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GIS Based Urban Flood Vulnerability Analysis in Western Zone of Ahmedabad City

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Abstract: *The hazards and disaster are not area specific and their vulnerability is high in urban area where the concentration of high risk population. Floods are major hazard occurs frequently across every part of the world, which causes damage to environmental, social, economical and human lives at about 43 per cent of all natural disasters. Floods in urban areas are flashy where runoff is manifolds over what would have accrued on natural terrains causing wide spread destruction to urban properties. The floods in the city occur mainly due manmade activities pertaining to blockage of natural drainage, high rainfall intensity and haphazard construction of roads, building and storm water drainage network. The first step of flood management is to evaluate the area, which is under threat of flood disaster. Therefore, present study focused on identifying flood vulnerable zone in western zone of Ahmedabad city using multi-criteria evaluation approach in a geographical information system with remotely sensed data.*

Keywords: *Disaster, Flood, GIS, Multi-Criteria Decision Analysis, Remote Sensing, Urban, Vulnerability*

1. INTRODUCTION

Flood is considered to be one the most devastating and frequently occurring natural hazards in the worldwide (Komolafe et al., 2015). In recent years, the growth of population and diffusion of settlements over hazardous areas have sharpened the impact of the flood disaster on the society and its effect on sustainable development (Winsemius et al., 2013). Floods have caused immense economic and social losses, mainly due to unplanned urbanization, uncontrolled population density and not strictly inspected construction by authorities. Floods kill thousands of people and destroy billions of dollars worth habitat and property each year (Manfreda et al., 2011). Vulnerability is the degree of loss to a given element or set of elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude (Mundhe, 2008). For urban planning purposes, a hazard map is not completely useful (Jalayer et al., 2014). The location of the areas where the largest economical losses due to natural disasters could occur is of invaluable importance. Therefore, the need of complementing natural hazard studies with vulnerability and risk assessments. The main aim of this study is to generate a composite map for decision makers and identified flood vulnerable zone by using some effective factors causing flood. The study reviewed the role of GIS in decision-making and then outlined the evaluation approach for many criteria in decision process (Malczewski, 1999; Abah, 2013; Papaioannou et al., 2015).

In the analyses, causative factors for flooding in watershed are taken into account as annual rainfall, size of watershed, basin slope, and gradient of main drainage channel, drainage density and land use. A case study of flood vulnerable areas determination in a part of Ahmedabad city is employed to illustrate the different approaches.

1.1. Justification of Study

As we know that the developing countries are characterized by subsistence form of urbanization, so often these cities expose the limitations and constraints in terms of rehabilitation and their squatter settlement, lack of infrastructure amenities, (drainage, water supply, sanitation, transportation and social services), congestion. There are many examples in the mega cities, which characterize by aggravation of this problem due to occurrence of some natural events and hazards. As hazards and disaster are not area specific and their vulnerability is high in urban center as concentration of high population. So in short the non-arrangement and the infrastructural constraint in the urban centers aggravate the severity of natural hazards and causes catastrophic loss to life and property (Müller et al., 2011).

Specifically the focus is on urban flooding, as it is one of the most frequent hazards that occurred across every part of world, with some varying character (Fuchs et al., 2011). As the flood can be large-scale riverine flood to storm runoff flood, cyclonic flood to the meteorological flood. However, on average these floods have some sort of problems, with variations in magnitude of severity and its impact. This study would particularly concentrate on local floods, which may not have severe impact but could be a threat to the future sustainability of the city. As there are many examples when the flash flood were over looked and eventually resultant to large scale flood onset of heavy monsoon (Behanzin et al., 2015). Therefore, it is very essential to sort out the different reasons and their impacts in terms of city wise distribution and subsequently formulating a proper decision system for avoiding any future occurrence.

1.2. Objective

The main objective of this present research work is to identify the flood vulnerable zone using multi-criteria decision approach in a geographical information system with remotely sensed data and suggest strategy for flood management. It may aid in quick and useful decisions for the purpose of administration and planning for a disaster management.

