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Research Article

A Study on Urban Flood Vulnerability in Vrishabhavathi Valley Watershed, Bengaluru, Karnataka using AHP, GIS and RS Techniques

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Abstract Urban flood problems are common in urban areas. These are due to heavy rainfall, adverse topographical conditions and anthropogenic factors, lead to destruction of drainage, damage to buildings, and even loss of life and property. To control such problems, systematic urban flood studies are necessary. The present study focused on the mapping and spatial analysis of urban flood vulnerability in Vrishabhavathi valley watershed, Bengaluru using AHP, GIS and remote sensing techniques. Some of the causative factors for flooding considered are rainfall, slope, drainage density, land use, building density, road density, non-existing natural drainage and non-existing Lake. Each thematic map of these factors was converted into raster maps. Numerical weight and ranking scores were assigned to each element factor according to fundamental scale of Analytical Hierarchy Process (AHP) technique. Urban Flood Vulnerability Zone (UFVZ) map was computed using weighted overlay analysis of GIS technique and classified into five categories, viz., very low, low, moderate, high and very high flood zone classes. UFVZ map was compared with the flood prone locations exist in Bengaluru city to assess the accuracy of result. Plot of flood prone locations on flood vulnerability zone map shows that, 50% of flood prone locations found under moderate flood vulnerability zone class and comparatively very less of flood prone locations 28% found in high zone class. The result depicts the fact that, urban flood vulnerability is highly influenced by anthropogenic factors than natural factors in urban environmental study area. The predicted flood vulnerability zones are found to be good agreement with known flood prone locations data.
Keywords *AHP technique; Geographic information system; Remote sensing; Urban flood*

1. Introduction

Urban floods are caused by a localized heavy rainfall. Flood disaster is considered a major natural hazard due to its devastating effects on the affected area. Floods are increasing both in urban and rural areas due to natural and manmade causes. Heavy rainfall is one of the major natural causes. In urban areas, inadequate capacities of drains, encroachment of drain boundary, dispose of solid wastes and debris in to drains, asphalting or concreting of roads giving no scope for percolation of water, are the important causes (SUDA, 2007). Bengaluru (the study area) is one of the cities of India. The cosmopolitan nature of the city has resulted in the migration of people from other states. Buildings and pavement area has been increased to 45.19% in 2005 from 27.30% in 1973 in Bengaluru. Author Ramachandra T.V, analysis revealed that the wetland numbers have declined from 51 in 1973 to 17 in 2007 and the number of lake water bodies reduced from 159 in 1973 to 93 in 2007. A case study of urban flood in Bengaluru reported that improper solid waste management, encroachment of drains boundary, siltation of sewers are leading to urban flood (Ramachandra et al., 2009). The recent study on urban flooding impacts on climate change says rainfall intensity is increasing in Bengaluru (Mujumdar, 2012). Rapid urbanization requires the integration of flood risk management into regular urban planning and governance (Jha et al., 2012). From the above reviews, it is required to study flood vulnerability analysis for sustainable urban flood management.

In the present paper, urban flood vulnerability of Bengaluru using GIS (Geographical Information System) and AHP (Analytical Hierarchy Process) techniques has been studied. Various factors both natural and anthropogenic that causes urban flood were selected for preparing Urban Flood Vulnerability Zone (UFVZ) map. All these factors are integrated into urban flood vulnerability maps using GIS techniques. Prioritization (Determining the relative merits of members of a set of alternatives) and ranking (putting set of alternatives in order from most to least desirable) process of selected factors are employed by AHP techniques. The AHP is a structured technique for analyzing complex decisions where multiple decision criteria involved, based on mathematics. It was developed by Thomas L. Saaty in the 1970s (Saaty, 1992). AHP has particular application in group decision making and is used around the world in a wide variety of decision situations in many fields (Forman et al., 2001).

AHP has been applied to numerous areas of the world. AHP technique has been used to obtain urban flood vulnerability and risk map in Eldoret municipality, Uasin Gishu County, Kenya and the proposed AHP approach is reliable up to 92% of accuracy level in his study (Ouma et al., 2014). AHP method in Northern Philippines, applied for the municipality of Enrile, Pinacanauan river basin to assess floodplain risk (Siddayao et al., 2014). AHP method has been applied to assess flood vulnerability in Austria, Italy and Germany (MOVE, 2011). Ramu et al., (2014) presented AHP technique to find out potential zones of ground water in Mysore taluka, Karnataka, India and result compared with the collected borewell sample data, given 95% of accuracy. AHP method to prepare landslide hazard zones of the Coonoor and Ooty, part of Kallar watershed, The Nilgiris, Tamil Nadu, India (Abdul Rahamana, et al., 2014). Siddayao et al., (2014) analyzed the various disaster criteria used in nine different research paper work (all nine studies have a reasonable Consistency Ratio less than 0.1) related to flood studies adopting AHP as the methodology for decision support system. This shows the power and versatility of AHP in multiple criteria for disaster analysis.

AHP as an multi criteria analysis approach has been used for solving various flooding problems. Author Willet used AHP to select the optimal flood control projects for the Grand River and Tar Creek in Miami, USA (Willet et al., 1991). In India, flood risk analysis using AHP and mapped by GIS has been applied to the Kosi River Basin (Sinha et al., 2008). A two-dimensional diffusive overland flow model to simulate inundation status in northern Taiwan, and further used GIS to illustrate the area and depth of inundation (Chen, et al., 2004). Based on the inundation map, they developed a model to evaluate the possible damage from floods by using grey AHP (Chen et al., 2004). The above reviews shows that AHP is mostly applied in natural environments and not in developed urban areas. The present study focuses on the mapping and spatial analysis of urban flood vulnerability in Vrishabhavathi valley watershed, Bengaluru using advanced technology of remote sensing, GIS and AHP for the planning and management of urban flood.

