality Monitoring site located at Colombo Municipal Council, Colombo 07 (Latitude:6°54'54.89"N, Longitude:79°51'52.28"E), Sri Lanka. The $PM_{2.5}$ monitoring methodology used at the site was standard Beta Attenuation Monitoring (BAM) technique [10] in which the instruments are well maintained by regular calibrating according to the monthly and annual maintenance procedure.

$PM_{2.5}$ 24-hr average data at the site were extracted from monthly air quality reports obtained for the period of January 2019 to July 2022[4]. Descriptive statistics were utilized to analyze and assess the air pollutant levels with respect to National Ambient Air Quality Standards and WHO Guidelines. Data were further analyzed to obtain the seasonal variation for the four climatic seasons in Sri Lanka and to obtain any critical conditions according to the USEPA Air Quality Index (USAQI) levels [7]. In addition, data were further analyzed to identify whether there is any trans-boundary effect on the air quality, depending on the seasonal climate variations. Wind patterns during high pollution conditions were obtained by International Wind Forecasting System, Windy.com. Accordingly, actions to minimize or manage the high-risk conditions were identified. During the identification of relevant actions, pollution sources in the surrounding area that contribute to the pollutant (especially Particulate Matter level) at the locations were recognized by available literature and actions were proposed to minimize or manage their emissions. However, the exact amount of contribution from each source are not estimated separately, since there is no such data available in Sri Lanka.

3. Results and discussion

Summary statistics of 24hr $PM_{2.5}$ presented in Table 1. Daily average $PM_{2.5}$ of each month from January 2019 to July 2022 at Colombo are presented in

Figure 3.1. The results indicate that, the $PM_{2.5}$ concentration varies from 4 to 130 μg/m³ and high levels are shown during November to March in each year. It indicates that the level of $PM_{2.5}$ has exceeded the WHO Guideline level in most of the days throughout the year and exceeded the National Ambient Air Quality Standard level during the North-east monsoon period (November to March). The mean $PM_{2.5}$ levels for the period from April to October is 17 μg/m³ and the mean value for the period of November to March is 32 μg/m³ each year.

Table 1: Summary Statistics of 24hr $PM_{2.5}$ levels

Month	Mean (μg/m³)	Median (μg/m³)	Minimum (μg/m³)	Maximum (μg/m³)	Std Dev
Jan	38	33	12	130	19.8
Feb	38	37	13	66	11.6
Mar	30	27	5	100	17.3
Apr	18	16	7	55	9.1
May	16	16	6	33	6.3
Jun	18	18	5	38	8.9
Jul	18	17	8	37	7.2
Aug	16	17	7	28	4.4
Sep	17	13	6	36	8.5
Oct	18	15	7	58	8.4
Nov	23	19	7	87	14.1
Dec	32	27	11	80	15.0

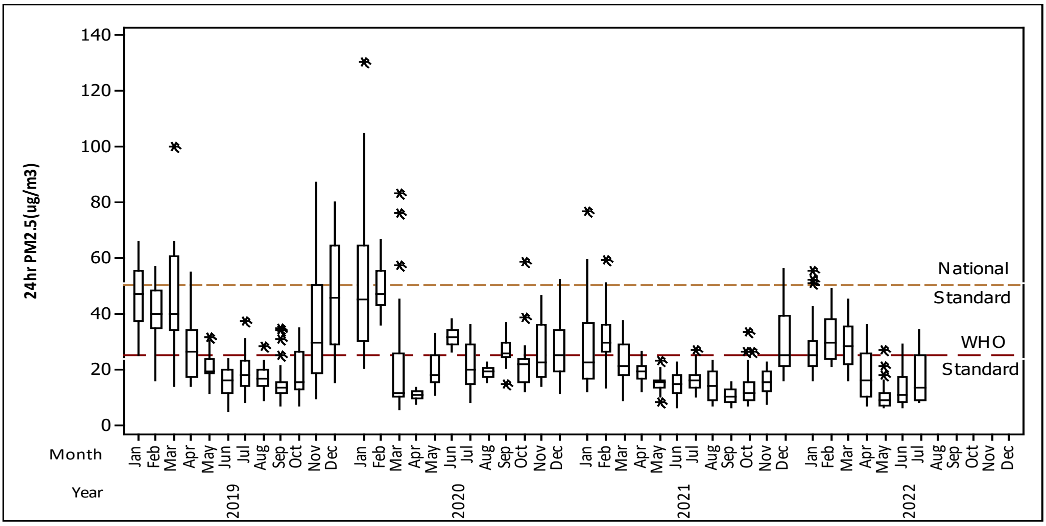

Figure 3.1: Variation of daily average $PM_{2.5}$ in each month (January 2019 - July 2022)

The seasonal variation of $PM_{2.5}$ levels in Colombo during the study period are presented in Figure 3.2. It clearly indicates high levels during the North-East monsoon period and low levels during the South-West monsoon period. Further, during the North-East monsoon period, high values were recorded in certain days. Accordingly, the data confirms that North-East monsoon is the critical time period regarding the air pollution in Colombo area. This significant increase during November to March (North-East monsoon season) every year could be due to the contribution of trans-boundary pollution from neighboring countries and "Asian Brown Cloud" over the Asian cities during this period depending on the seasonal wind pattern. This increment in pollutant levels due to the contribution of trans-boundary pollution is estimated as 83% compared to other seasons.

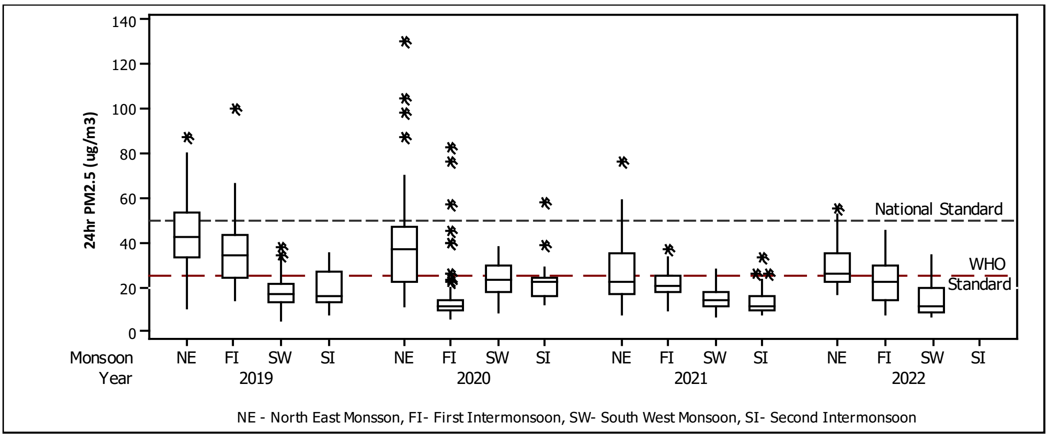

Figure 3.2: Variation of daily average $PM_{2.5}$ in each season (January 2019 - July 2022)

The percentage of days that exceeded 24-hour WHO guideline value in each month is presented in Figure 3.3. As shown in Figure 3.3, the number of days that the $PM_{2.5}$ level exceeded the WHO Guideline level are scattered around the year and high in North-East monsoon period range. The results further specify that more than 40% of days during the North-East monsoon period exceeded the level of National Standard level.

However, the percentage of days that the 24-hr average $PM_{2.5}$ level exceeded the National Ambient Air Quality standard levels is only concentrated to North-East monsoon period as shown in Figure 3.4

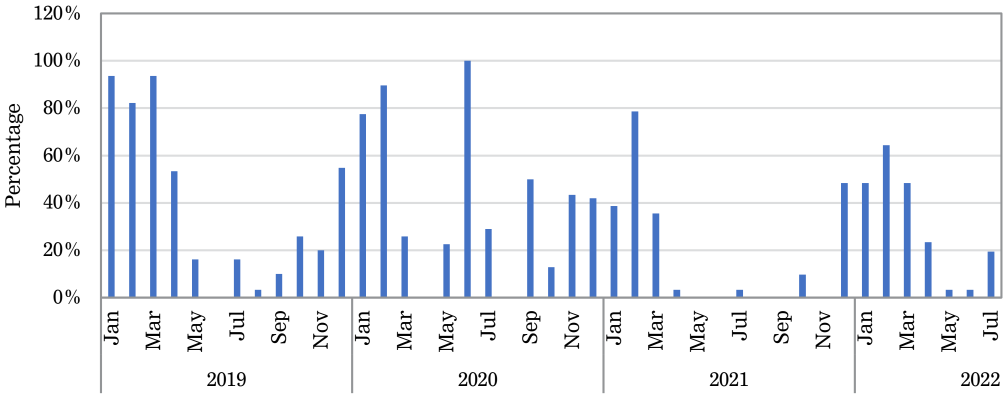

Figure 3.3: 24-hr WHO Standard Limit Exceedance Percentage (January 2019 - July 2022)

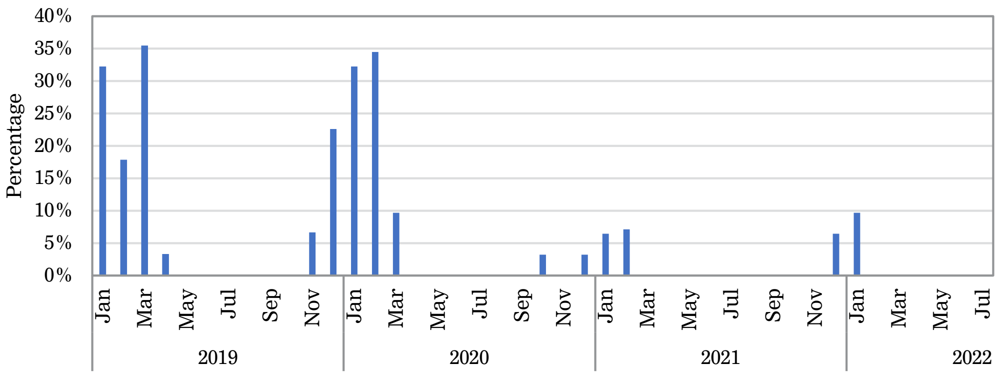

Figure 3.4: 24-hr National Standard Limit Exceedance Percentage (January 2019 - July 2022)

The percentage of days that indicated as Unhealthy for Sensitive groups according to the United State Air Quality Index (USAQI) as $PM_{2.5}$ during the study period is summarised in Figure 3.5. Accordingly, days that recoded as Unhealthy for Sensitive groups according to USAQI with respect to $PM_{2.5}$ are scattered around the year and high in North-East monsoon period.

