Participatory GIS to response climate exacerbated disasters; a flood mapping case study of Batticaloa City, Sri Lanka

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ABSTRACT: Flood is identified as one of the most frequent climate exacerbated disasters in Sri Lanka. Meteorological records reveal that the extreme rainfall events and frequent occurrence of floods is on increase over recent decades in most of the cities in Sri Lanka. The assessment of vulnerability in terms of temporal and spatial is identified as a prerequisite for adaptation planning, to make cities more resilient to climate change. The current information base related to flood hazard, which is produced by national agencies, is appropriate for decision-making at national and provincial levels but not at local level. Non-availability of reliable and reasonably accurate flow of information among all stakeholders at local level has hampered the development of cities as climate resilient to respond disasters. The production of flood hazard database for a city using conventional methods and approaches (engineering and surveying) is an expensive and time consuming task. In this context, this research has been carried out to test the applicability of Participatory GIS (PGIS) to produce acceptable and realistic flood maps to identify the flood risk for the city in shortest time period based on evidenced risk to respond climate exacerbated disasters. This paper demonstrates the use of PGIS methodology adapted to collect and integrate the community knowledge and the capability to develop reliable and realistic flood map database for their own city. The overall contribution of this work lies in demonstrating a grass-root level participatory approach to collect, analyze and demonstrate flood records for the development of a database to respond climate exacerbated disasters in the process of making climate resilient cities.

Key words: *Participatory geographical information system, Flood Mapplig, Climate exacerbated disasters, Disaster response*

1. INTRODUCTION

1.1 Climate change and vulnerability to floods, a climate exacerbated natural disaster

Climate Change is defined as statistically significant variation in either mean state of the climate or in its variability, persisting for an extended period, typically decades or longer (Intergovernmental Panel on Climate Change, 2001). Climate change could severely exacerbate the impact of natural hazards, disaster and extreme weather. In this context, vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity (Mahanama, 2010). Cost effective adaptation measures can mitigate much of the potential loss and vulnerability of climate exacerbated disasters.

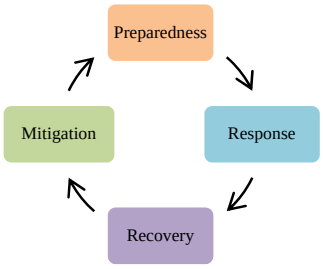
1.2 Vulnerability to floods, a climate exacerbated natural disaster

In global as well as local context, Hazards related to climate and weather affects more people and cause more economic damage than other disasters. Vulnerability to floods is defined as a measure of risk combined with the level of social and economic ability to cope with a flood event (Cannon, 1994). This refers to the personal or group characteristics in terms of their capacity to anticipate, and cope with the impact of floods (Scoones, 1999; Smith, 1996). River and flash flooding is an environmental problem decision makers have to deal with. This is because flooding causes more death, economic loss and social destruction than any other type of natural hazard worldwide (Burby, 1998; Tierney, 1998; Mileti, 1999; Messner & Myer, 2006).

1.3 Need of a spatial information system to respond natural disasters

To respond natural disasters, disaster management is used. The disaster management cycle is as of diagram 1.

Diagram 1: Disaster management cycle



Source: Virtual University for Small States of the Commonwealth (VUSSC)

Disaster response is the total of actions taken by community, government and the local authorities to face of disaster. These actions commence with the warning of an oncoming event or with the event itself if it occurs without warning. A response system is important to reestablish the self sufficiency of the local community and essential services as quickly as possible. Some of the modern methods of disaster response are identified as use of cell phones, spatial information technology and social media.

1.2 Gap in Sri Lankan local context (city level) with regard to spatial information on natural disasters

The information on disasters in Sri Lankan context is on national scale. Disaster management center, an organization established to implement the functions indicated in the Disaster Management Act No.13 of 2005, consists of two databases to facilitate disaster response systems. The databases are, Sri Lanka Disaster Resource Network (SLDRN) and Disaster Information Management System (DesInventar). Disaster Information Management System (DesInventar) is the disaster information database of the country.

Though the community, government and non-government organizations respond to disasters in an isolated manner in Sri Lankan context, a proper management network is needed to respond to disasters in a much smoother, effective and efficient manner. The integration of local knowledge with the institutions to empower the local community and to gather local knowledge on disasters to develop a cyber-based geographical information system is required to face and minimize disasters and to recover the local community to its previous state at city level. Therefore, there is a gap of spatial information and a database to manage the information on climate exacerbated disasters in local context to respond disasters and it is needed to develop this type of spatial information database at city level by using a specific approach to support decisions.