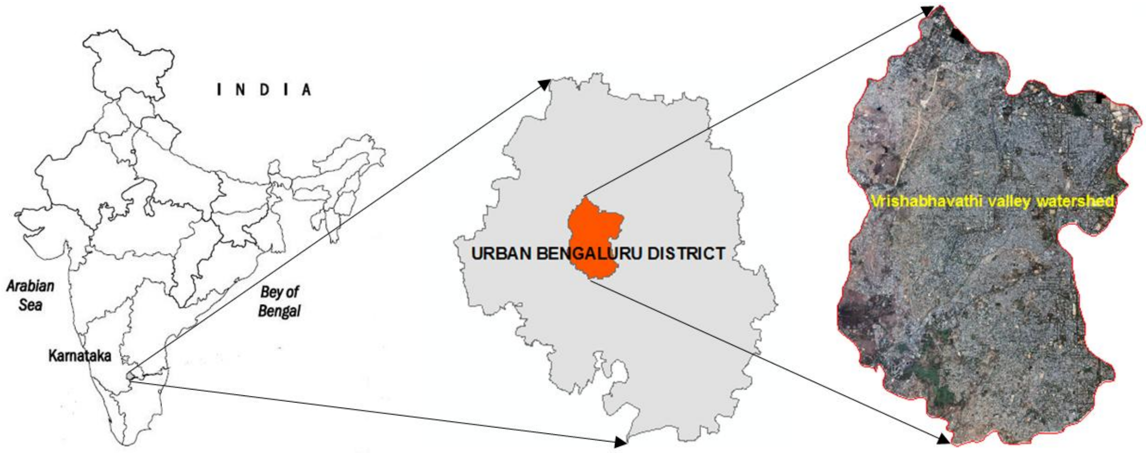

Figure 1: *Location map of the study area*

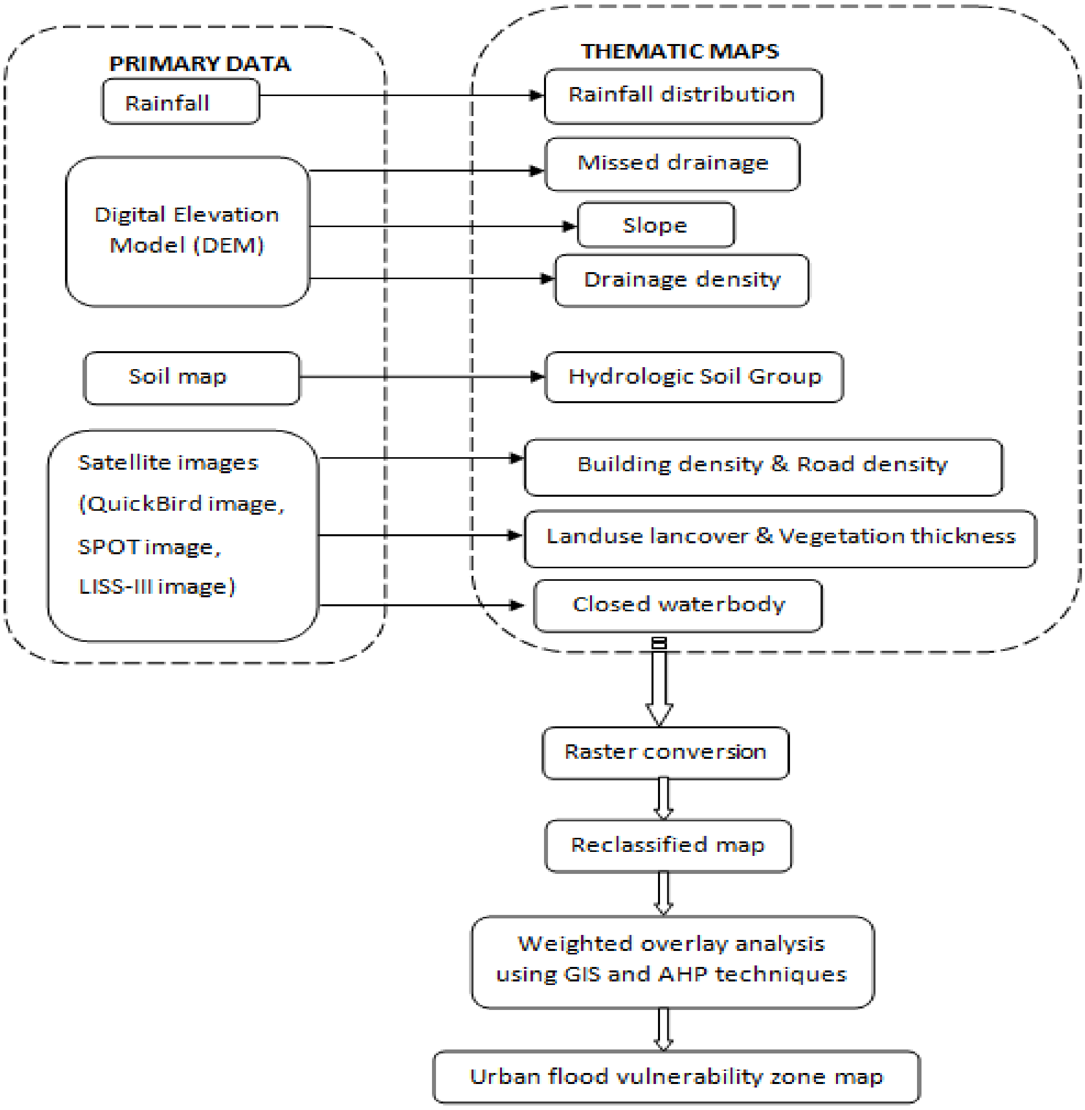

Figure 2: *Flow chart for delineating the flood vulnerability zones*

1.1. Study Area

Vrishabhavathi watershed is located in Bengaluru district and covers a surface area of 350Km^2. A part of the watershed lies in the urban area of Bengaluru city covering around 92.51Km^2. The basin stretches from west to east between longitudes 77^0 23' E to 77^0 35' E and from south to north between latitudes 12^0 45' N to 13^0 03' N (Figure 1). The study area has a semi-arid subtropical climate with mild summers and cold winters. The normal annual average rainfall is about 950mm in a period about 52 days. A major portion (i.e. about 70%) of it is during South – West monsoon period (May to August). Lithologically Vrishabhavathi watershed is characterized by the presence of xenolith and migmantites which are found in small patches. In general the area of study is characterized by red soil, the source rock being undoubtedly gneiss. Locally the soil may be lateritic, red clayey, red loamy or sandy in nature. The topography of the study area is undulating to plain. The relief of the area is 800m above the mean sea level.