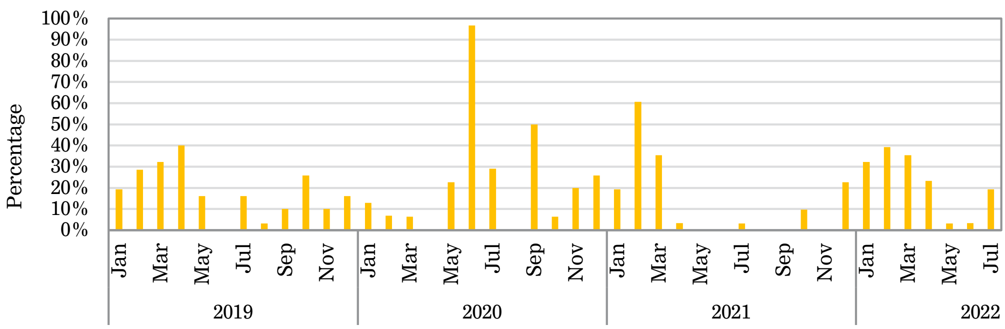

Figure 3.5: Percentage of days as Unhealthy for Sensitive Groups (January 2019 - July 2022)

As shown in Figure 3.6, the percentage of number of days that lies above the unhealthy level of USEPA AQI with respect to 24 hour $PM_{2.5}$ level above unhealthy level with respect to USEPA AQI are concentrated in North-East monsoon period. However, the data indicates that the levels of unhealthy conditions during the North-East monsoon of 2020-2021 were lower than that was in 2019. This could be due to the Covid-19 lockdown period during 2020 and 2021

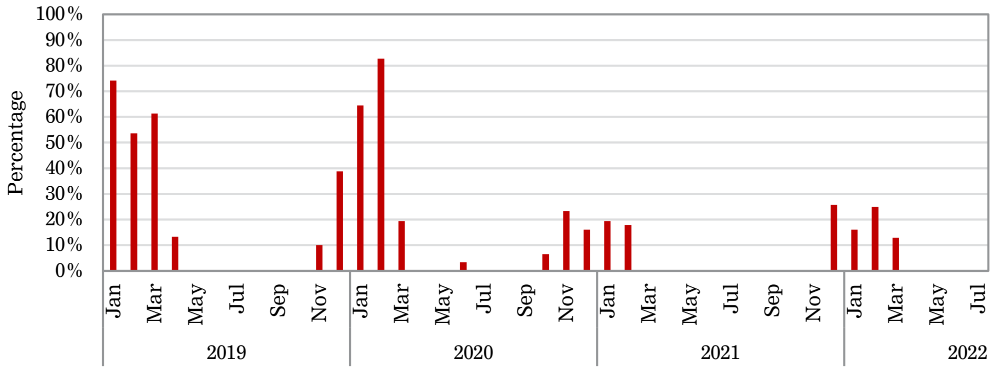

Figure 3.6: Percentage of days as Unhealthy according to AQI (January 2019 - July 2022)

According to the details obtained from international predictions, all days that recorded as unhealthy as per USAQI were due to the contribution of trans-boundary pollution levels. This situation is highly critical in Colombo, since the population that exposure to these high pollution levels is significantly high. Exposure to these unhealthy conditions of air pollutants could cause health impacts, particularly for sensitive groups, younger children (0-10 years) and elderly persons, who are susceptible to air pollution and are at high risk. [8] Not only sensitive groups, but other individuals may also be affected by this high short-term pollution condition mainly due to respiratory diseases such as changes in lung function, types of Asthma symptoms and frequent occurrence of wheezing, etc. In addition, there are many adverse effects of exposure to high $PM_{2.5}$ during pregnancy including preterm birth, low birth weight, intrauterine growth restriction and congenital anomalies, etc. [9]. Therefore, necessary actions should be taken to minimize exposure to air pollutants during these days.

Since this situation occurs during North-East monsoon period every year, it will be critical in the future with the urbanization and climate change impacts. Therefore, it is high time to take action and implement strategies to overcome or face this situation before it escalate into a disaster. The following actions are identified as a preparedness plan to overcome or to minimize exposure levels on critical days due to air pollution in Colombo area.

- Aware public to take precautionary actions and limit exposure to high pollution levels
- Limit operation of thermal power plants around the Colombo urban area at this critical period during increased levels of $PM_{2.5}$
- Limit vehicle entry to the city through public awareness programs during the high-risk period
- Limiting open burning within the city area during the critical period

- Limiting commercial activities and operations of their power generators as much as possible
- Providing the contribution from local government and changing of public attitudes through the awareness
- Consider this period as an emergency situation and work cooperatively with all the relevant stakeholders in public and private sector
- Closure of schools, stop public gathering, etc. within the city limit depending on the situation
- Adopting proactive environmental management strategies to become more efficient and compatible with the society

All these actions were identified as a Preparedness plan are local actions to reduce local emissions to minimize the high air pollution since it is difficult to curtail trans-boundary contribution. Hence, we can effectively address these air quality problems through these measures. However, the actual contribution from each source has to be estimated to assess the effectiveness of the above activities and to estimate the actual reduction of exposure level which requires further studies.

4. Conclusion and way forward

The study showed a significant increase of $PM_{2.5}$ concentration during the North-East monsoon period of the year. Accordingly, the risk level of short-term exposure level in certain days during this period is relatively high. Therefore, more concern should be drawn to air quality management in Sri Lanka during this period. Local emissions can be controlled by limiting the operation of thermal power plants and open burnings within the city, implementing effective vehicle entry system to the city and public awareness with effective government intervention. This study is an identification of the risk level with respect to $PM_{2.5}$ and further studies should be carried out to assess the effectiveness of actions proposed to minimize the risk by quantifying the contribution of each pollutant source and emission reduction through the activities mentioned in the proposed plan.

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Building Resilience amidst
Economic Challenges

Mechanical and physical parameters of plant growing pervious concrete made from recycled aggregates

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Abstract

Currently, various types of research are conducted on controlling surface water runoff and infiltration on steep terrains and riverbanks toward slope protection. The method of shotcreting is one of the most popular solutions used to stabilize slopes, but covering a large area of land with concrete significantly increases surface runoff and reduces rainwater infiltration. On the other hand, cultivation on sloping land incurs the opposite effect. Therefore, a study is conducted to develop a media which can control those parameters and towards slope protection. Furthermore, with the abundance of concrete materials on earth, researching recycled materials became a new topic in construction. Therefore, this study focuses on reusing recycled concrete to develop a new medium called porous/pervious concrete. By vegetating the surface of pervious concrete, the researchers believe in achieving several other benefits in controlling surface water runoff and infiltration. Therefore, several laboratory tests were conducted to find the physical and mechanical parameters of recycled aggregates and pervious designs. Considering the observed physical and mechanical parameters of recycled aggregates and pervious concrete and based on the literature, The product can be suggested for the applications such as ground covering or pavings. Further, the study was conducted toward identifying a grass type that can be recommended to endure the high alkaline property of pervious concrete.

Keywords: Pervious Concrete, Recycled aggregate, Vegetation

1. Introduction

With rapid urbanization, concrete became the most abundant manufactured material used in the modern world. Although, the high demand and production of concrete will leave a high amount of construction waste on the earth. As a solution, various types of research are conducted towards utilizing this wastage. One of the most researched fields of study is reusing or utilizing recycled concretes for construction purposes. This manuscript is focused on testing the possibility of using recycled aggregates to develop a pervious concrete. The pervious concrete is known by different names such as no fine concrete, permeable concrete, and porous concretes. The absence of fine aggregates causes a significant impact on the number of connected porosity inside the structure, leading to higher water infiltration and lower strength of the concrete. Therefore, pervious concrete is popularly used in applications related to water management, such as eliminating water retention areas, controlling stormwater runoff, reducing glare on road surfaces, etc. (ACI Committee, 2011).

Nevertheless, there are many limitations regarding producing pervious concretes. Specifically, these concretes have a high response to the water content. The excess water content in the mixing process will cause the clogging of connected pores and reduce water infiltration levels as much as the loss of strength. Nevertheless, lack of water could be affected the inhomogeneity of the mixture, which could be caused lower strength values. Also, this type of concrete needs extended curing time (ACI Committee, 2011).

The concept of sprouting on concrete is very new to the field of pervious construction works. The sufficient space among the coarse aggregates/recycled concrete and the high volume of connected porosity provide sufficient space for the root growth of vegetated grasses. But the lack of nutrition within the pores and the high alkali substance of concrete dismissed by the cement hydration process severely affect plant growth. Considering the pore diameter, the thickness of the concrete cover and the alkalinity, a suitable vegetation type should be selected.

Due to the above difficulty of lacking nutrition inside the concrete, the pervious design is planned to be filled with soil, nutrition, and water-mixed slurry. The diameter of the pores should be between 2 mm – 3 mm for root growth through the concrete more effectively. If the pores are larger than 3 mm, the water content inside the pervious design will quickly evaporate and lose moisture. Accordingly, the total volume of pore content should be maintained between 20% - 40% of the concrete volume. Therefore gradation aggregate between 12.5 mm – 20 mm is used to develop pervious concrete.

Further, apart from the aggregate size and gradation, the mix details significantly impact pore size and density. Hence strength and rate of water infiltration directly depend on those factors. Here, due to the high water absorption property of the recycled aggregate, less water is left for the cement hydration process, resulting in the loss of strength of the pervious concrete. Further, flaky and elongated recycled aggregate particles cause a slight impact on the strength properties.

However, those as mentioned earlier, physical and mechanical parameters can be considered controllable factors. But attention should also be paid to some unavoidable natural phenomena, such as rapid carbonization and air slacking, which directly impact the durability of pervious concrete. The pervious concrete has a significantly larger area exposed to the air and water compared to the conventional concrete. Since the initial casting, the concrete is extremely exposed to CO_2 and other gasses in the air and dissolved in water as well. In this exposure period, rapid carbonization can occur; therefore, the alkalinity of the concrete is reduced, and cracks can occur due to contractions in the cement paste, which leads to severe losses in concrete strength.