1.3. Materials

The data collection involved collection of topographical maps, ward maps, satellite data, rainfall data and demographic details. The nature of these data and their source is indicated in Table 1.

Table1. *Data Requirement and Sources*

Sr. No	Data Types	Sources
A	**Spatial data** 1) Base map of Ahmedabad City 2) Topographical maps & TP scheme maps scale (1:25,000) 3) Flood level map 2005 4) Landsat TM satellite images 5) Google Earth Image	1. Ahmedabad Municipal Corporation (AMC) 2. Survey of India 3. PWD, Ahmedabad City. 4. www.glcf.com. 5. Internet services
B	**Non Spatial data** 1. Daily rainfall data 2. Land use/land cover 3. Population data	1. Metrological Department of Ahmedabad City 2. Ahmedabad Municipal Corporation 3. www.censusindia.gov.in

2. STUDY AREA

Ahmedabad city is located between 72^{0}32’06”E to 72^{0}35’14”E longitude and 22^{0}59’01”N to 23^{0}05’45”N in North-central Gujarat. The average elevation is 53 meters. It is located on the banks of the Sabarmati River (Mahadevia et al., 2014). The city is the administrative centre of Ahmedabad district, and was the capital of Gujarat after the bifurcation of the State of Bombay on 1 May 1960 to 1970; the capital was shifted to Gandhinagar thereafter. Ahmedabad is the sixth largest city and seventh largest metropolitan area of India (Census of India, 2011).

This means that the city limits has expanded. The demand has increased in the quantity and quality of infrastructure facilities and services. The ignorance of guided planning, fast and haphazard development may emerge this result in many problems. The flood in the city may occur due to manmade activities, improper construction of roads and buildings, insufficient storm water drainage system, high intensity rainfall and many more reasons. The result due to flood is very much known, it affects the daily life and the economic activities. It is essential to find out the causes, reasons and the measures to mitigate the flood situation in any given condition.

3. METHODOLOGY

Pre-processing operations involved scanning, geo-referencing and digitization of Survey of India (SOI) topographical maps, classification of satellite image and other base maps. Firstly, Survey of India (SOI) toposheets has been geo-referenced using WGS 1984, Universal Transverse Mercator (UTM) projection system. After geo-referencing the SOI toposheets and other maps are digitized in different features like point, line and polygon such as ward boundaries, road, railway line, streams, drainage block sites, contours, population density and river etc. The remotely sensed image acquired by the Landsat TM sensor with a spatial resolution of 30m on January 21, 2007, was used for visually interpreting the land use/land cover. Based on data prepared various maps like slope, drainage density, surface runoff and drainage density maps were generated for flood vulnerability mapping.

The present research work follows a multi-criteria evaluation approach using criterion weights method and integrates slope, land use / land cover, population density, drainage density and surface runoff to identify the flood vulnerable zone presented in Figure 1 (Heywood et al., 1993; Yalcin, 2002). Multi-criteria approaches have the potential to reduce the costs and time (Siddique et al., 1996; Ologunorisa, 2004; Kontos et al., 2005; Yelcin & Zuhal, 2005). The procedure by which the weights were produced follows the logic developed by Saaty (1980) under the analytical hierarchy process (AHP) which is utilized to determine the relative importance of the criteria in a specified decision-making problem (Heywood et al., 1993; Yalcin, 2002; Jaybhaye et al., 2014).

There are many reasons use reclassification criteria including replacing values based on new information, grouping entries, reclassifying values to a common scale. The reclassification functions reclassify or change cell values to alternative values using a variety of methods. Classification was done on various layers and the values were assigned ranging from very low vulnerable to very high vulnerable (Isma'il & Saanyol, 2013). Whereas, reclassification of layers were classified into the 1 to 5 ranking system, where first, represented very low vulnerable, second, low vulnerable, third, moderate vulnerable, fourth, highly vulnerable and fifth, very high vulnerable respectively. Giving higher values to attribute within each data set that are more venerable to flood. It means higher the value higher is the vulnerability. However, in this case slope is considered as negative factor because as the slope increases the flood vulnerability decreases and vice versa. Finally, these layers are integrated using 'Raster Calculator' of the Spatial Analyst extension of ArcGIS through the map algebraic expression.