2. Methodology

The study has been conducted based on the primary data which have been collected from concerned department. The study has considered eight parameters for the mapping of urban flood vulnerability zone, Vrishabhavathi valley watershed in Bengaluru. The methodology adopted for the present study is shown in Figure 2. The eight factors that have significant influence to induce occurrence of urban flood considered are rainfall, slope, drainage density, land use, building density, road density, non-existing natural drainage and non-existing Lakes.

There are 6 rain gauge stations located in the study area namely Bengaluru palace, Bengaluru city railway station, Bengaluru municipal office, Bengaluru Lalbagh, Uttarahalli and Kengeri. For each rain gauge stations maximum annual rainfall depth was calculated for different return periods based on Gumbel's rainfall distribution method. Gumbel's distribution is most commonly used for modeling storm rainfalls and maximum flows (Subramanya, 2008). This method is used to model the distribution of the maximum (or minimum) of a number of samples of various distribution. This distribution might be used to represent the distribution of the maximum level of a river in a particular year if there was a list of maximum values for the past ten years. It is useful in predicting the chance that an extreme earthquake, flood or other natural disaster occurrence. The potential applicability of the Gumbel distribution is to represent the distribution of maximal values. In hydrology the Gumbel distribution is used to analyze sample of a random variables as monthly and annual maximum values of daily rainfall and river discharge volumes and also to describe droughts (Burke et al., 2010).

The extreme annual rainfall depth for 50 years return period was calculated from 43 years daily rainfall data for each rain gauge station as shown in Table 1. It can be observed that, there is high rainfall at Bengaluru lalbagh and Bengaluru Municipal Office rain gauge station and comparatively low rainfall at Kengeri and Uttarahalli rain gauge station. The daily rainfall data of urban Bengaluru for 43yrs from 1970 to 2012 was collected from Indian Meteorological Department, Bengaluru. The annual maximum rainfall values were geo-spatially interpolated using Inverse Distance Weighted (IDW) method to obtain rainfall distribution map in Arc GIS 9.3 software. To predict a value for any unmeasured location, IDW uses the measured values surrounding the prediction location. The measured values closest to the prediction location have more influence on the predicted value than those farther away. IDW assumes that each measured point has a local influence that diminishes with distance. It gives greater weights to points closest to the prediction location and the weight diminishes as a function of distance, hence the name inverse distance weighted.

Table 1: *Maximum annual rainfall depth for various raingauge stations*

Return period (T), year	Annual Maximum Rainfall (X_T), mm					
	Bengaluru municipal	Bengaluru railway station	Bengaluru palace	Bengaluru Lalbagh	Uttaralli	Kengeri
2	83.40	81.15	76.06	79.95	73.72	73.40
5	110.40	107.52	101.09	108.55	96.70	93.08
10	128.28	124.98	117.67	127.47	111.92	106.11
25	150.86	147.04	138.61	151.39	131.15	122.58
50	167.61	163.40	154.15	169.13	145.42	134.79

Slope map of study area was developed using DEM (Digital Elevation Model) of 3m resolution in Arc GIS software. DEM raster data was collected from STUP Consultants Pvt. Ltd., Bengaluru. Drainage density is a measure of how well or how poorly a watershed is drained by stream channels. Natural drainage vector map was collected from Karnataka State Remote Sensing Application Centre (KSRSAC), Bengaluru. Drainage density map was prepared from the natural drainage map using line density tool in Arc GIS software. The land use and land cover (LU/LC) map was prepared using LISS III (Linear Image Self scanning System) scanner image data freely downloaded from Bhuvan website (Bhuvan.nrsc.gov.in) and image is the source of IRS (Indian Remote Sensing) satellite. LISS III image has 23.5m spatial resolution and image sense captured for the date 13th February 2012. LU/LC analysis was done by supervised image classification method using maximum likelihood classification algorithm. 51 training sites of ground truth data were collected to train the images using global positioning system (GPS). LULC classes were defined into 5 classes namely buildings, roads, open ground, vegetation and water body based on how these classes encourages and diminishes the overland flow. The overall classification accuracy of 91.67% was assessed by Kappa matrix method.

Urban density plays a guiding role in city planning, land management and environmental protection. Building density also called building coverage ratio, refers to the ratio of the total standing area of all the buildings to the total interest area (Xian-Zhang et al., 2006; Bratsolis et al., 2016). To get the building density distribution information, Quick Bird image of high resolution 0.6m was collected from STUP Consultants Pvt. Ltd., Bengaluru. The building density map was prepared by visual image interpretation method. Based on contribution of building density towards impact of flood, the map is grouped into very low, low, moderate, high and very high. Very High category includes more congested building plots and very small gap between buildings. High category includes an area has many dwellings on a small amount of land and planned layout area. In the moderate category, building construction rising up and open land sites are more. Low category includes detached big buildings on a larger land and relatively large distance between buildings. Very low category includes water body or vegetated land or stadium or bus terminals with isolated buildings.

The road density refers to length of road for every square kilometer of area. The poor road density is an indicator of highly unsustainable situation of a city. Drainage is one of the primary components of road. The primary purpose of a road drainage system is to remove water from the road and its surroundings and to avoid water logging problem on road. Roads in urban areas are classified into expressway, arterial road, sub-arterial road, collector road and local road as per code of IRC-69 (Indian Road Congress, 1977). For the study purpose, expressway, arterial road and sub-arterial road classes are considered. The road data was extracted from the Bangalore city development plan (CDP) map-2021 and from toposheets of SOI (Survey of India). Natural drainages and lakes are an essential part of living in an urban area, as drainage reduces flood damage by carrying water away and lake water body acts as flood storage reservoir. Non-existing drains and lakes were extracted by overlaying the existing (2016 year) water body and natural drainage map on the old (KSRSAC-1989) water body and drainage map.

Various factors include both natural and anthropogenic factor, causes flood in urban area. The eight factors that have significant influence to induce occurrence of urban flood are selected. They are rainfall, slope, drainage density, land use, building density, road density, non-existing natural drainage and non-existing Lakes. These eight factors were used for integration to delineate Urban Flood Vulnerability Zone (UFVZ) map in study area. GIS technique was applied for generating new thematic data layer of each factor. All thematic maps were reclassified and proper weight given based on their relative importance to urban flood vulnerability as per the Satty's Analytical Hierarchy Process (AHP). The AHP process introduced by Thomas Saaty in the year 1980, which is an effective tool for dealing with complex decision making and aid the decision maker to set priorities and make the best decision. The AHP considers a set of evaluation criteria and a set of alternative options among which the best decision is to be made. The AHP generates a numerical weight or priority (relative importance) for each evaluation criterion according to the decision maker's pair wise comparisons (Comparing each other, relative importance to the goal, two at a time in the hierarchy) of the criteria. Decision makers use the AHP fundamental scale in assigning the weights. It is the essence of the AHP that, decision maker's judgment can be used in performing the evaluation (Saaty, 2008). Each subclass is analyzed independently. Numerical priorities are calculated for each of the decision alternatives. Higher the assigned weight, more important the corresponding criterion. Higher the score, better the performance of the option with respect to the considered criterion.