2. Methodology

To ensure the performance of the pervious design, the parameters such as water absorption, density, aggregate crushing value, flakiness index and elongation index were determined. On the other hand, it is essential to maintain proper mix-design to gain physical and mechanical properties. Afterwards, the mechanical and physical parameters of the pervious concrete design, such as compressive strength, and flexural strength, were determined. This manuscript reported all the parameters mentioned above except water infiltration.

2.1. Determination of the density and water absorption coefficient of recycled aggregates

The recycled aggregates were tested to determine the density and the water absorption by following the test standard BS 812-2 (British Standards Institution, 1995).

Figure 1: (a) specific gravity frame, (b) SSD aggregate sample

First, the recycled aggregates were immersed in a tank using a wire basket and let it saturate for 24 hours. Then the basket was attached to a balance and took the apparent mass of the sample (M_1). Then gently empty the aggregate from the basket, and using a dry cloth, the aggregates were wiped until the saturated surface dry SSD condition was obtained. The mass of the SSD aggregate (M_2) was taken. Finally, the sample was oven dried at 105°C ± 5°C and took mass (M_3). The equations for determining the densities and the water absorption (WA) of the aggregate sample are as follows;

$$WA = \frac{100 \times (M_2 - M_3)}{M_3} \qquad \rho_{dry} = \frac{M_3}{M_2 - M_1} \qquad \rho_{SSD} = \frac{M_2}{M_2 - M_1} \qquad \rho_{apparent} = \frac{M_3}{M_3 - M_1}$$

2.2. Determination of the crushing value of recycled aggregates

Determining the Aggregate Crushing Value (ACV) of recycled aggregate is essential when researching low-strength class concretes. Due to the crumbled cement paste and a high amount of flaky particles, the crushing value of the recycled aggregate mixture is expected to be lower than virgin aggregates. The recycled aggregates were tested for determining the ACV by following the test standard BS 812-110 (British Standards Institution, 1990b)

2.3. Determination of the flakiness and elongation index of recycled aggregates

Generally, recycled aggregates mostly consist of cement-coated aggregates and crumbled cement paste. Here the aggregates coated with cement paste can be assumed to be rounded particles, but the crumbled cement paste is more likely flaky. Similarly, the crushed recycled aggregate content does have elongated particles, which cause lower workability of the mixture. It is essential to determine those parameters of the recycled aggregate as the influence cannot be eliminated. Due to the lack of information regard to determining flakiness and elongation indexes for pervious concretes/ recycled aggregates, the British international standards defined for virgin aggregates were used (British Standards Institution, 1989, 1990a).

Figure 2: (a) Determination of flakiness index, (b) Determination of elongation index

2.4. Determination of proper mix design by theoretical calculation

Apart from the mechanical and physical parameters of recycled aggregate, controlling the mix proportion is essential due to the mechanical and physical properties of the final concrete design are strongly correlated to the mix ratio. Furthermore, the water-cement ratio of the mix design is a critical parameter when considering the performance of the final design. Therefore all the mix proportions were determined following the guideline provided by the American Concrete Institute (ACI Committee, 2011). The calculation of the mix proportion is in section 3.3;

2.5. Determination of compressive strength of pervious concrete

Compressive strength is a crucial factor in the study of concrete works. But there is no specific method/standard defined for testing pervious concretes. Therefore BS 1881-116 (British Standards Institution, 1983) defined for conventional concretes was used to determine the compressive strength of pervious concrete.

Also, flexural strength is an important parameter as much as the compressive strength of concrete, indicating the stress at failure in bending. But due to a lack of information regarding a specific method/standard defined for testing pervious concretes. Therefore BS EN 12390-5 (British Standards Institution, 2019), defined for conventional concretes, was used to determine the flexural strength of pervious concrete.

Figure 3: Test for compressive & flexural strength

3. Results and discussion

To ensure the performance of the pervious design, the parameters such as water absorption,

3.1. Density & water absorption coefficient of recycled aggregates

As defined in section 2.1, the density and water absorption coefficient of recycled aggregates were determined. Due to the high water absorptivity of cement paste coated around the aggregate, significant mass change can be observed. The water absorption of 3.4% to 7.4% was observed for 10 – 20 mm graded recycled aggregates. The density was obtained by considering oven-dry weight, apparent weight, and saturated surface dry weight. The water absorption of the recycled aggregate can be accepted considering the sufficient evidence recorded in previous research data (Cheng, Hsu, Chao, & Lin, 2011).

Table 1: Comparision of the water absorption of virgin and recycled aggregates

No	Type of aggregate		Average water absorption (%)
1	Virgin aggregate		0.36
2	Recycled aggregate	Low content of cement paste	3.45
		Medium content of cement paste	4.43
		High content of cement paste	7.35

Table 2: Comparision of the density of virgin and recycled aggregates

No	Condition of aggregate (Medium content of cement paste)	Virgin aggregate (kgm^{-3})	Recycled aggregate (kgm^{-3})
1	The density of oven-dry basis (ρ_{dry})	2670	2410
2	The density of SSD basis (ρ_{SSD})	2680	2510
3	Apparent particle density ($\rho_{apparent}$)	2700	2690

3.2. Flakiness index and elongation index of recycled aggregates

As defined in section 3.2, the flakiness and elongation indexes of recycled aggregates were determined. The observations are as follows. According to the data (Table 3), the flakiness index recorded a significantly higher value than the virgin aggregates (Shrestha, Bhandari, & Chhetri, 2022)

Table 3: Flakiness & elongation indexes

	Sample 1	Sample 2	Sample 1
Flakiness index (%)	13.42	12.64	20.72
Elongation index (%)	26.66	26.92	16.03

3.3. Theoretical mix proportion

The binder used in the mixed design was Ordinary Portland Cement (OPC), and no additives were used. Here the dry aggregate mass was found by using the following equation.

$$W_a = \rho_a \times \left(\frac{b}{b0}\right) \times v$$

$$W_a = 1224.24kgm^{-3} \times 0.99 \times 0.0033m^3 = 3.999kg$$

Here Wa represents the dry aggregate mass and the dry rodded density (ρ_a) given as 1224.24 kgm^{-3}. The b/b0 represents the ratio of the dry-rodded volume of coarse aggregate per solid volume of coarse aggregate, which is 0.99 taken in accordance with the test standard of ASTM C33/C33 M (ACI Committee, 2011; ASTM Standard C33, 2003). The volume of one cube mould is 0.0033 m^3.

Secondly, the Saturated Surface Dry (SSD) mass was found. Here the average value of the predetermined water absorption coefficient of 1.05076 was considered.

$$W_{SSD} = 3.999kg \times 1.05076 = 4.201kg$$

The paste volume was determined using the relationship between the required void content and the paste content (Figure 4) reported by the ACI committee (ACI Committee, 2011).

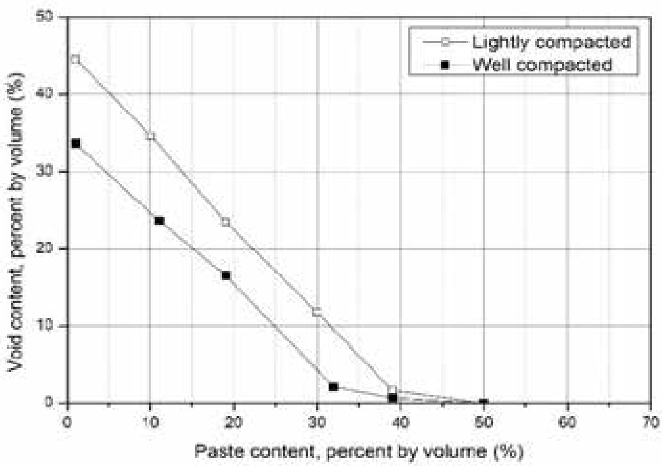

Figure 4: Relationship between paste volume and void content (ACI Committee, 2011)

The paste content required to obtain 20% of the void percentage for light compaction is 22%. Twenty-two per cent of 0.0033 m3 is 0.000726 m^3. The required cement content was found by using the following equation. Here 0.315 is taken as the specific gravity of cement, and 0.3 is taken as the w/c ratio.

$$c = \left(\frac{V_{void} \times 0.22}{SG \times R_{wc}}\right) \times \rho_w$$

$$c = \left(\frac{0.000726m^3}{0.315 + 0.3}\right) \times 1000kgm^{-3} = 1.18kg$$

Accordingly, the water content was found using the mass of cement content and the w/c ratio.

$$w = 1.18kg \times 0.3 = 0.354$$

The ratio between the masses of cement, recycled concrete aggregate, and water content were determined, and the mix proportion was obtained as follows.

$$1.18kg : 4.201kg : 0.354kg \rightarrow 1:3.5:0.3$$

In the experimental mixing process, it was observed that the required water content for the best mix design is less than the theoretical ratio. Here, water was added to the mixture until the pervious concrete mixture, which was rolled by hand, turned into a ball without collapsing or losing its hollow structure.

Figure 5: Pervious concrete mixture

3.4. Compressive & flexural strength of pervious concrete

As mentioned in section 2.5, the compressive strength of the pervious concrete was tested to determine the compressive and flexural strength of the pervious concrete. The data obtained from the test series are as follows.

Table 4: Data Obtained from compressive and flexural strength tests

Curing period (days)	7 days	28 days	28 days <
Average compressive strength (MPa)	5.33	5.66	6.16
Average flexural strength (MPa)	0.979	1.135	1.487

According to the data obtained from the test series, the pervious concrete shows a slight enhancement in strength development. Compared to the previous research (Li, 2012; Sriravindrarajah, Wang, & Ervin, 2012; Wang, Sun, Ding, Kang, & Nie, 2019) conducted on developing pervious concrete with recycled aggregates, the obtained value is acceptable.