2. RESEARCH OBJECTIVES

The overall goal of this research is to identify the vulnerability of Sri Lankan coastal cities to climate exacerbated disasters (Flood hazard specified) by using participatory geographical information system approach. To achieve this goal, the objectives of this research are:

1. Identify the flood hazard and vulnerability to floods in the study area by using participatory geographical information system approach.
2. Development of a spatial information database to respond the climate exacerbated disaster, flood by using the gathered data and information from the above participatory geographical information system approach.

3. LITERATURE REVIEW

3.1 Methods of flood mapping

Flood hazard maps are important tools for understanding the hazard situation in an area. Hazard maps are important for planning development activities in an area and can be used as supplementary decision making tools (Cities and Flooding, A Guide to Integrated Urban Flood Risk Management for the 21st Century, 2011). The most important element flood mapping is the production of a Digital Terrain Model (DTM) which demands accurate elevation data. The techniques used for the production of Digital Elevation Model as of table 1.

Table 1: Techniques used for the production of Digital Elevation Model

Technique	Description	Advantages	Disadvantages
Photogram metry	Determining the geometric pr operties of objects from photographic images	Availability of data for different time periods at low cost	Low altitude data, effected by the vegetation cover
Light Detection And Ranging	Determining the distance to an object or surface by measuring the travel time of laser pulses	"faster, better" way to create large, high-resolution terrain model	High cost attached, technical knowledge attached is high
Synthetic Aperture Radar	Radar which use relative motion, between an antenna and its target region, to provide distinctive long-term coherent-signal variations.	A large area could be covered, high resolution models could be developed	High cost attached, technical knowledge attached is high
PGIS	Building of stand-alone scaled relief maps over which are overlapped thematic layers of geographical information.	Integration of local knowledge, suitable for areas with no data	Accuracy may be low

3.2 Method of participatory geographical information system

Geographic Information Systems is defined as a "powerful set of tools for storing and retrieving, transforming and displaying spatial data collected from the real world for different purposes" (Burrough, 1986). The participation of society in local decision making is significant in safeguarding their interests in the decision making process. The use of traditional GIS technology was critiqued based on its tendency to privilege "expert" knowledge over "local" knowledge (Talen, 2000). The top down representation of knowledge in traditional GIS distorted the true information base of the local society and did not facilitate accurate decision making (Weiner, 1995). In this context, participatory GIS were developed by the social theory critiques of GIS. PGIS is defined as the most useful tool for extracting lay (indigenous) knowledge, perceptions of environmental problems and hazards, and presenting and communicating it to environmental scientists. 'The clarity and conciseness of 'citizen maps' allows decision makers to take into account citizen inputs which used to be ignored.'(Forrester, 2003). PGIS is a term that was created to express the adoption of GIS to empower indigenous and local communities of the world (Kyem, 2002).

4. USE OF PGIS IN BATTICALOA MUNICIPAL COUNCIL

4.1 Vulnerability of Batticaloa Municipal Council to floods, a climate exacerbated disaster

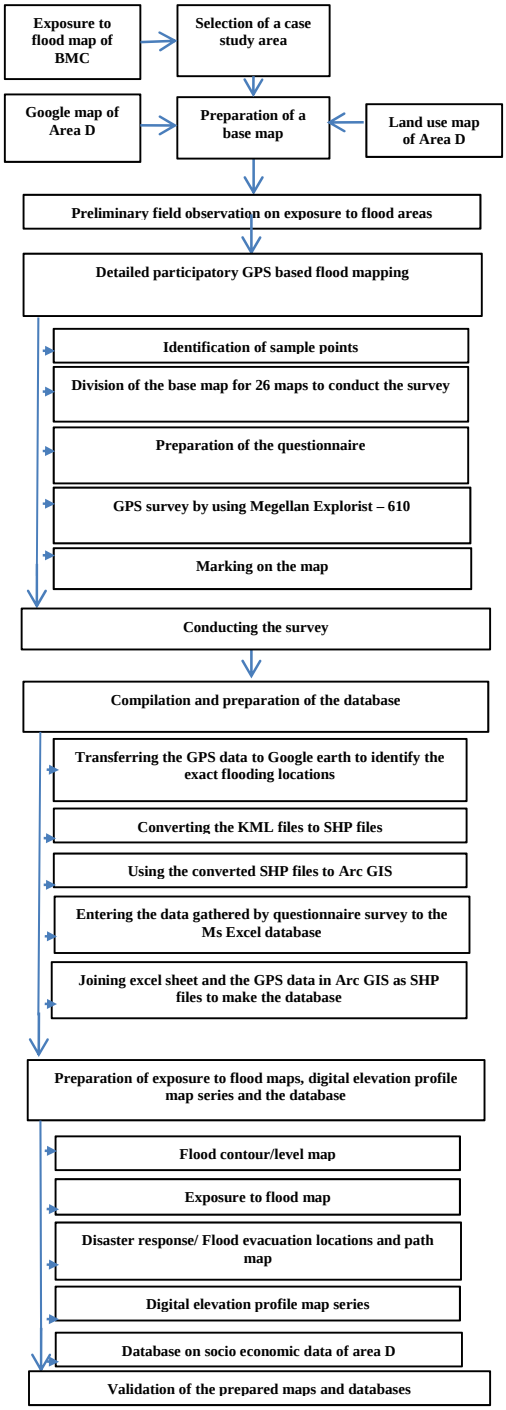
From the number of flood events occurred in the country from 1974- 2008, Batticaloa district consists of a higher flood limit. Vulnerability assessment conducted by faculty of architecture, University of Moratuwa to formulate a city development strategy for a Sri Lankan city to respond climate change (2010) analyzed 40 year records of meteorological data of Batticaloa Municipal Council. The rainfall data of this analysis revealed a strong trend of monsoon rainfall increase (28% in Batticaloa Municipal Council) and correspondent increase of occurrence of minor floods.