Table 2: *Continuous weightage scale of Satty's Analytical Hierarchy Process (AHP)*

1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
Extreme		Strong		Moderate		slight		Equal		Slight		Moderate		Strong		Extreme

LEAST IMPORTANT ← → MORE IMPORTANT

Table 3: *Percentage of influencing factor based on Saaty's Analytical Hierarchy Process (AHP)*

Influencing factor	value	Saaty's scale (in Fraction)	Saaty's scale (in Decimal)	% Influence = (Satty's scale/sum)*100	Relative influence value
Rainfall	High	1	1	36.76	37
Slope	↓	1/2	0.50	18.38	19
Drainage density		1/3	0.33	12.13	12
Landuse		1/4	0.25	9.19	9
Building density		1/5	0.20	7.35	7
Road density		1/6	0.17	6.25	6
Non-existing natural drainage		1/7	0.14	5.15	5
Non-existing lakes	Low	1/8	0.13	4.78	5
			Sum = 2.72		

By integrating different thematic maps in GIS software's weighted overlay analysis tool, the Urban Flood Vulnerability Zone (UFVZ) map was prepared and classified. The results in Table 2 shows the procedure of assigning weightage for each factor based on the relative importance of it in contributing flood. The value 9 in the table shows highest important while 1/9 shows the least important and 1 shows the equal weight of a factor. Based on these weightage criteria, each factor in the study has been classified and Table 3 shows the weightage assigned for eight factors for the study. Weightage for the subclass of each factor has been determined as mentioned in Table 4.

Table 4: *Assigned weight according to Satty's Analytical Hierarchical Process (AHP)*

Influencing factor	Class interval	Urban flood vulnerability level	Satty's scale (in Fraction)	Satty's scale (in Decimal)	% Influence = (Satty's scale/sum) *100	Relative influence value
Rainfall, mm	140-146	Very low	1/9	0.11	6.18	6
	146-152	Low	1/7	0.14	7.87	8
	152-158	Moderate	1/5	0.20	11.24	11
	158-164	High	1/3	0.33	18.54	19
	164-170	Very high	1	1	56.18	56
				Sum=1.78		
Slope,%	0-1	Very High	1	1	45.45	45
	1-3	High	1/2	0.50	22.73	24
	3-5	Moderate	1/5	0.20	9.09	9
	5-10	Low	1/7	0.14	6.36	6
	10-15	Low	1/7	0.14	6.36	6
	15-30	Very low	1/9	0.11	5.00	5
	Above 30	Very low	1/9	0.11	5.00	5
				Sum=2.20		
Drainage density, Km^{-1}	0-0.25	Very High	1	1	56.18	56
	0.25-0.50	High	1/3	0.33	18.54	19
	0.50-0.75	Moderate	1/5	0.20	11.24	11
	0.75-1.00	Low	1/7	0.14	7.87	8
	1.00-1.27	Very low	1/9	0.11	6.18	6
				Sum=1.78		
Landuse	Buildings	Very High	1	1	56.18	56
	Roads	High	1/3	0.33	18.54	19
	Open ground	Moderate	1/5	0.20	11.24	11
	Vegetation	Low	1/7	0.14	7.87	8
	Water body	Very low	1/9	0.11	6.18	6
				Sum=1.78		
Building density	Congested building	Very High	1	1	56.18	56
	Small gap between buildings	High	1/3	0.33	18.54	19
	Well planned area	Moderate	1/5	0.20	11.24	11

	Industrial area	Low	1/7	0.14	7.87	8
	Detached buildings	Very low	1/9	0.11	6.18	6
				Sum=1.78		
Road density, Km^{-1}	0-1.41	High	1	1	65.36	65
	1.41-2.82	Moderate	1/3	0.33	21.57	22
	2.82-4.23	Low	1/5	0.20	13.07	13
				Sum=1.53		
Non-existing drainages, Km^{-1}	0-0.1	Low	1/3	0.33	24.81	25
	0.1-0.69	High	1	1	75.19	75
				Sum=1.33		
Non-existing lakes	Non-existing lake catchment	High	1	1	75.19	75
	existing lake catchments	low	1/3	0.33	24.81	25
				Sum=1.33		

Table 5: *Flood vulnerability zone wise distribution of flood prone locations*

Flood hazard zones	Area coverage, Sq. Km	Area , %	No. of flood prone locations
Very low (Zone-1)	6.48	7	2
Low (Zone-2)	19.43	21	2
Moderate (Zone-3)	38.85	42	14
High (Zone-4)	24.05	26	8
Very high (Zone-5)	3.7	4	2
	∑92.51	∑100	∑28

3. Results and Discussion

As mentioned in the methodology the selected eight factors of thematic maps have been generated using GIS techniques and integrated by weighted overlay analysis to produce Urban Flood Vulnerability Zone (UFVZ) map of study area. The detailed discussion of each factor is shown below.

3.1. Rainfall

Heavy rainfall is one of the major causes of urban flood. The amount of runoff is related to the amount of rain a region experiences. For study area the maximum annual rainfall for 43 years was calculated using Gumbel's distribution for 6 rain gauge stations. The calculated maximum annual rainfall values were then spatially interpolated using Inverse Distance Weighted (IDW) method to obtain rainfall distribution map as shown in Figure 3. Major study area of 67% receives heavy rainfall of about 158 to 169mm. The coverage area experienced heavy rainfall is at South East Basavanagudi region, Vijaynagar, Laggere, Yashwantpur region at North of the study area.