3.5. Discussion on the possibility of vegetating the pervious concrete design

As mentioned in the previous sections, the pervious concrete was designed and developed to have at least 20% of void volume to create sufficient space for growing roots through the concrete medium. As the most critical parameter affecting vegetation growth is the alkaline quality of the substrate, this development may have some difficult conditions for grass growth. Therefore the authors suggest reducing the alkalinity of the medium before plantation. However, the alkalinity of concrete can be reduced due to rapid wash-off with rainwater and carbonation. But it can be affected the strength as well. Also, the porous volume can be filled with a high nutrient medium with an appropriate pH level. Considering the alkalinity of the complex medium alkaline endurance, perennial grass species can be suggested for sprouting. The "Chrysopogon Zizanioides" (aka Vetiver grass or Savandara) was identified as an excellent alkaline endurance species (ADPC, 2020). The authors believe this species will survive because of its highly suitable root characteristics and tolerance to extreme weather, climate and soil conditions.

4. Conclusion and recommendations

Through this approach, the authors investigated the applicability of recycled aggregate for developing pervious concrete. The purpose of developing this pervious concrete by utilizing a waste product is to address two significant problems in the modern world: difficulties incurred in slope protection and waste management. Therefore identifying the mechanical & physical parameters of this novel design is essential. But due to the lack of information regarding the use of pervious concrete, it is quite challenging to compare the test data, and most of the tests were conducted following the test standards defined for conventional concretes. The behaviour of the pervious concrete is utterly different from the conventional concretes. Also, the pervious concrete could not reach high strength due to its significant void content. The main focus of the manuscript was to investigate the material performance of pervious concrete and develop a mix design. Afterwards, the study was conducted to investigate a suitable perennial grass species. As the next stages of the study, this will continue by altering the pH level of the internal medium of the pervious design and investigating the vegetation performance, including water infiltration and surface runoff.

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Building Resilience amidst
Economic Challenges

Development of ISO standard sand from local silica deposits for cement testing

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Abstract

ISO standard sand is a siliceous natural material used in the testing of cement for the SLSI certification process, material approval in construction projects, and material clearance in importing cement. Testing laboratories in Government institutes and cement manufacturers import standard sand as it is not produced in Sri Lanka. Under the current economic situation in Sri Lanka, the government has imposed restrictions on importing standard sand required for the testing of cement. Hence, this research is mainly focused on developing ISO-standard sand using locally available material. SLS ISO 679 standard describes the requirement and testing procedures for the standard sand. There are several requirements specified in SLS ISO 679 (Institution, 2008) for standard sand, such as particle size distribution and moisture content, and it has to be verified with reference sand. Locally available vein quartz and silica sand were selected for this study due to their high silica content. In this study, standard sand was prepared by combing both silica sources to satisfy the requirements of standard sand specified in SLS ISO 679. Inter-laboratory test results of different cement types with the developed local standard sand indicate that the repeatability and reproducibility of the compressive strength test results are at a satisfactory level.

Keywords: ISO standards sand, Silica sand, Compressive strength

1. Introduction

International and local standards describe testing on the physical and mechanical properties of cement to check product quality. In the SLS certification process, materials clearance for consignment and source approval in construction projects, the test results of compressive strength of cement based on cement mortar are essential. The method for assessing the compressive strength of cement is given in SLS ISO 679, where ISO standard sand is required for the testing of cement.

1.1. Market survey

Currently, ISO-standard sand is not produced in Sri Lanka. According to the market survey conducted among the cement manufacturers and testing agencies, standard sand is imported mainly from China, France and Germany. Further outcomes of the survey, eighty thousand US dollars was spent importing around 40,000 packets of standard sand in 2021. Each packet contains 1,350g of sand required to test one sample of cement.

1.2. Literature review

Specifications of ISO standard sand are given in the SLS ISO 679 Standard (Institution, 2008). The main properties of standard sand are particle size distribution and moisture content. Particle size distribution shall lie within the requirements given in Table 1, and moisture content shall be less than 0.2%, expressed as a percentage by mass of the dried sample.

Table 1: Particle size distribution of standard sand

Square mesh size (mm)	Cumulative sieve residue %
2	0
1.6	7 ± 5
1	33 ± 5
0.5	67 ± 5
0.16	87 ± 6
0.08	99 ± 1

During the production of standard sand, particle size distribution and moisture content should be determined daily. To ensure the standard sand is equivalent to reference sand, a certification testing programme comprises a comparison of the standard sand with the reference sand as described in SLS ISO 679. The ISO reference sand is a natural, siliceous sand consisting preferably of rounded particles and has a silica content of at least 98%. In Sri Lanka, vein quartz (pure silica) deposits are found in Matale, Dambulla, Trincomalee, Balangoda and Badulla. It is the main ingredient used in manufacturing computer chips and other electronic devices. The main product of pure silica is pure silica crystal and quartz powder (Pathirage, Hemalal, Rohitha, & Ratnayake, 2019). Silica sand deposits are found in Nattandiya, Marawila, and Madampe, which extend south of Colombo as a sporadically distributed deposit. Quartz (silica) sand is the main raw material used in manufacturing glass. It has specific features such as fine graded, white in colour and high purity, making it a commercially viable silica source (Somapala & Fernando, 2011).

2. Methodology

2.1. Preliminary study

Preliminary studies were conducted to analyze the properties of ISO-standard sand imported from China, France, and Germany to determine the particle size distribution, void content, mineralogical composition and particle shape. A sieve analysis test on standard sand was conducted to observe the particle size distribution.

Since the angularity, sphericity, and surface texture of sand particles affect the workability of cement mortar, it is important to compare those properties of the standards sand obtained from different sources and use those properties as a guide in developing local standard sand. When finding a suitable source of sand, the mineralogical composition is also an important parameter. The XRD test was conducted to analyze the mineralogical composition of standard sand and as well as silica sand sources available in Sri Lanka.

2.2. Local standard sand preparation

According to the mineralogical analysis, as tabulated in Table 2, the main mineral phase in standard sand and other local sources is quartz. Therefore, silica sand and quartz powder were selected as local sources for this study. Silica sand was obtained from the Marawila area in the Puttalam district, and Quartz powder from Naula in the Matale district. According to the mineralogical analysis, as tabulated

The silica sand obtained from Marawila was washed thoroughly to remove clay and silt. The washed sand was dried in the oven at 105 ^{0}C and cooled to room temperature. The sieve analysis was conducted for both washed silica sand and quartz powder using the relevant sieves available in the laboratory to separate each size fraction. It was observed that the percentage of particles less than 150 microns in silica sand is very small. Therefore, quartz powder is used to replace the above size range in producing standard sand. Particles retained on each sieve were collected in separate bins. Particles less than 2mm and greater than 0.15mm were obtained from silica sand, and particles less than 0.15mm were obtained from quartz powder. By mixing the required size fraction to satisfy the particle size distribution given in Table 1, local standard sand packets containing 1 350 ± 5 g were prepared.

3. Test results and discussion

3.1. ISO standard sand

As preliminary studies, particle size distribution and uncompacted void content were determined as per relevant standards.

Analysis of particle size distribution of all standard sand sources was conducted according to ASTM C136 (American society for testing and materials, 1996). Figure 1 shows the particle size distribution of each standard sand source, and it can be seen that all standard sand sources comply with the limits given in SLS ISO 679 standard except sources II where there is a small deviation in the percentage of particles retained on 1.7mm sieve size.

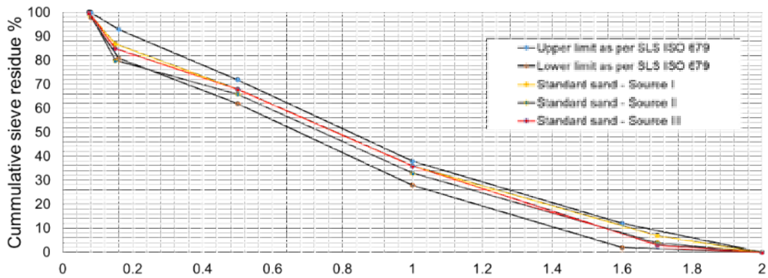

Figure 1: Sieve analysis of ISO standard sand sources

The uncompacted void content of all standard sand samples was determined according to the ASTM C1252-17 (American society for testing and materials, 2017), and the void content of ISO standard sand sources I, II and III was found to be 38.72%, 37.25% and 39.13% respectively. Particle shape was observed by optical microscope and found to be rounded in shape (See Figure 2).

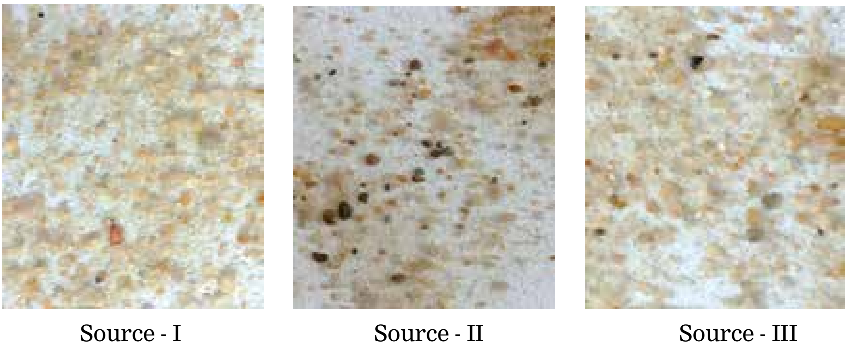

Figure 2: Particle shape of standard sand

The mineralogical compositions of standard sand and local silica sand sources were determined by conducting the XRD analysis. Test results of all samples tested are given in Table 2.

Table 2: Mineralogical composition by weight %

Mineralogical component	Mineralogical composition by weight %		
	Standard sand – Source III	Silica sand	Quartz powder
Quartz	90.55	94.88	94.44
K-Feldspar	2.5	0.69	0.45
Albite	1.89	0.3	0.06
Illite	1.41	0	0
Anorthite	0.51	0.73	0.67
Pyrite	0.05	0	0.01
Calcite	0	0.01	0.04
Dolomite	0	0	0.06

It can be seen that the main mineral component of standard sand source- III is quartz which is the crystal form of SiO2. XRD test results also show that the quartz percentage of local sand sources exceeds 94 %. Hence, the study was conducted with these two local sources and sieve analysis was conducted on these sources.