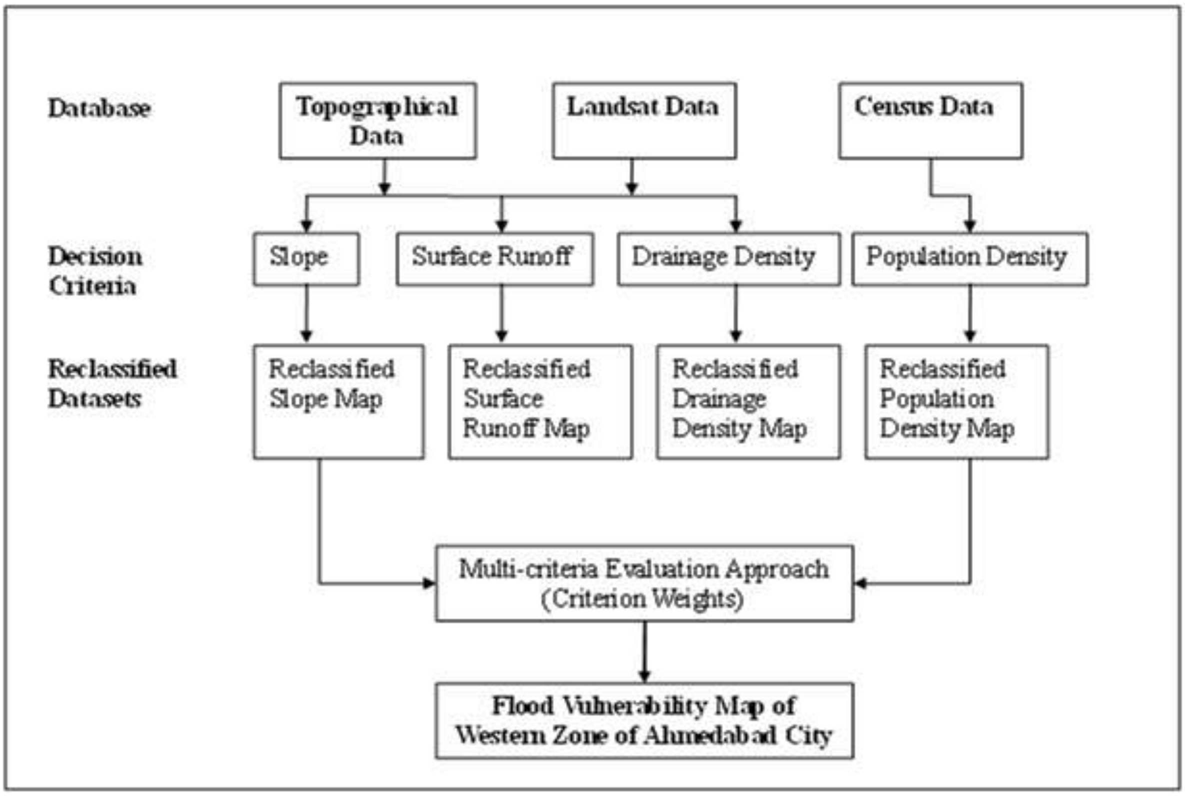


Figure1. *Flowchart of Methodology*

3.1. Decision Criteria for Identification of Flood Vulnerable Zone

On the basis of availability of data and detail primary survey in the studied region four major criteria's are considered for flood vulnerability mapping (Bapalu & Sinha, 2006; Mmom & Ayakpo, 2014). There are major four criteria to find out the urban flood vulnerable zone i.e. surface runoff, slope, population density and drainage density.