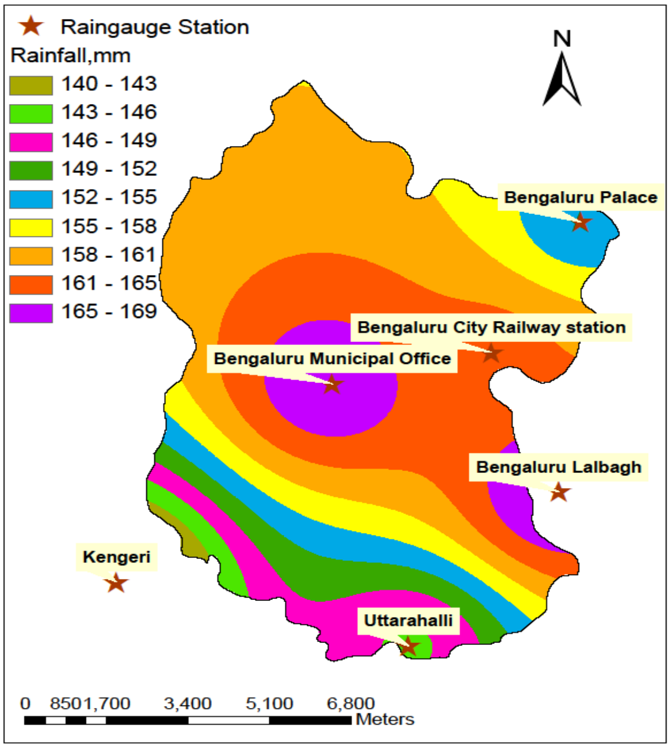

Figure 3: *Rainfall distribution map of study area*

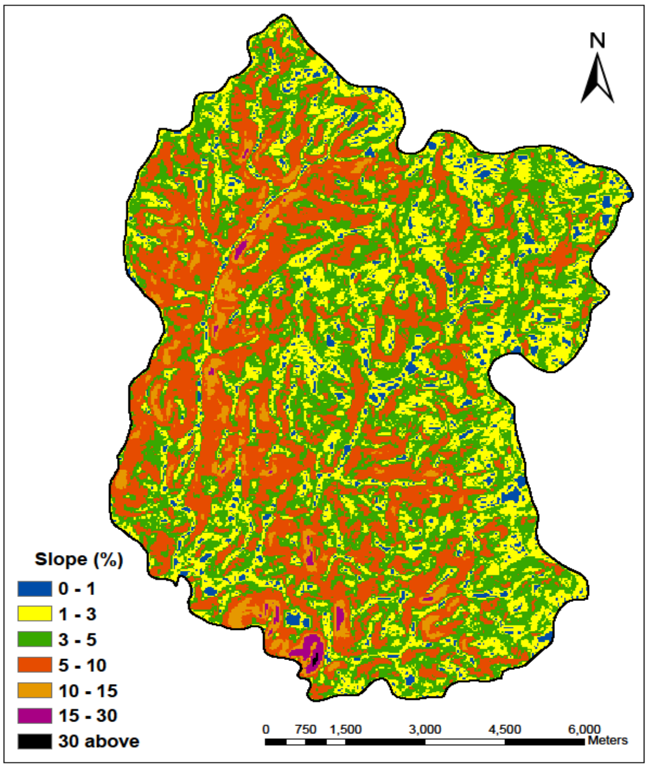

Figure 4: *Slope map of study area*

3.2. Slope

Slope plays an important role in controlling the surface runoff reaching a particular place. Steep slope generates more velocity than smaller slopes and hence can dispose the runoff faster. For flat to gentle slope, runoff gets stored over an area and disposes out gradually over a time. Therefore low gradient slopes at lower reaches are highly vulnerable to flood occurrence compared to high gradient slopes. Steeper slopes shed out the surface runoff faster while flat terrains are susceptible to water logging. Figure 4 shows the slope map of study area. In Vrishabhavathi valley watershed, area coverage on both side of the drainages found to be 5-15% steep slope and very little area less than 1% of study area is occupied by very high steep slope above 15%. Flat to gentle slope 0-5% can be seen in upland and upstream of valleys covers 64% of study area and is more susceptible to water logging.

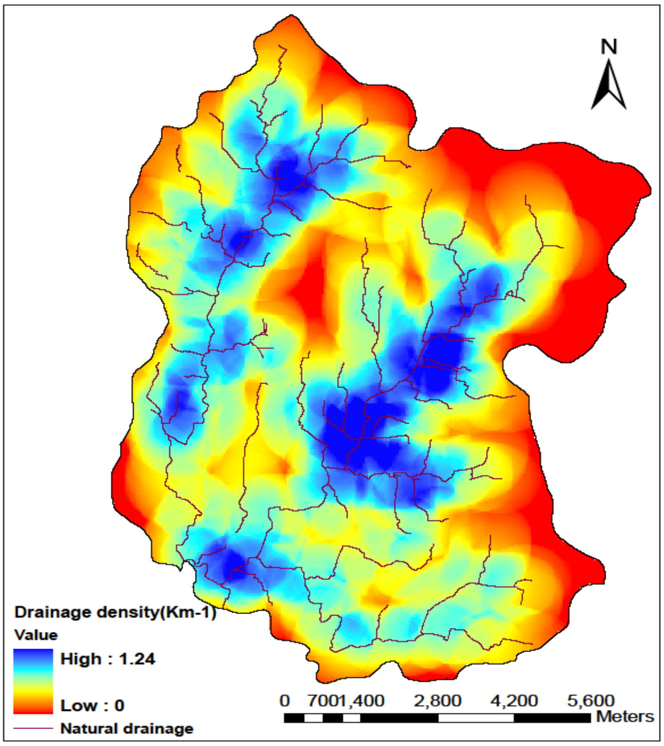

Figure 5: *Drainage density map of study area*

3.3. Drainage Density

Drainage density is the ratio between the total length of the channel in a drainage basin and the area drained by them. The effect of drainage density on runoff volume is associated with the time during which the runoff remains in the watershed. Low drainage density allows for long residence time, therefore, obstruction mechanisms have more time to discharge out the water from a watershed. The drainage density map of study area is shown in Figure 5. The maximum value of drainage density found in the study area is 1.24 Km/Km^2.

3.4. Land Use Land Cover

The land use and land cover (LU/LC) of an area is also one of the primary concerns in flood hazard mapping. Land use types like buildings, road decreases the water penetration capacity of the soil. The existing land use classes of the area were reclassified into five groups in order of their capacity to decrease the rate of flooding. The major land use types in the study area are buildings, roads, open ground, vegetation and water body. The land use land cover map of study area is shown in Figure 6. Buildings area alone comprises around 53% of study area. There is significant less percentage coverage of vegetation (12%) and water body (3%).