4.1 Need to use PGIS in Batticaloa municipal council for participatory flood mapping

As flooding is a main phenomenon in BMC, further identification of this hazard is important. Although the community in Batticaloa is vulnerable to flood, an updated flood map for Batticaloa municipality is not available. The lowest level of contour height in survey department maps is 5m. The municipality contour height is lower than this level, whereas the height of the whole municipality varies in between 3- 4m. Therefore, flood modeling could not be done from the existing data of the municipality. Furthermore, the water for Batticaloa municipality flows to it from its surrounding 22 catchments. When it rains for the upper area of the catchments, the BMC area is flooded. In this context, availability of detailed spatial information on flooding in BMC is important. Therefore, Participatory flood mapping method was used to identify the hazard vulnerability of this area. This method was used so that the knowledge with regard to floods in Batticaloa flows both bottom up as well as top to bottom. By integrating local knowledge to the mapping process, a map with a higher accuracy could be developed and the local community could be empowered. Participatory flood mapping was preferred rather that other technical methods due to the high costs and the requirement of highly technical knowledge in other methods.

4.3 Adopted participatory geographical information system approach in Batticaloa Municipal council

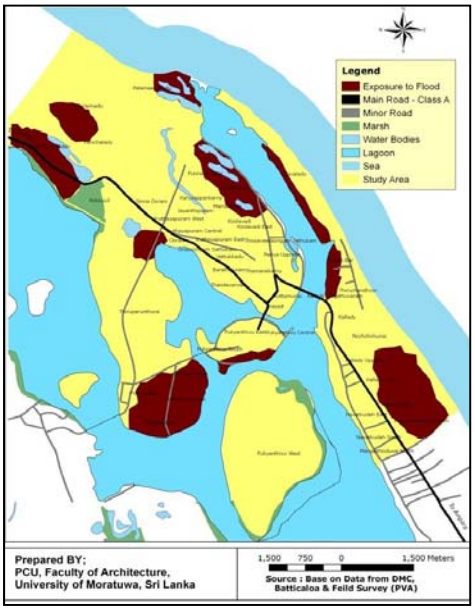
Diagram 2: Process of participatory GIS flood mapping adopted in Batticaloa municipal council



Selection of a case study area

To carry out participatory flood mapping, a case study was selected by the research team. The case study, Area D, the highest flood vulnerable area of Batticaloa Municipality was selected by consulting the local authority, the locals of Batticaloa Municipality (Manmunai North DSD), and the relevant agencies. Area D consists of 4 Grama Niladari Divisions. These divisions are, Puthunagar, Thimilathevu, Sethukudah and Veechchikalmunai. Total area of the field Map, Area D is 3.4 sq. km. To select the case study area, Area D, level of vulnerability was considered.

Figure 1: Exposure to flood map



Source: Vulnerability assessment on climate change scenarios, Batticaloa Municipal Council

Preparation of a base map

The base map was developed by adding the administration boundary, roads and geographical features to an Arc GIS layer. This map was verified with the updated Google map of 2012. This verification was done to make an updated base map. By comparing and assembling these two maps, an updated map was developed. The scale of the verified map is 1: 5,000.