3.1.1. Surface Runoff

Runoff is defined as the portion of the precipitation that makes its way towards rivers or oceans as surface or subsurface flow (Corbitt, 1999). After the occurrence of infiltration and other loses from the precipitation (rainfall), the excess rainfall flows out through the small natural channels on the land surface to the main drainage channels. Such types of flow are called surface flows. A part of the infiltrated rainwater moves parallel to the land surface as subsurface flow, and reappears on the surface at certain other points. Such flows are called interflows. Another part of the infiltrated water percolates downwards to ground water, moves laterally to emerge in depression and rivers, and joins the surface flow. This type of flow is called the subsurface flow or ground water flow. Runoff can be estimated by rational method. The Rational equation is the simplest method to determine peak discharge from drainage basin runoff (Chin, 2000).

Rational Equation: $Q=ciA$

The Rational equation requires the following units:

Q = Peak discharge, (m^3/s)

c = Rational method runoff coefficient

i = Rainfall intensity, inch/hour

A = Drainage area, acre/km^2.

In metric units, this equation is expressed as.

$Q = 1/3.6\ ciA$

Where, Q = Peak runoff rate (m^3/s)

c = Rational method runoff coefficient

i = Rainfall intensity, inch/hour

A = Area of the drainage basin (km^2).

Coefficients of runoff for the Catchments characteristics shown in Table 2.

Table2. *Simplified Table of Rational Method Runoff Coefficients*

Ground Cover	Runoff Coefficient, c
Lawns	0.05 - 0.35
Forest	0.05 - 0.25
Cultivated land	0.08-0.41
Meadow	0.1 - 0.5
Parks, cemeteries	0.1 - 0.25
Unimproved areas	0.1 - 0.3
Pasture	0.12 - 0.62
Residential areas	0.3 - 0.75
Business areas	0.5 - 0.95
Industrial areas	0.5 - 0.9
Asphalt streets	0.7 - 0.95
Brick streets	0.7 - 0.85
Roofs	0.75 - 0.95
Concrete streets	0.7 - 0.95

Source: *http://www.LMNOeng.com*

The catchment area is indicated in Table 3. In study area, there are nine catchment areas like Navrangpura South, Gandhigram South, Naranpura, New Wadaj, Sabarmati, Paldi, Stadium, Vasna, Gandhigram North. Figure 2 (a) revealed that, the South Navrangpura catchment has the maximum runoff 116.16 cum/sec due to influence of Sabarmati River. While Stadium catchment has minimum surface runoff of 2.45 cum/sec.

Table3. *Total Surface Runoff of Western zone of Ahmedabad city*

Sr. No	Name of catchment	Area of catchment (Ha)	Watershed Runoff (cum/sec)
1	Navrangpura South	1382.68	116.16
2	Gandhigram South	487.98	41.9
3	Naranpura	240.55	18.22
4	New Wadaj	494.12	41.25
5	Sabarmati	181.00	15.04
6	Paldi	172.47	15.34
7	Stadium	36.89	2.45
8	Vasna	56.52	4.85
9	Gandhigram North	179.73	14.2

3.1.2. Slope

Slope is another indicator responsible for flood, which is taken into consideration. The slope function calculates the maximum rate of change between each cell and its neighbors, for example, the steepest downhill descent for the cell (Chang, 2010). Every cell in the output raster has a slope value. The lower the slope value flatter the terrain and the higher the slope value steeper the terrain. The output slope dataset can be calculated as percent or degree of slope (Jensen, 2004).

Slope map is generated based on contour line in Arc GIS platform. There are five categories of slope are identified and calculated as degree unit. Figure 2 (b) indicates that, northwest and middle part of the city mostly flat and northeast and southwest part is covered by hilly area. In the results, most of the study area falls under slope category less than 0.50, which covered 90% of the total study area. This is highly flood vulnerable zone in western part of Ahmedabad city due to low-lying area.