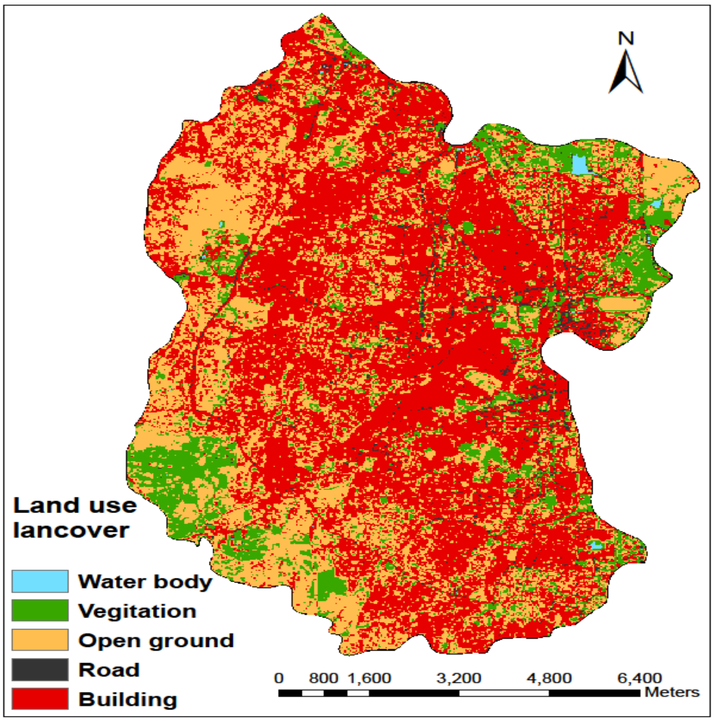

Figure 6: *Land use and land cover map of study area*

3.5. Building Density

Urban building density is an important indicator for quality assessment in aspects of urban design, planning, land management and environmental protection. Measuring urban form and compactness of cities becomes more important for understanding the spatial urban structure to intervene accordingly for sustainable urban development (Kotharkar et al., 2014). Cities are extremely complex ecosystems. Physical assets such as offices, hospitals, schools and transit systems are often concentrated in small spaces and interact with large and diverse populations including commuters, tourists and residents. This density can intensify the impact of storm floods, disease outbreaks and other events. Many a time urban floods are result of not a natural calamity, it's due to an anthropogenic activities (Mukherjee, 2016). Impervious cement cover (buildings) is not capable to soak up water. This excess water is directed to nearby streams which then overflow due to the excess amount of water. The building density map was prepared by visual image interpretation method. Based on contribution of building density towards impact of flood, the map is grouped into very low, low, moderate, high and very high as shown in Figure 7. Very high class zone can be seen in the old and early developed area surrounding very close to the city centre. High class zone category area spread little far from the city centre and just after the very high category area. Moderate class zone category can be found more in outskirt of city. Low class zone category includes detached big buildings on a larger land and relatively large distance between buildings. More of very low category is found in remote area from the city centre.

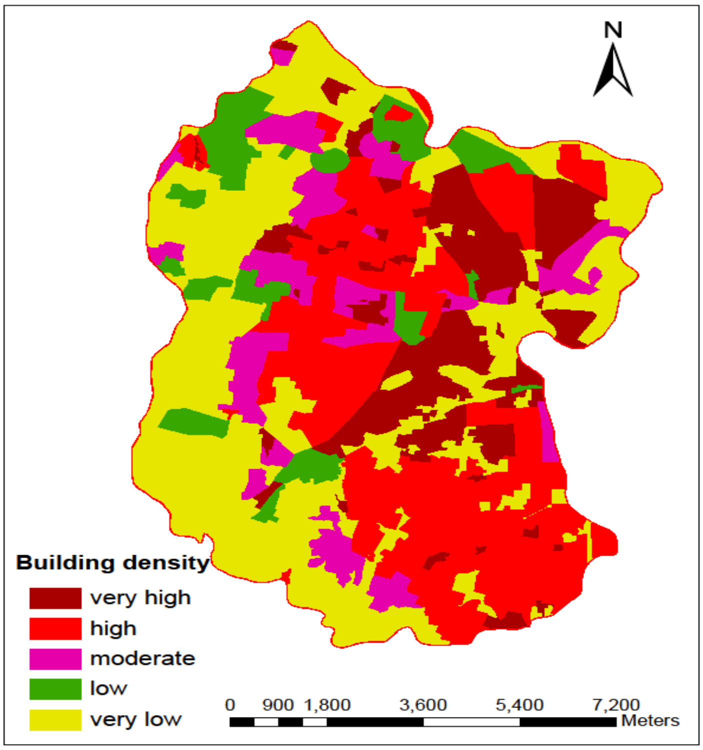

Figure 7: *Building density map of study area*

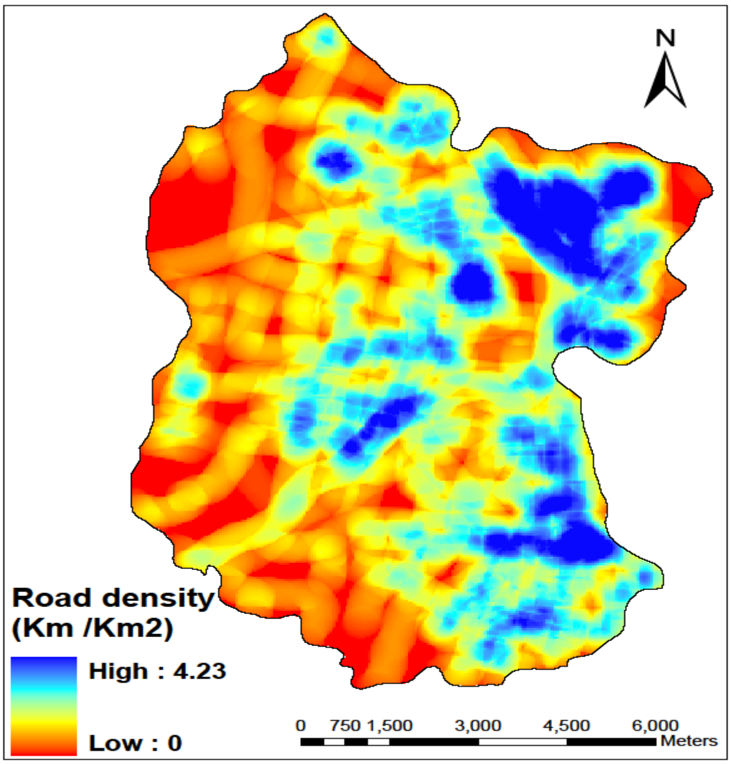

Figure 8: *Road density map of study area*

3.6. Road Density

Road density is the ratio of total road length to the total land area. The impact of road density is important in several aspects. Unplanned road construction decays the physical setup of a city. High road density usually dewater the surroundings but caused waterlogged problem due to heavy pressure small and giant size vehicles on road and leads traffic congestion (Roy et al., 2016). The urban road classes for the study, ring road, primary urban road, major and minor urban road are accounted as arterial and sub-arterial roads according to land use zoning classification map of Bangalore.