Table 3: Sieve analysis of Local sand sources

Square mesh size (mm)	Cumulative sieve residue %	
	Silica sand	Quartz powder
2	1	-
1.7	1	-
1	9	-
0.5	37	0
0.15	78	9
0.075	99	62
Pan	100	100

According to the sieve analysis test results in Table 3, the percentage of particles between 0.15mm to 0.075mm in silica sand is small compared to quartz powder. Hence, the standard sand sample was prepared by combining the size range of 2mm to 0.15mm from silica sand and the rest of the particle size range from quartz powder.

3.2. Testing on prepared standard sand with local silica sand

A test sample was prepared according to sieve analysis of standard sand source I, and void content was determined to check the compatibility. The void content of the local standard sand sample is found to be 34.37%, and it is not significantly different from the standard sand source I.

The compressive strength of cement mortar samples prepared with ISO standard sand (Source I) and standard sand prepared with local sand were determined as per the procedure given in SLS ISO 679 standard. All conditions in sample preparation, such as cement type, casting date, temperature, humidity, and curing procedures, were kept the same for all samples. The test results of the 28-day compressive strength of mortar samples are shown in Table 4. Consistent test results were obtained with both standard sand samples, and the variation of average strength results is less than five per cent.

Table 4: Compressive strength test results of ten sample

Sources	Compressive strength (N/mm^2)	
	Avg. value of each sample	Average
ISO Standard sand (Source- I)	42.9, 43.6, 43.2, 42.6, 43.0, 42.1, 42.2, 43.2, 43.3, 43.6	43.0
Prepared ISO standard sand	40.9, 41.3, 43.1, 41.1, 40.7, 39.6, 40.1, 42.0, 40.2, 40.9	41.0

Compressive strength tests with the other two ISO Standard sand sources were also conducted following the similar procedure described above, and test results are shown in Figure 3. It is important to note that the particle size distribution of local sand was varied to match each ISO standard sand particle size distribution. It can be seen that there is considerable variation in strength results with three different ISO standard sand sources (i.e., 43.0 MPa, 45.5 MPa and 41.9 MPa). Further, even with the same particle size distribution, there is a variation of strength with one ISO standard sand (i.e. Source III) and the local standard sand. These results indicate the effect of not only particle size distribution but also characteristics of sand particles, such as particle shape and surface texture, on the strength of cement mortar.

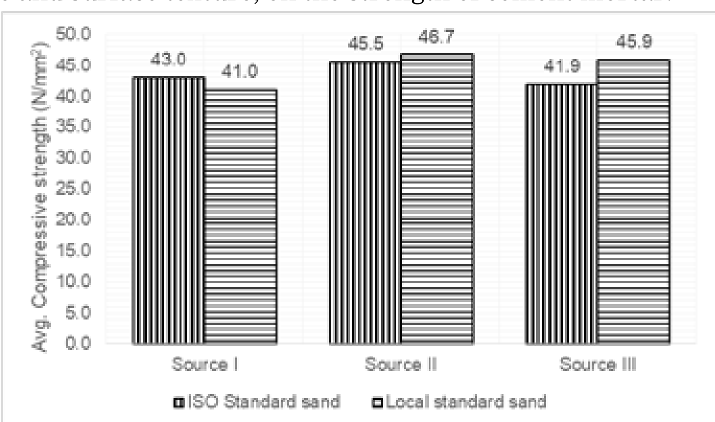

Figure 3: Compressive strength test result comparison with ISO standard sand

An inter-laboratory comparison was performed with six laboratories, including four accredited laboratories for compressive strength testing of cement at 2 days and 28 days for Ordinary Portland Cement, Blended Hydraulic Cement and Portland Composite Cement to evaluate the repeatability and reproducibility of strength test results under controlled conditions with the use of local standard sand. The variation of test results of each laboratory from the population was estimated by calculating Z-score. According to the Z-score analysis, the variation level between laboratories is at a satisfactory level, as shown in Figure 4 and Figure 5 (Brookman & Mann, 2021).

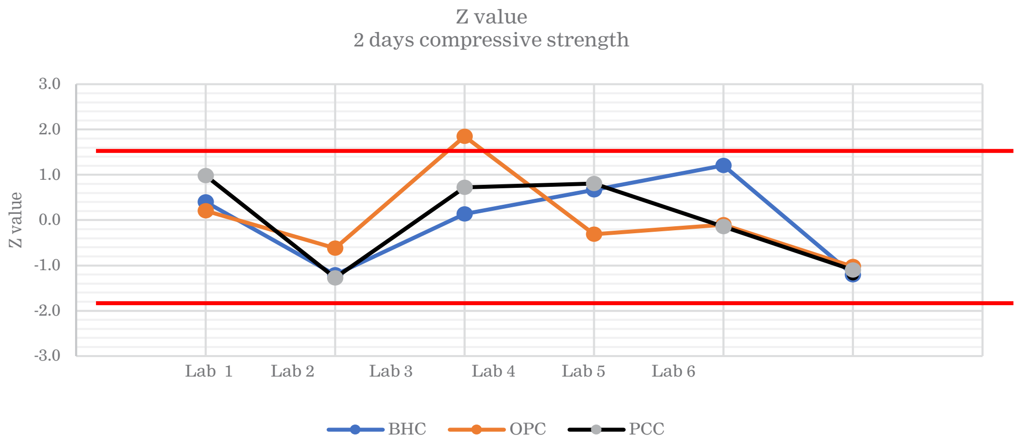

Figure 4: Z value of 2-day compressive strength

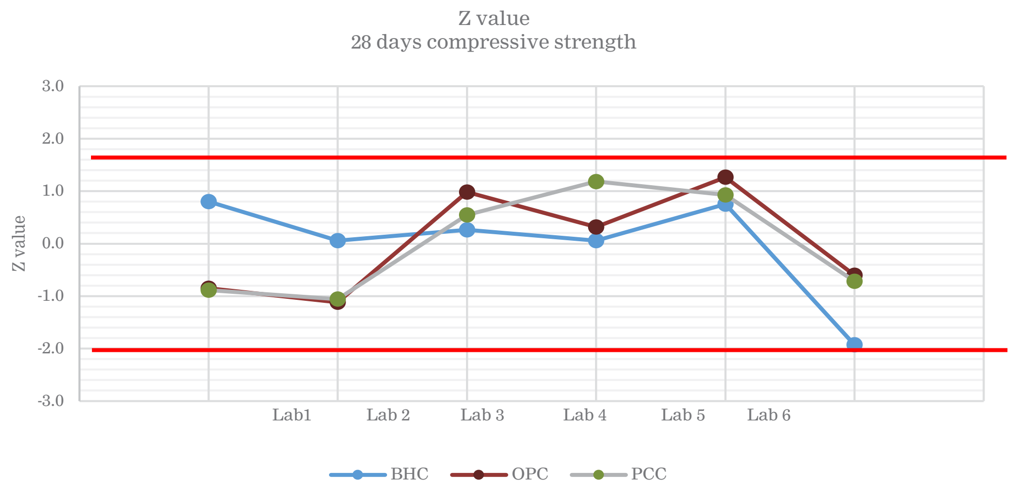

Figure 5: Z value of 28-day compressive strength

4. Conclusions

It was observed that there is a considerable effect of the particle size distribution of the ISO Standard sand on the compressive strength of cement mortar, even though the particle size distribution is within the recommended band limits as specified in SLS ISO 679. It was also observed that, even with the same particle size distribution, there was a variation of strength between different sand sources. These results indicate the importance of controlling not only particle size distribution but also characteristics of sand particles, such as particle shape and surface texture, when developing standard sand in order to obtain consistent results when testing cement for strength.

Inter-laboratory test results of different cement types with the local standard sand under controlled conditions indicate that the repeatability and reproducibility of the compressive strength test results are at a satisfactory level. The manufacturing process of the standard sand should be done under relevant quality control procedures and certification processes for production and quality.

Acknowledgement

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Building Resilience amidst
Economic Challenges

Use of off-shore sand sludge as a replacement for silica sand fillers in cementitious tile adhesive production

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Abstract

Off-shore sand is an alternative material for fine aggregate for construction. It has also been used in the local construction industry in Sri Lanka over the last two decades. Off-shore Sand Sludge (OSS) is produced as a byproduct rich in Calcium Carbonate during the processing of off-shore sand. OSS consists of very fine particles, most of which are below 0.6 millimetres. Since the chemical and physical properties of the filler affect the properties of the post-produced value-added product, OSS samples from the sand dump were first analysed. Investigations were carried out to explore the possibility of using OSS as the filler material replacing silica sand in producing cement-based tile adhesive. Tile adhesive mixtures were designed incorporating OSS(Filler), Cement (42.5N) (Binder), Redispersible Polymer Powder (RPP), and Hydroxypropyl Methyl Cellulose Ether(HPMC). Qualitative analyses were done for fresh adhesive mortar for crack resistance, workability, and consistency of mortar by adapting test methods specified in related research studies. Quantitative measures for produced tile adhesives were performed according to BSEN 12004-2 Adhesive for ceramic tiles. As the results obtained were almost compatible with the minimum requirements of the relevant standards and norms, it was testified that OSS could be successfully utilised in the production of cement-based tile adhesives. Upscaling the production process through further background investigations, this study can be considered a sustainable building construction practice that also addresses the problem of waste generation in offshore sand processing plants in the country.

Keywords: Off-shore sand sludge, Filler material, Ceramic tile adhesive

1. Introduction

Various types of tiles are used for interior and exterior finishing and decoration purposes in the modern construction industry. At present, tiles are attached to the surface using tile adhesives, and it was a long journey for tile adhesive technology to reach the present cement-based adhesive (Winnefeld, 2012). Although adhesion failure and detachment of the tiling were common failures when cement was used as the adhesive for ceramic tiling, cement-based tile adhesive with modifiers and additives was given as the solution and thus improved the quality of the tiling (Petit & Wirquin, 2013). Therefore, using tile adhesives to fix tiles on floors and walls is becoming increasingly popular now in Sri Lanka.

The development of additives and modifiers is a prominent factor in improving workability, flexibility, and adhesion. The quality of a tile adhesive mainly depends on the adhesion strength and maximum open time before laying the tile. Further, the downward movement of a tile is another major factor that affects the laying of tiles on verticle surfaces. Tile adhesives mainly consist of binders and mineral fillers and are modified using Cellulose Ether(CE) and Re-dispersible polymer powder(RDP). These additives function to fulfil different requirements throughout the time between the fresh state and the hardened state. Ordinary Portland Cement is the most typical binder in tile adhesive, and various types of mineral fillers, such as Carbonate fillers and natural sand, are used in combination with the binder to improve the adhesive's strength properties (Petit & Wirquin, 2013).