3.1.3. Population Density

It is one of the most powerful indicators for flood vulnerability mapping. It indicates the ratio of total population in a given area (Chandna, 2010). Importance has given to this indicator that higher the density, flood vulnerability is also high. Because more people will be affected and chances of property lose are more, daily activity will be stopping (Mundhe, 2008). The present research, population density calculated as ward wise. In western zone of Ahmedabad city, there are nine wards out of them New Wadaj ward has the highest population density that is 28453 persons per square kilometer due to concentration of market and satisfactory transport facilities. Lowest population density recorded in Gandhigram and Navrangpura ward that is 9655 and 9174 respectively indicated in Figure 2 (c).

3.1.4. Drainage Density

Drainage density is a measure of stream spacing (Langbein, 1947). Drainage density reflects basin’s geology and climate. Basins underlines by resistant, permeable materials have low drainage density; basins underlines by weak, impermeable materials have high drainage density (Strahler, 1958). For the same geology and slope angle, humid regions tend to have lower density due to growth of thick vegetation that promotes infiltration. Arid region would have tended to have higher density given in the same geology.

$$\text{Drainage density} = \frac{\text{Total length of streams within a Catchment/watershed (sq. km)}}{\text{Total area of the Catchment/ watershed (sq. km)}}$$

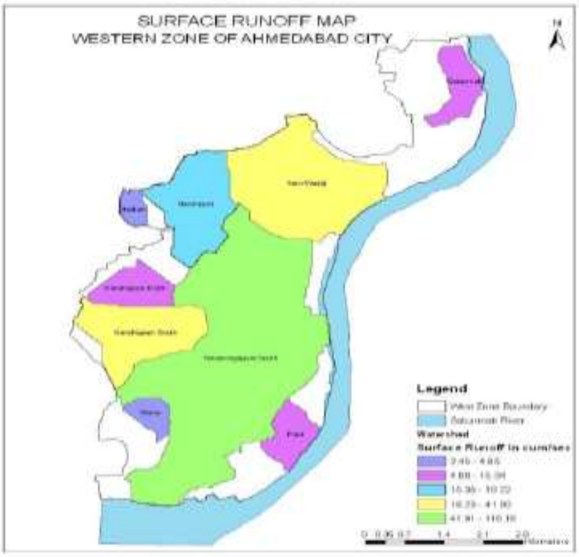
A high value of drainage density indicates a relatively high density of streams and thus a rapid storm process. The study area comprises in to nine catchments like Navarnagapura South, Gandhigram South, Naranpura, New Wadaj, Sabarmati, Paldi, Stadium,Vasna and Gandhigram North. Highest drainage density found in Vasna and Naranpura catchment that is 2.50 and 2.43 per hectare respectively in city and lowest in Stadium and Sabarmati catchment area. Moreover, moderate in Gandhigram south, Navrangpura and New Wadaj catchment area mentioned in Figure 2 (d).

3.2. Reclassifying Data Set

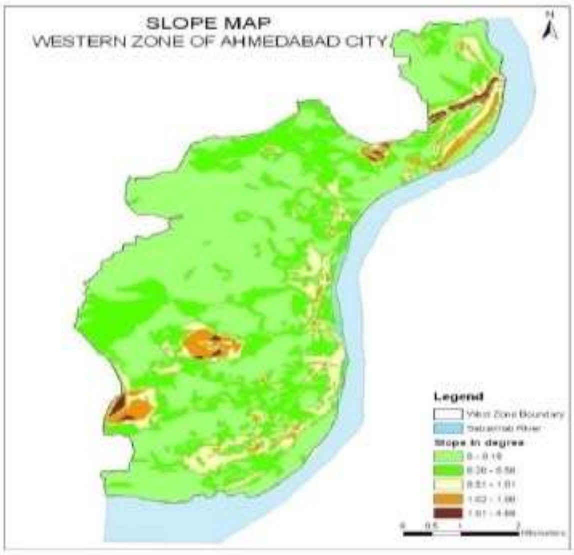
There are many reasons use reclassification criteria including replacing values based on new information, grouping entries, reclassifying values to a common scale, setting specific values to No Data, or setting No Data cells to a value. The reclassification functions reclassify or change cell values to alternative values using a variety of methods. Present study purpose reclassify one value at a time or groups of values at once using alternative fields; based on criteria, such as specified intervals to find out how much vulnerable to a particular location. Therefore, each dataset were reclassified, within the range 1-5, giving higher values to attribute within each data set that are more vulnerable to flood. It means, higher the value higher is the vulnerability.