Arterial and sub-arterial roads such as ring road, primary urban road, major and minor urban road of urban Bengaluru (study area) were accounted as road vector data input for producing road density map of the study area. The urban road density map is shown in Figure 8. The maximum road density of study area is 4.23km/km^2.

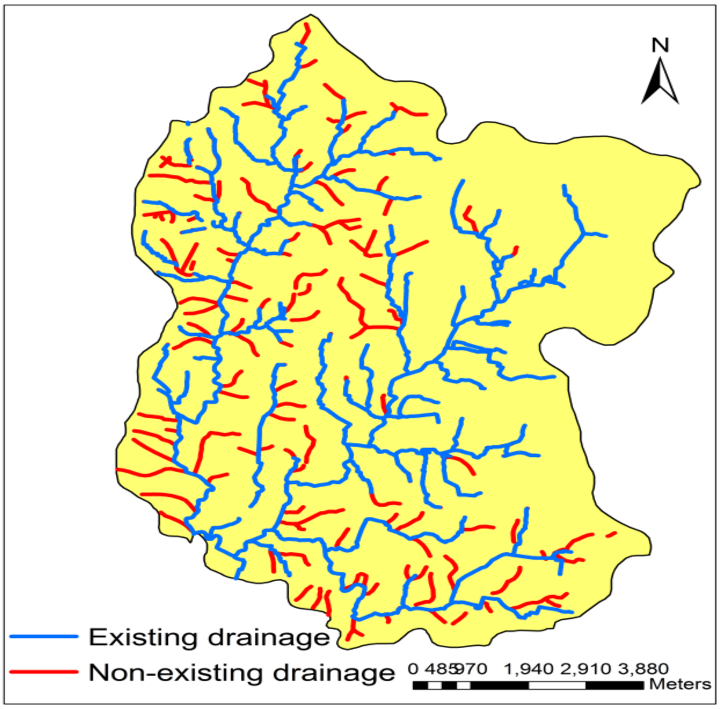

Figure 9: *Non-existing natural drainage map of study area*

3.7. Non-existing Natural Drainage

The importance of natural drainage systems cannot be overemphasized. Natural storm water drainages encroached, filled up, diverted are caused obstruction to the smooth flow of water creating severe water logging in the Dhaka city, Bangladesh every year during monsoon (Mowla et al., 2013). Non-existing natural drainage map of study area is shown in Figure 9. Non-existing drainage density map was generated and the maximum non-existing drainage density value found is 0.69. The map was reclassified into two groups. Non-existing drainage area as one group and remained area as another group. A considerable amount of 33% of study area is under the group of non-existing drainage area. Few tributaries of complete drainage way length and some tributaries of starting upstream drainage way have not been existed in the study area. New built up area was found when verified with field visit and Google earth images.

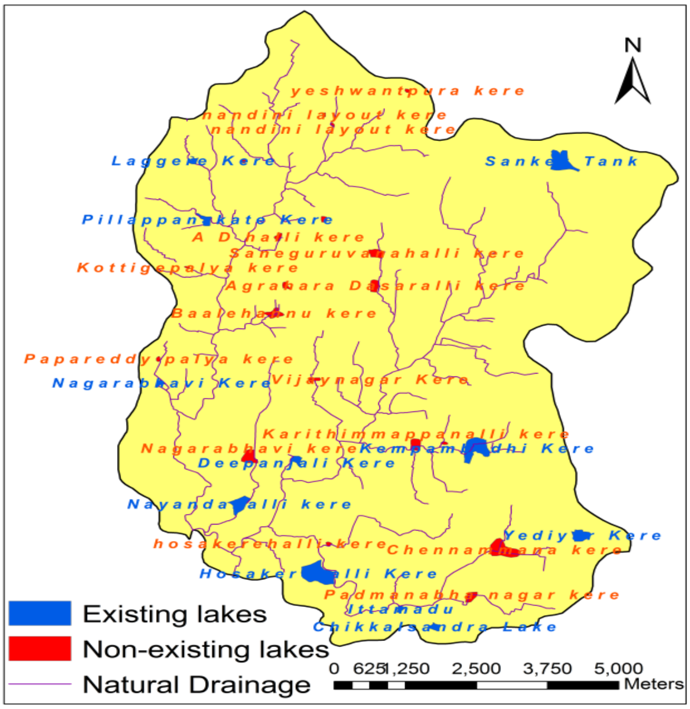

Figure 10: *Non-existing lake water body map of study area*

3.8. Non-existing Lakes

A lake water body serves as natural drainage system and prevents flooding. In Chennai city, on 12th September 2013, areas around the tanks were not waterlogged. Many roads with lack of storm water drain, where water bodies had facilitated runoff. Many areas escaped from inundation in Chennai city due to their proximity to water bodies. In many layouts in the suburbs (Chennai city) where storm water drains were accorded the least priority, water bodies served the purpose (Lopez, 2016). Non-existing lakes water body map of study area is shown in Figure 10. Present study reveals that, Vrishabhavathi valley study area had 30 lakes in the year 1989 and now in the year 2017, 11 lakes are alive but most of the alive lakes are sewage fed and eutrophicated. Lakes being vanished due to encroachments and closed lakes have been converted to park/play ground/stadium/community space.