Off-shore sand properties depend on the sand extracted area in the ocean. The composition, chemical properties, and particle size distribution depended on the sand sedimentation budget and the ocean ecosystem of that area. Also, the quality of off-shore sand can vary according to the different pollutants added to the ocean. The extracted off-shore sand undergoes a particular washing and sieving process to obtain certain properties before sending them to the local market. Large shells and gravels are removed first, and then systematic washing and sieving process is done using normal drinking water to reduce the Chloride content and remove the fine particles in the off-shore sand. These fine particles removed here in the back-wash water are then separated by a sedimentary process, which is the primary concern in this project to study the feasibility and development as a value-added waste.

Off-shore sand sludge(OSS) is a low gained sandy material enriched with Calcium Carbonate. The properties of OSS were already investigated and published in 2021, and it suggested use as a filler for tile adhesives (Suraweera, Fernando, Muthurathna, & Guluwita, 2021). Therefore, tile adhesive material was manufactured by replacing mineral fillers using OSS, and the properties are evaluated to confirm the suitability of OSS in producing the tile adhesive mixtures. The main focus of the current investigation is to study the effect of the particle size distribution of OSS on the properties of tile adhesive.

2. Materials and mixture proportioning

2.1. Off-shore sand sludge (OSS)

The properties of OSS depend on the characteristics of the raw off-shore sand. For instance, types of organic and inorganic compounds dissolved in the off-shore sand, amounts of dissolved salts, amount of clay, fine silt, and fine dust in the off-shore sand, the amount of shell content, and the number of coal residues in off-shore sand are some of the vital factors. Because off-shore sand is widely used as a fine aggregate in the construction industry, it must be free of these impurities. For that, off-shore sand has undergone a process of washing and sieving in which the OSS is produced. The chemical and physical properties of the OSS should be confirmed before utilising it for any product. Properties of the OSS were discussed under the "Analysis of the Waste

Sludge Produced from the off-shore sand and Processing Plants in Sri Lanka" paper published in 2021. (Suraweera, Fernando, Muthurathna, & Guluwita, 2021)

Two types of Mixtures were prepared using OSS by changing the particle size range: M1 and M2. 0.6mm to 0.125mm OSS was used to manufacture M1, and below 0.6 mm particle range was used to manufacture M2. Furthermore, Cement (OPC-42.5R), Re-dispersible polymer (RDP), and Cellulose ether (HPMC) modifiers proportioning the constant weight percentages to study the behaviour of OSS particles in cementitious tile adhesive mixtures were used. The OSS should be dried under normal conditions and sieved to appropriate scales, as mentioned in Table 1.

Table 1: Tile adhesive mix proportions

	M1	M2
Cement (OPC-42.5R) *(mass % of dry mixture)*	35	35
Off-Shore Sand Sludge (OSS) *(mass % of dry mixture)*		
(0.6 – 0.125) mm	61.6	-
<0.6 mm	-	61.6
Re-Dispersible polymer (RDP) *(mass % of dry mixture)*	3	3
Hydroxypropyl-methyl cellulose (HPMC) *(mass % of dry mixture)*	0.4	0.4

2.2. Tile adhesive manufacturing

Typically, C2T ceramic tile adhesive formulation was used to investigate the suitability of OSS as filler for tile adhesives. The constituents' weights were measured separately, corresponding to each tile adhesive mixture, and dry mixing was performed until it became a homogeneous mixture. Half of the weight of OSS and cement were initially added to the container, and then all the polymer modifiers were added. After that, all the remaining half of the OSS and cement potions were added and mixed for 5 minutes. Then the mechanical mixing was stopped, and manual hand mixing was done in 2 minutes to collect the dispersed materials. Again that mechanical mixing was performed for another 8 minutes to achieve a homogenous adhesive mixture.

3. Experimental procedure

3.1. Tile adhesive preparation

Mortar properties can be affected by the mixing procedure and equipment. To have comparable results, the same mixer and mixing sequence were used for each set of adhesive mixtures. A minimum of 2kg of manufactured tile adhesive powder was mixed with the corresponding water content as per the details in Table 2. The adhesive was prepared by an electrical mortar mixer (220v, 1600kW) using a slow-speed setting. First, the water was poured into the pan and then scattered the dry adhesive powder over the liquid. Immediately after, mixing was started and mixed for 1 minute. After being mixed, the mixture was scraped down from the paddle and the pan to collect the scattered adhesives within 30 seconds, and the mixing was resumed for an additional 1 minute. All the equipment used for the mixing and testing was maintained at a constant temperature of 25±2°C

(i) (ii) (iii)

Figure 1: (i). OSS (ii). All the components used for tile adhesive production. (a). RDP (b). HPMC (c). Cement (d).OSS (iii). Homogenous tile adhesive mixture

Qualitative inspection of the adhesive when the adhesive material lies in a field is essential. If there is any crack propagation when the tile adhesive gets hardened, it is investigated by performing a cracking test, especially between the substrate and mortar (interface) and through the mortar surface. A thin adhesive mortar layer was applied first with a straight-edge trowel on a concrete substrate (400mm×400mm×50mm). Then thick adhesive mortar layer was applied and combed with a notched trowel having 6mm×6mm notches at 12mm centres. The specimen was cured at 25±2°C and inspected after 24 hours.

Consistency is a measure of the wetness of the fresh mortar and gives a measure of the deformability of the fresh mortar when subjected to certain types of stress. Therefore, fresh title adhesive mortar consistency is measured using the plunger penetration and flow table in accordance with BSEN 1015-4:1999 and BSEN 1015-3:1999, respectively.

The compressive strength of tile adhesive mixtures was carried out in accordance with BS EN 1015:11-2015. Specimens were cured for 2 days at 25°C and 95% RH with mould; then, de-moulded specimens were cured in the same condition for another 5 days and then cured at 25°C and 65% RH until the test date. In accordance with BS EN 1015:11-2015, the loading rate of $400Ns^{-1}$ was applied when testing for compressive strength of title adhesive mortar at 3, 7, 14, and 28 days. Tensile adhesion strength, open time, and slip were tested according to the BS EN 12004-2 standard. For Tensile adhesion and open-time tests, specimens were prepared on grade 30 (400mm×400mm×50mm) concrete substrates, and the test was processed in three different environmental conditions. Tensile adhesion strength was tested when specimens(50mm×50mm) were cured at normal conditions(25±2°C), after water immersing, and after heat ageing at (70±5°C) in accordance with a BS EN 12004-2.

The downward movement of the tile mortar system was analysed by the slip test for each mixture. Ceramic tile (100mm×100mm) with a weight of 200±10g was used to test the slip of the adhesive as per the BS EN 12004-2. Shrinkage is one of the significant parameters affected by a detrimental failure of the mortar systems in cement-based applications (Winnefeld, 2012). Therefore, the shrinkage of the mortar was tested using the mortar bar method in accordance with ASTM C1148. Three specimens (S1, S2, S3) were tested, and length change was measured within 25 days cured at 25°C to 27°C and 65% RH.

4. Result and discussion

The OSS colour varies from a light brownish colour to dark brownish colour depending on absorbed water content. Dry OSS has a light brownish colour, as shown in Figure 5. It is a sandy material, with no such heavy amount of soil and mud. Analysis of the OSS shows that it can be used as a filler material for the tile adhesive manufacturing process (Suraweera, Fernando, Muthurathna, & Guluwita, 2021). Therefore, two tile adhesive mixtures were prepared to identify the physical properties variation, changing the OSS particle size range. M1 was prepared using the 0.6mm to 0.125mm range, and M2 was prepared by using OSS particle size of less than 0.6 mm. The other constituents of the tile adhesive mixtures are mentioned in Table 1.

The manufacturing process was carried out as described in section 3.1, and 10 kg samples were prepared for each mixture for the laboratory testing process. Each tile adhesive mortar was prepared with 25% of water by mass of the mixture in accordance with Table 2. Mortar consistency was measured using the plunger penetration and flow table tests; the test results are shown in Table 2.

Table 2: Water consumption and consistency of the mixtures

	M1	M2
Water/Powder *(mass % of dry mixture)*	25	25
Flow Table *(%, (mm))*	28(128)	20(120)
Plunger Penetration *(mm)*	16	13

Consistency was not as high as the conventional mortar because of the HPMC, which improves the viscosity of the mixtures, and the liquid gap in tile adhesive concentration is very high (Petit & Wirquin, 2013). Manufactured tile adhesive mixtures with OSS are more sticky than commercially available adhesives. But consistency and workability are the same as the commercially available tile adhesives.

HPMC and RDP react as rheological modifiers to achieve fresh adhesive mortar properties for a certain application. HPMC prevents the segregation and obtains plasticising properties to the fresh mortar. It works as a water retention agent through the process of entrapment (Petit & Wirquin, 2013). When RDP is dispersed and emulsified in a mortar, it creates a thin film to prevent crack initiation and propagation (Phan, 2013) (Tarannum , Pooja, & Khan, 2020). Additionally, adhesion properties also improve by RDP. Therefore no crack initiation and propagation were observed (See Figure 2) in the cracking test for both M1 and M2 mixtures.

(a) (b)

Figure 2: Cracking inspection results (a) M1 (b) M2

The compressive strength of the tile adhesive mixtures in different ages is tested, and the test results show slightly higher compressive strength in M2 than the M1, depending on their void amount in the adhesive. The compressive strength development of the mixtures at different ages (3 days, 7 days, 14 days, and 28 days) is clearly illustrated in Figure 3.