Figure 2: Land use map of Area D

Figure 3: Google map of Area D

Figure 4: Updated base map for Area D

Preliminary field observation on exposure to flood areas

By the preliminary field visit, it was identified that the entire area is flooded. Some areas were flooded at least by the 50 year floods.

Detailed participatory GPS based flood mapping

i. Identification of sample points**:** A 30% sample was selected to conduct the survey by using the preliminary field observation. From the 1,365 houses of area D, 500 households were selected to conduct the survey.

ii. Division of the base map for 26 sub maps to conduct the survey: Area D was divided to 1:500 scaled 26 maps consisting of 4 grids in each map.

iii. Preparation of the questionnaire to be conducted on field: By consulting the participatory flood mapping experts (DMC, UoM & NIVA) and conducting a literature review, a questionnaire was developed.

iv. GPS survey by using Megellan Explorist – 610: Magellan Explorist- 610 was used to identify the exact geographical location of the flooded area. The vertical accuracy of this GPS was between 1-3 meters.

v. Marking on the map: The flood was marked on the map to identify the flood prone areas, to recognize the direction the flood water inflow and outflow, to identify safe location or evacuation shelter, evacuation path to safe location and to temporary evacuation shelter.

Figure 5: Flood direction marked in Maps

Source: CCSL Project

Conducting the survey

The survey was conducted by the research team by using the above methods. When conducting the survey, GPS points were taken at the households where the questionnaire survey was conducted. Field mapping was done to identify the flood occurring areas and the level of floods. Research team involved the local community at this process.

Compilation and preparation of the database

By incorporating the data gathered by using GPS and the questionnaire survey, a spatial information database was developed for the Area D of Batticaloa Municipal council. This database consists of common attributes.

The steps used in compilation and preparations of the database are:

i. Transferring the GPS data to Google earth to identify the exact flooding locations and converting the GPX files to KML files.

ii. Converting the KML files to SHP files.

iii. Using the converted SHP files in Arc GIS.

iv. Entering the data gathered by questionnaire survey to the Ms Excel database.

v. Joining excel sheet and the GPS data in Arc GIS as SHP files to make the database.

Preparation of exposure to flood maps, digital elevation profile map series and the database

The outputs of the PGIS process, the developed spatial information database is as of table 2.

Table 2: Outputs of the adopted PGIS process

Output	Description
Flood contour/ level map	This map was developed using the flood elevation model. A 3 D elevation model was developed by using the interpolation tool of GIS. From this model, flood variation was recognized. Using this model, a flood contour map was developed by using the contour option of spatial analysis tools of GIS. The flood contour map consists of contours with flood heights.
Exposure to flood map	Exposure to flood map was developed by digitizing the field maps. This map consists of flood flowing directions and low frequent, moderate frequent and extreme frequent flooding sites.
Disaster response map	This map was developed by including the safe locations and the paths to these locations.
Digital elevation profile map series	A map series of elevation was developed along all the roads of area D. This profile was developed because a contour map was not available in BMC. The flood direction of Area D were along the roads to the paddy fields. Therefore, this profile revealed that there is no drainage system in Area D. This map series was developed by using the elevations profile option of Google earth.
Database on socio economic data of area D	The map series facilitated the vulnerability to floods of Area D. To incorporate the socio economic data of Area D, a socio economic database was developed.

Table 3: Flood status of Area D

Flood Status	No of Buildings
Low frequent	376
Moderate frequent	518
High frequent	91