3.9. Mapping of Urban Flood Vulnerability Zone (UFVZ)

Flood vulnerability is the process of determining the degree of susceptibility of a given place for flooding. The flood vulnerability zones for the study area were generated through the integration of various thematic maps viz. rainfall, slope, drainage density, land use, building density, road density, non-existing natural drainage and non-existing Lakes using weighted overlay analysis. The “Weighted Overlay” is a tool built inside ArcGIS software and this tool has been used to perform an overlay analysis. The weighted overlay tool overlays several raster using a common measurement scale and weights each according to its important. The result of overlay analysis has been classified into five class zones as very low, low, moderate, high and very high zones as shown in Figure 11. From the resultant urban flood vulnerability zone map, it has been showed that, 6.48Km^2 area is having very low, 19.43 Km^2 area is having low, 38.85 Km^2 area is having moderate, 24.05 Km^2 area is having high and 3.7 Km^2 area is having very high flood vulnerability zone. The study depicts that 42% of vast area comes under moderate flood vulnerability zone.

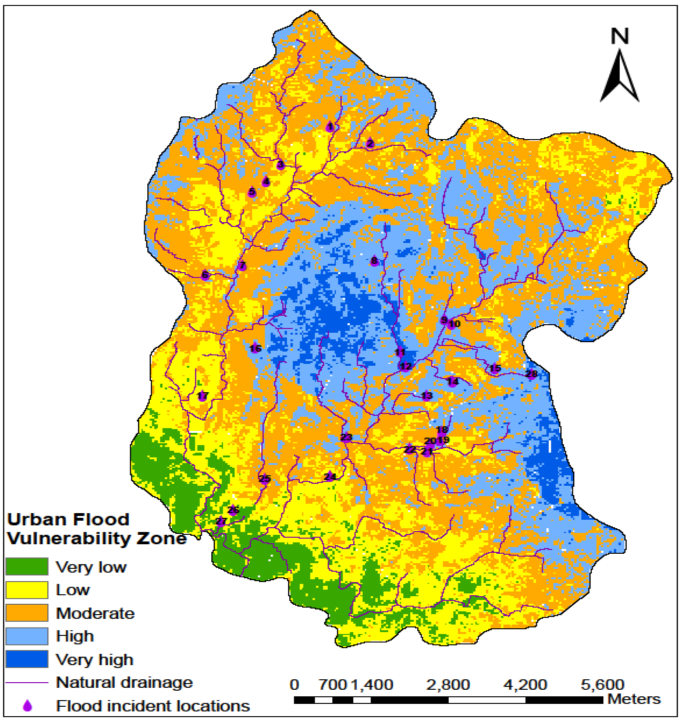

Figure 11: *Urban flood vulnerability zone map of study area with flood prone locations*

Flood vulnerability zone map was compared with the flood prone locations found in Bengaluru city to assess the accuracy of result. Flood prone locations in Vrishabhavathi Valley watershed study area were surveyed by author and identified based on local information, news of flooding in newspapers and other available literature that recorded the past events of flood prone areas. Besides this information, BBMP (Bruhat Bengaluru Mahanagara Palike) the Bengaluru municipal city corporation as well identified, documented and reported the flood prone locations found in Bengaluru city from reconnaissance survey based on history of flood, the severity of inundation and the time of inundation during 2011 (BBMP, 2011). Totally 28 number of flood prone locations have been found in the Vrishabhavathi Valley watershed study area Figure 11. These flood prone locations were numbered and overlaid on the flood vulnerability zones map. The percentage covering area of each flood zone classes are shown in Table 5 along with number of known flood prone locations fall on each zone. The resulted UFVZ shows 50% of flood prone location numbers i.e. 14 out of 28, lies within the moderate flood vulnerability zone class. This implies that anthropogenic factors (land use, building density, road density, non-existing drainages and non-existing lakes) have much influence to flood vulnerability in the urban study area rather than natural factors (rainfall, slope and drainage density) even though more weightage assigned to natural factors (Table 3) because of flood is a natural disaster. Study depicts that anthropogenic factors are more influenced to a flood disaster in urban environment. Supporting the result, in small area five flood prone locations numbered 18, 19, 20, 21 and 22 is found very closely (Figure 11) and flood events being reoccurred every monsoon, majorly due to the two lakes closed (Karithimmappanahalli lake converted to park and Azad Nagar lake using as automobile stand) in that area (Figure 11). Similarly flood prone locations numbered 1, 8 and 25 is found very proximity to the two closed lakes in nandini layout area; saneguruvanahalli closed lake and Nagarbhavi closed lake respectively. Flood prone locations numbered 28b (Bhakshi Garden-Cottonpete) and 15 (Nagamma Nagara near Minerava Mill) lies on very high building density class zone and low road density class zone and that locations are the slum area where very narrowed and haphazard road network with no proper storm water drains. Flood prone locations numbered 14 (Jagajeevan Ramanagara) and 13 (Goripalya-Guddadahalli) found at very high building density class zone area. Flood prone locations numbered 4, 5 (Laggere) and 16 (Moodalapalya) lies upon non-existing drainage area. Flood prone locations numbered 26 and 27 even though lies under very low building density class zone, blockage of road side chamber inlet due to silt and solid waste causes flood events. 68% (19 no.) of flood prone locations found along Vrishabhavathi valleys and closed to drainage.

4. Conclusions

Delineating the Urban Flood Vulnerability Zone (UFVZ) in Vrishabhavathi valley watershed of Urban Bengaluru using AHP, GIS and remote sensing techniques can aids in quick decision-making for sustainable urban flood management. Each thematic maps namely rainfall, slope, drainage density, land use, building density, road density, non-existing natural drainage and non-existing lakes were assigned with proper weightage through AHP technique and then integrated by weighted overlay analysis tool in GIS, to prepare the UFVZ map of study area. The map showed 42% of study area is prone to moderate flood vulnerability. The result of present study has been compared with the known flood prone locations to assess the accuracy of result. 50% of flood prone locations found under moderate flood vulnerability zone class and comparatively very less 36% flood prone locations found in high and very high zone class. The results indicate that, in urban environmental study area, the flood disaster is more influenced by anthropogenic impacts.

The proposed methodology would be suitable for mapping flood vulnerability zones through Analytical Hierarchy Process (AHP) approach. The present paper shows a simple and cost effective empirical method for delineating flood vulnerability zones using remote sensing and GIS from the available data. The present work identified zones required for urban flood disaster management. The study can also aids for planning future urban flood projects in the study area in order to ensure sustainable urban flood management.

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