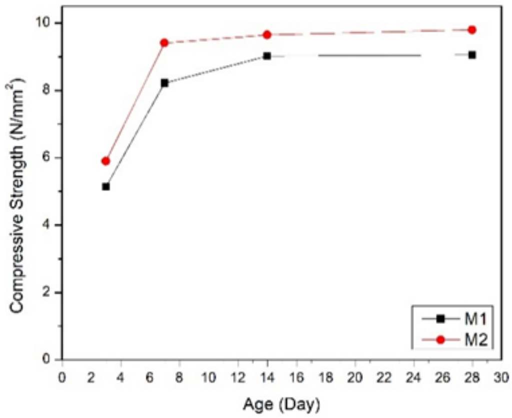

Figure 3: Cracking inspection results (a) M1 (b) M2

Fine particles (below 0.125mm) give a good packing density to the M2 mixture, and it is caused to achieve high compressive strength M1 than M2 (Hayilu & Sahu, 2013). Average Adhesion strength in standard conditions for tile adhesive mixture M1 and M2 are 1.6N/mm² and 1.8N/mm² respectively. These results are well above the specified adhesion strength limit (≥1.0N/mm² /type C2) according to the BSEN 12004-1:2017. Similarly, Adhesion strength after water immersion and adhesion strength after heat ageing test results are also satisfied (≥1.0N/mm² /type C2) for both M1 and M2 mixtures according to the BSEN 12004-1:2017. But M2 achieves better adhesion strength in all 3 conditions rather than the M1 adhesive mixture (See Table 3). All the failures have occurred as cohesive fractures through adhesive or adhesive fracture between adhesive and substrate. Both failure modes are acceptable for calculating the average adhesion strengths in certain conditions.

Table 3: Fresh and hardened properties of tile adhesive mortar

	M1	M2
Fresh properties Cracking *(*See figure 2)*	Not observed	Not observed
Hardened Properties		
Compressive Strength (*N/mm²*)		
3 Day	5.14	5.90
7 Day	8.22	9.41
14 Day	9.02	9.65
28 Day	9.05	9.80
Adhesion Strength (*N/mm²*)		
In Standard Condition	1.6	1.8
After Water Immersion	1.1	1.1
After Heat Aging	1.5	1.6
Open Time (*N/mm²*)		
20 minutes	0.5	0.4
Slip (*mm*)	0.2	0.2

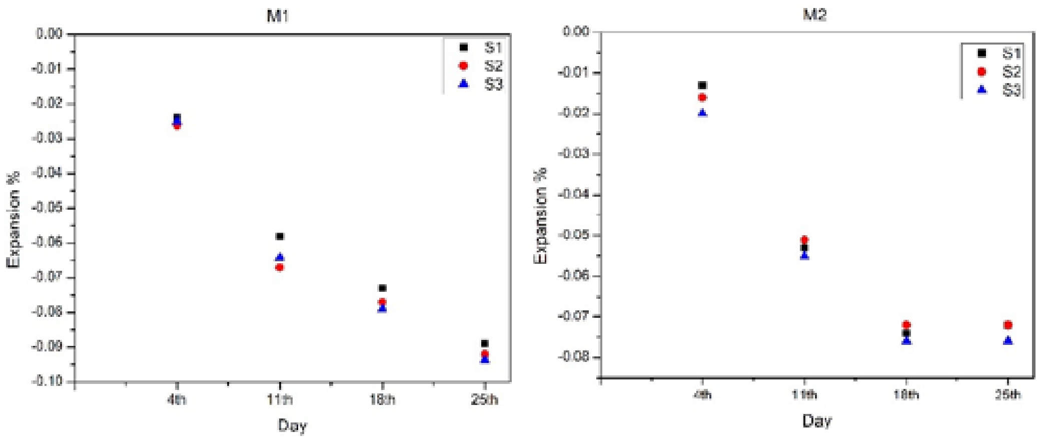

Figure 4: Linear Shrinkage of the M1 & M2

The 20 minutes of open time give a low tensile adhesion strength, as specified in Table 3. M1 satisfied the limit of the open-time tensile adhesion strength (≥0.5N/mm^2 after not less than 20 minutes), but M2 was only able to achieve 0.4N/mm^2 adhesion strength in the 20 minutes open time. Water retention of the M2 is getting lower than M1 due to the presence of fine particles, which causes it to have low open-time tensile adhesion strength than the M1. According to the properties of the OSS, water absorption of the OSS is higher than the natural sand due to the high amount of fine calcium carbonate (Suraweera, Fernando, Muthurathna, & Guluwita, 2021). It would affect to low tensile adhesion strength records in the open-time test.

The slip test satisfied M1 and M2 adhesive mixtures and is lower than the maximum allowable slip limit(≤0.5mm) as per the BSEN 12004:2017. Linear shrinkage of the adhesive materials was tested, and all the shrinkages are illustrated in Figure 4. The maximum shrinkage of the M1 and M2 is 0.094% and 0.076%, respectively, and it is observed on the 25th day and both lowering the shrinkage percentage compared to the initial drying period.

5. Conclusion

According to the results gathered for M1 and M2 tile adhesive mixtures, M2 has better compressive and adhesion strength properties. But both adhesive mixtures satisfied most of the adhesion strength requirements as per the BS EN 12004-1:2017. Further studies on the effects of HPMC and RDP content on cement-based tile adhesive mortar can be studied for achieving more preferable tile adhesive properties. However, the particle size range of OSS filler material mainly influenced gaining compressive and adhesion strength properties to ceramic tile adhesive materials. Anyhow, OSS can be used for the tile adhesive manufacturing process as a filler material replacing natural sand and carbonate fillers. If this tile adhesive manufacturing process can be developed as mass production, it resolves environmental and industrial waste problems with value addition.

Acknowledgement

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Building Resilience amidst
Economic Challenges

Artificial intelligence in non-destructive testing of reinforced concrete structures

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Abstract

Recently, artificial intelligence prediction models have gain considerable popularity in predicting the compressive strength of concrete by using results from the Non-Destructive Testing (NDT) methods as an input. In this research, 270 number of NDT results from rebound hammer (RH) and ultrasonic pulse velocity (UPV) test results from concrete samples with different sand type, cement type and concrete grades were used as input parameters. Concrete compressive strength results were obtained from Destructive test (DT) results of the same. Artificial intelligence (AI) method was implemented using MATLAB software. This study indicates the ability of a multilayer feed forward model as a good technique for determining the concrete compressive strength. Analyzing the results obtained at the end of the study it can be concluded that using UPV, RH data and artificial neural network (ANN), trained using the gradient descent algorithm and two hidden layer architecture, was a suitable method to estimate the compressive strength of concrete specimens. The research results provide a valuable reference for both researchers and the industry practitioners when evaluating in-situ concrete compressive strength using NDT methods.

Keywords: Non-destructive test, Destructive test, Rebound hammer, Ultrasonic pulse velocity, Compressive strength, Artificial intelligence, Artificial neural network

1. Introduction

Non–destructive testing (NDT) methods are more frequently used recently over destructive test (DT) to determine compressive strength and uniformity of reinforced concrete structures. Leshchinsky (1991) summarized the advantages of NDTs by comparing core testing results; a smaller amount of structural damage to the elements, a possibility of testing concrete strength in structures where cores cannot be drilled, reduction in the labour consumption of testing and preparatory work, and relatively time-efficient. However, these advantages signify no value if the results are not reliable, representative, and as close as possible to the actual strength of the tested part of the structure.

Two popular such NDT methods are the Rebound Hammer (RH) test and the Ultrasonic Pulse Velocity (UPV) test for examine the concrete properties. One major drawback of RH test is that the concrete compressive strength estimations are less accurate compared to the results obtained from core tests which is a DT. UPV test gives the integrity of the concrete depending on the density, uniformity, and homogeneity of the specimen. Due to many drawbacks and limitations of the NDT results, the interpretation of gathered data from NDT is a challenging task faced by engineers who are assessing the RC structures. Furthermore, classical methods of assessing structures involves a skilled human interpreters, since human operators are challenged by different factors results can be unreliable. Few factors resulting in unreality can be noted as; using data from a single source to make judgments, human error, experience, physical and emotional constraints, extent of knowledge, enormous size of data etc. (Yella, et al., 2006)

In this research, 270 concrete cube samples were casted in the laboratory to represent the grade 20 and 25 concrete with different types of sand and cement. Aggregates were used in SSD condition and slump was maintained at 110-115mm. After 28 days, samples were first tested using UPV and RH and finally subjected to compressive strength.

In this study, a new approach is presented by considering the combination between compressive strength - UPV - RH of concrete specimens. To this end, an ANN based approach to the estimate the compressive strength of concrete specimens, using UPV and RH values, is utilized in the study.

2. Ultrasonic Pulse Velocity (UPV) test

UPV testing is used to measure the travel time of an ultrasonic wave, normally at 54 kHz, through two points on the concrete and having measured the distance between those points, the apparent velocity is calculated. Direct transmission was used in the study for take readings (Refer Figure 1). The velocity of travel depends on the elastic modulus of concrete. The time taken to travel from one point to another depends on the properties of material encountered through travel. The transducer is placed in contact with the material so that the vibrations are transferred to the material. The vibrations travel through the material and are picked up by the receiver. The wave velocity is calculated using the time taken by the pulse to travel the measured distance between the transmitter and the receiver.

Figure 1: UPV testing for concrete cubes (UPV test was carried out in accordance with BS EN 12504-4:2004)

3. Rebound Hammer (RH) Test

Operation of RH test is illustrated in Figure 2. Although this method is not ideal for measuring compressive strength, it is a useful tool to gauge the variability of the quality of concrete. Clause 5.1 of ASTM C805M describes the same.

Readings were taken on dry concrete surface. About two readings holding the hammer perpendicular to the concrete surface in two sides are taken within an area of 150 mm * 150 mm, and the average value is reported after discarding outliers. Rebound number was obtained by using a correlation between strength and rebound number.

RH test was carried out in accordance with BS EN 12504-2:2001 "Testing concrete in structures- Part 2: Non-destructive Testing-Determination of Rebound number."