Figure 6: Flood contour/ levels map

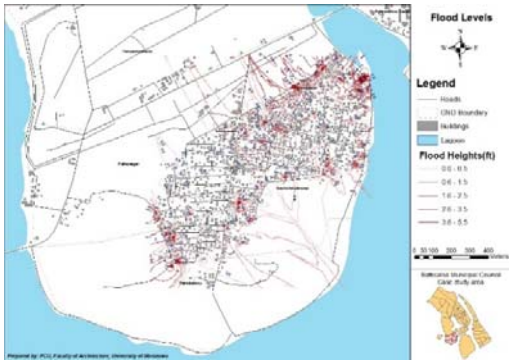


Figure 7: Exposure to flood map

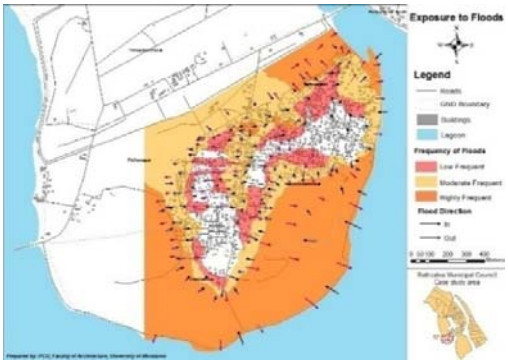
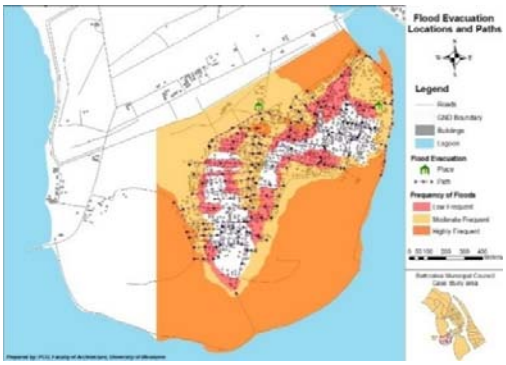


Figure 8: Flood evacuation locations and path map



5. RESULTS

5.1 Validation of the adopted process

To test the validity of the adopted process, research team interviewed 50 houses of Area D where the survey was not conducted. The level of validity of the adopted process is as of table 4.

Table 4: Level of Validity of the adopted process

Parameter	Accuracy based on % of responded			
	100%	+-5	+-10	+-15
Flood Height	91%	5%	3%	1%
Frequency	95%	4%	1%	-
Flow Direction	94%	3%	3%	-

5.2 Lessons learnt

The lessons learnt at the process on the use of participatory GIS for flood hazard mapping to respond climate exacerbated disasters in Batticaloa municipality are:

- To increase and enhance the accuracy and validity of data, data should be gathered using several techniques.
- As BMC is a low elevated area and no information on the floods in Batticaloa was available, the adopted PGIS technique

was most suitable to map the flood hazard of the study area.

- The selection of a sample of 30% eases the survey. Conducting a survey to the total population of the study area is time and resource consuming.
- Ad hoc discussions with the individuals further validated the survey conducted.

The lessons learnt on the use of GIS software are:

Table 5: Lessons on the use of GIS software

Lesson	Description
Elevation/ coordinate change and attribute change in extraction of GPS points to Arc GIS	When extracting GPS points to ArcGIS, the exact geographical location where the coordinates were taken was not clearly shown on the map. Therefore, 1st, the GPX files gathered in the GPS was extracted to Google earth as a KML file. In Google earth, the exact location where the GPS points were taken was shown.
Attribute change in extraction of GPS points to Arc GIS	The KML to SHP converter was used to convert this file because when converting these files using GPS plugin/ GPS tool in GIS, in the attribute table, and the statistical / numerical data changes.
Coordinate change when opened the converted GPS points (shape files) in Arc GIS	When the converted shape files using the KML to SHP converter was added to the GIS database and opened in the map layer a coordinate error occurred. This error was about 100m distance error from the exact geographical location. To reduce this error and to bring the shape files to the exact location on ground, spatial adjustment tools and editing tools of GIS were used. This error adjustment couldn't be done using the coordinate systems of GIS.
Misplaced GPS data	Each and every GPS point which was taken on field wasn't available as shape files when opened on the GIS layer. Research team recognized that this could be due to an error of the GPS machine or the KML to SHP converter used for the file conversion.
The data entering format of the excel sheet	The data should be entered in number format when entering to the excel sheet. Or else further analysis of this data in GIS to create elevation maps using flood heights cannot be done.

6. CONCLUSION

The main goal of this study was to identify the vulnerability of Sri Lankan coastal cities to climate exacerbated disasters (Flood hazard specified) by using participatory geographical information system approach. Flood hazard is one of the main climate exacerbated hazards in Batticaloa Municipal Council. The knowledge and information base of the community and the relevant authorities of the climate exacerbated disasters and climate change at city level was low. Also, the information flow from top to bottom as well as bottom up didn't occur in a proper manner and the data and information on disasters were often overlapped or ignored. In this context, as there was knowledge and an information gap, to make the society and the authorities more knowledgeable on climate exacerbated disasters and to prepare them to respond to these disasters in a proper manner, the use of a participatory geographical information system approach to respond climate exacerbated disaster was done.

This research identified the flood hazard and vulnerability to floods in Batticaloa municipality by using participatory geographical information system approach. Also, based on these findings, a spatial information database was developed in the form of a digital elevation profile map series, socio economic database, exposure to flood map, flood contour map, and safe location and evacuation paths map to respond to climate exacerbated disasters in a timely manner based on the gathered data and information. Therefore, this research emphasizes the importance of the use of participatory GIS to develop informed spatial information database to respond to climate exacerbated disasters at local level in a timely, efficient and effective manner to support the decisions to make more resilient cities to climate exacerbated disasters.

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