Figure 2: Picture showing the RH Testing of representative concrete cube

4. Artificial Neural Network (ANN)

ANNs are parallel systems composed of many processing elements connected by links of variable weights. ANN networks are similar to biological neural networks in the sense that functions are performed collectively and parallel with the units, rather than having a clear description of subtasks to which various units are assigned. The term ANN currently tends to refer mostly to neural network models employed in statistics and artificial intelligence. ANN models are designed with emulation of the central nervous system in mind, which makes them subjects of theoretical neuroscience (Tapkin, 2004; Tapkin et al., 2006). In this work an ANN is created for two different phases in the most general sense. The first phase is the training phase and the second phase is the testing (simulation) phase (Tapkin et al., 2006). ANNs have the ability of performing with generalization from the patterns on which they are trained. Training consists of exposing the neural network to a set of known input–output patterns. In literature several methods exist to train a network. One of the most successful and widely used training algorithms for Multi Layered Perceptron (MLP) is the back propagation (Flood and Kartam, 1994) (MLP is the ANN network, back propagation is an algorithm to train it). The neural network is trained using back propagation training algorithm in this study. Back propagation neural networks generally have a layered structure with an input layer, an output layer, and one or more hidden layers (Kewalramani, Gupta, & Manish, 2006).

ANN applications and results

A total of 270 concrete cube samples, casted from different types of sand, different types of cement and grades, were tested in this study. In the Artificial neural network model, the number of input variables was chosen as four and the number of output variables was chosen as one. Out of the total number of 270 specimens, 92% namely 250 specimens were assigned to the training step and 8% namely 20 specimens were assigned to the testing step. The typical multilayer feed forward neural network is used in the current application. There are four nodes in the input layer, corresponding to UPV, RH, Sand Type and Cement Type of concrete specimens, and one node in the output layer corresponding to compressive strength of concrete.

Figure 3 shows the validation performance established in MATLAB software for the training, validation, and test steps. The results demonstrates the Mean Squared Error (MSE) of the network for the three steps of training, validation, and test, which indicates the fact that the network is learning. The best validation performance occurred at epoch 6 which has the least Mean Squared Error (MSE). In addition to that, according to the results, it is demonstrated that the analysis stop point is equal to 12, namely considering 6 error repetitions after the best validation performance (epoch 6).

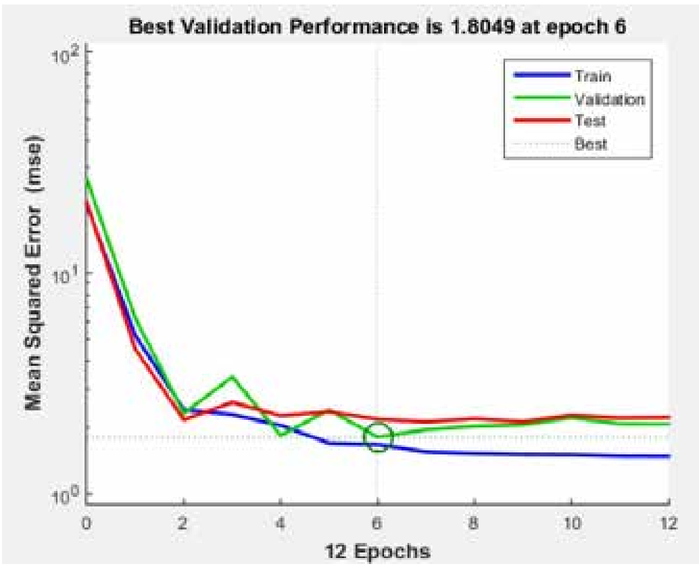

Figure 3: Training, Validation and Testing metric of the selected ANN model

Figure 4 illustrates the training state of ANN. According to this figure, the errors are repeated 6 times after epoch number 6 and training is stopped at epoch 12. In other words, the last epoch before the error repetitions, namely epoch 6, is considered as the best performance and its related weights are assumed as the final model weights.

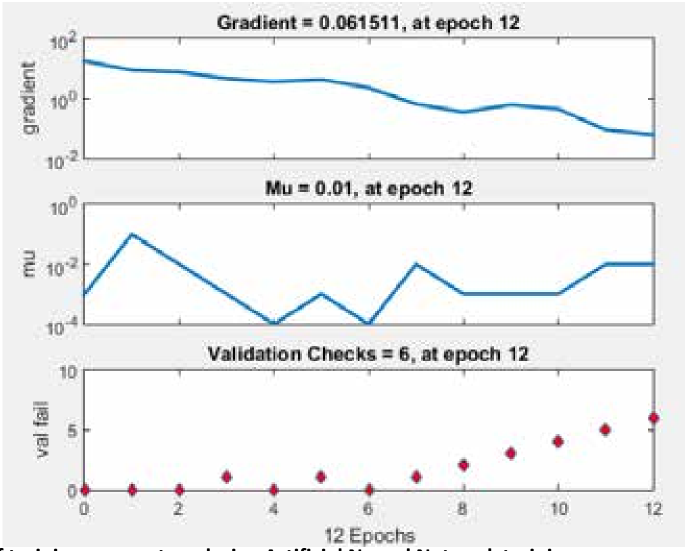

Figure 4: Change of training parameters during Artificial Neural Network training

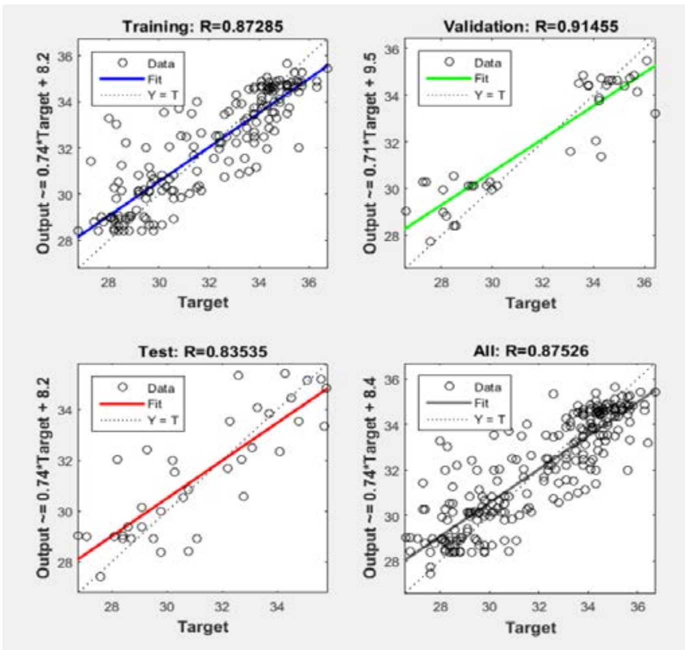

Figure 5: Regression analysis of Training, Validation and Testing subsets of ANN model

Figure 5 shows the relationship between the measured compressive strength (target values) and predicted compressive strength (output values) for the training, validation and test steps, respectively. R^2 is a statistical measure of how close the data are to the fitted regression line. In all of the figures the model presents good results in the case of R-values.

For the testing phase, 20 samples were casted and UPV, RH and Compressive strength were checked separately. Actual compressive strength and predicted compressive strength values are given in the Table 1.

Table 1: Actual and predicted compressive strength values for 20 numbers of samples

Sample	Actual Com. Strength (MPa)	Predicted Com. Strength (MPa)
1	34.6	34.7
2	34.2	34.7
3	29.6	30.2
4	29.1	29.1
5	34.3	33.7
6	34.9	34.6
7	30.8	31.6
8	30.4	30.2
9	35.7	34.9
10	34.1	32.2
11	28.8	28.8
12	27.6	27.8
13	33.1	32.2
14	34.5	33.9
15	30.1	31.3
16	33.5	34.0
17	34.6	34.8
18	34.4	35.0
19	28.2	27.5
20	28.1	28.8

The obtained results were graphically plotted showing the comparison of actual and predicted results through the ANN analysis (Figure 6). The predictions on Figure 6 are based on data from the testing set implemented to samples that were not in the training set. The figures clearly show that experimentally evaluated values of compressive strength of concrete are in strong consistency with the values predicted through ANN for most of the specimens.

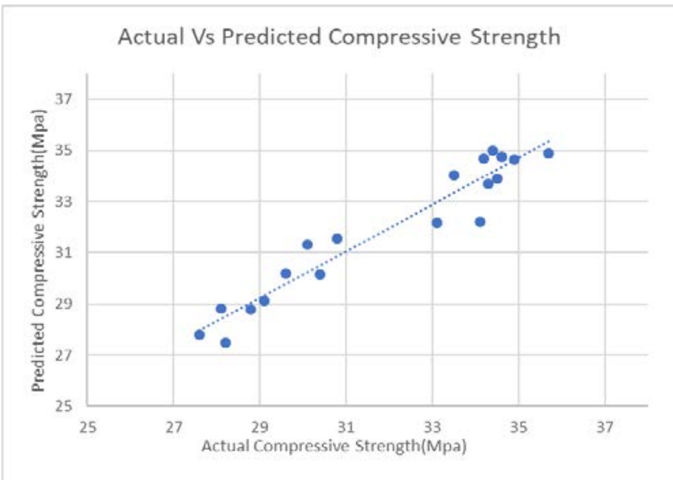

Figure 6: Comparison of Actual compressive strength obtained using experiments Vs Prediction values for compressive strength obtained from the ANN model

5. Summary and conclusions

The neural network model to predict compressive strength based on UPV, RH, Sand type and Cement type of concrete specimens is examined in this study. The predictions made using the ANN show a high degree of consistency with experimentally evaluated compressive strength of concrete specimens. Thus, the present study suggests an alternative approach of compressive strength assessment against the typical destructive testing methods.

Neural networks can indicate correlations between sets of data. This study indicates the ability of a multilayer feed forward model as a good technique for determining the concrete compressive strength. Analyzing the results obtained at the end of the study it can be concluded that using UPV, RH data and ANNs, trained using the gradient descent algorithm and two hidden layer architecture, was a suitable method to estimate the compressive strength of concrete specimens. The RMSE values were reasonably small indicating that the estimates were fairly accurate and the trained network yielded superior results. Carrying out destructive tests is generally not possible, especially on concrete elements which are in service. Therefore, using UPV and RH test results and material properties of concrete for the estimation of concrete strength can be done using an ANN. The advantage of such estimation is that it can help the site engineers to make reasonable estimates about the concrete compressive strength of these structural members. That means, an ANN model can be constructed in order to provide a quick and dependable means of predicting the compressive strengths of concrete of structural elements. Approximate value of compressive strength in any point of concrete can then be practically found, by ignoring the mixture ratio of concrete through and using only UPV and RH, with the ANN modelling. Furthermore, different factors which can affect compressive strength of concrete such as density and so forth should also be considered in future studies.

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