The present research work considered four major criteria like Surface runoff, Slope, Population density and Drainage density for mapping of flood vulnerable zone. Subsequently, reclassify the above-mentioned raster layers within the range 1 to 5 ranking system showing in Figure 3. Here, higher the values means more vulnerable to flood. However, in slope map is considered as negative factor because as the slope increases the flood vulnerability decreases and vice versa. Lastly, these layers were integrated or overlay using 'Raster Calculator' function in ArcGIS spatial analyst's tool through the map algebraic expression. This analysis produced flood vulnerability map of western zone of Ahmedabad city.

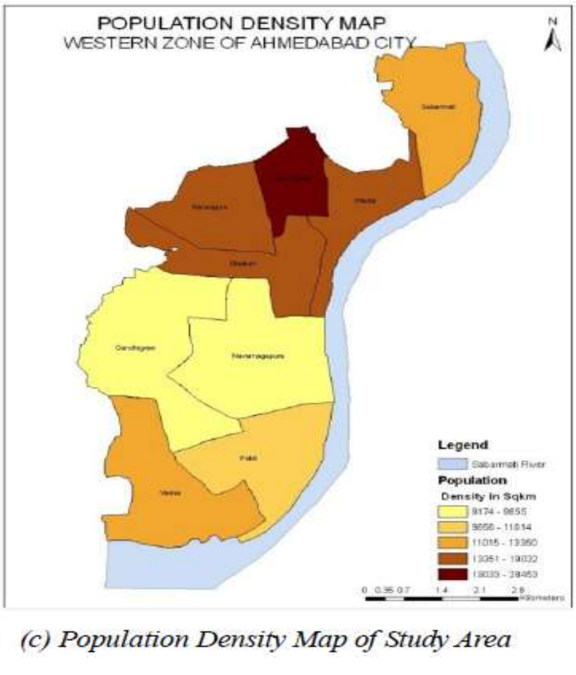
Figure2.



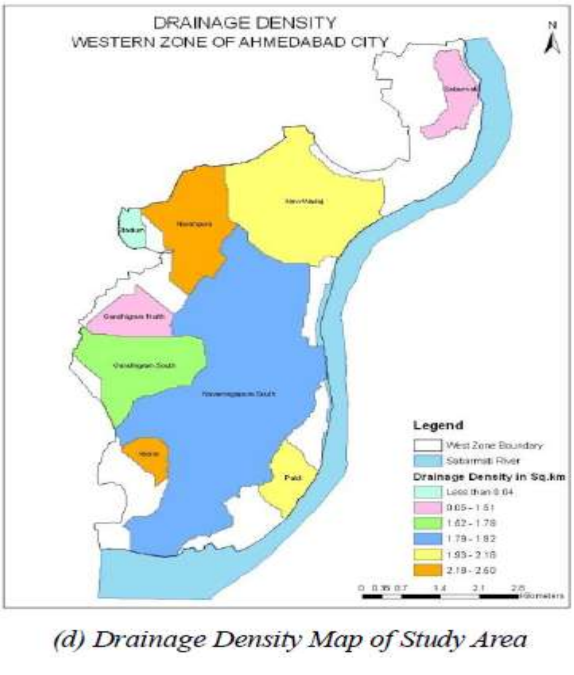
(a) *Surface Runoff Map of Ahmedabad city*



(b) *Slope Map of Study Area*



(c) *Population Density Map of Study Area*



(d) *Drainage Density Map of Study Area*

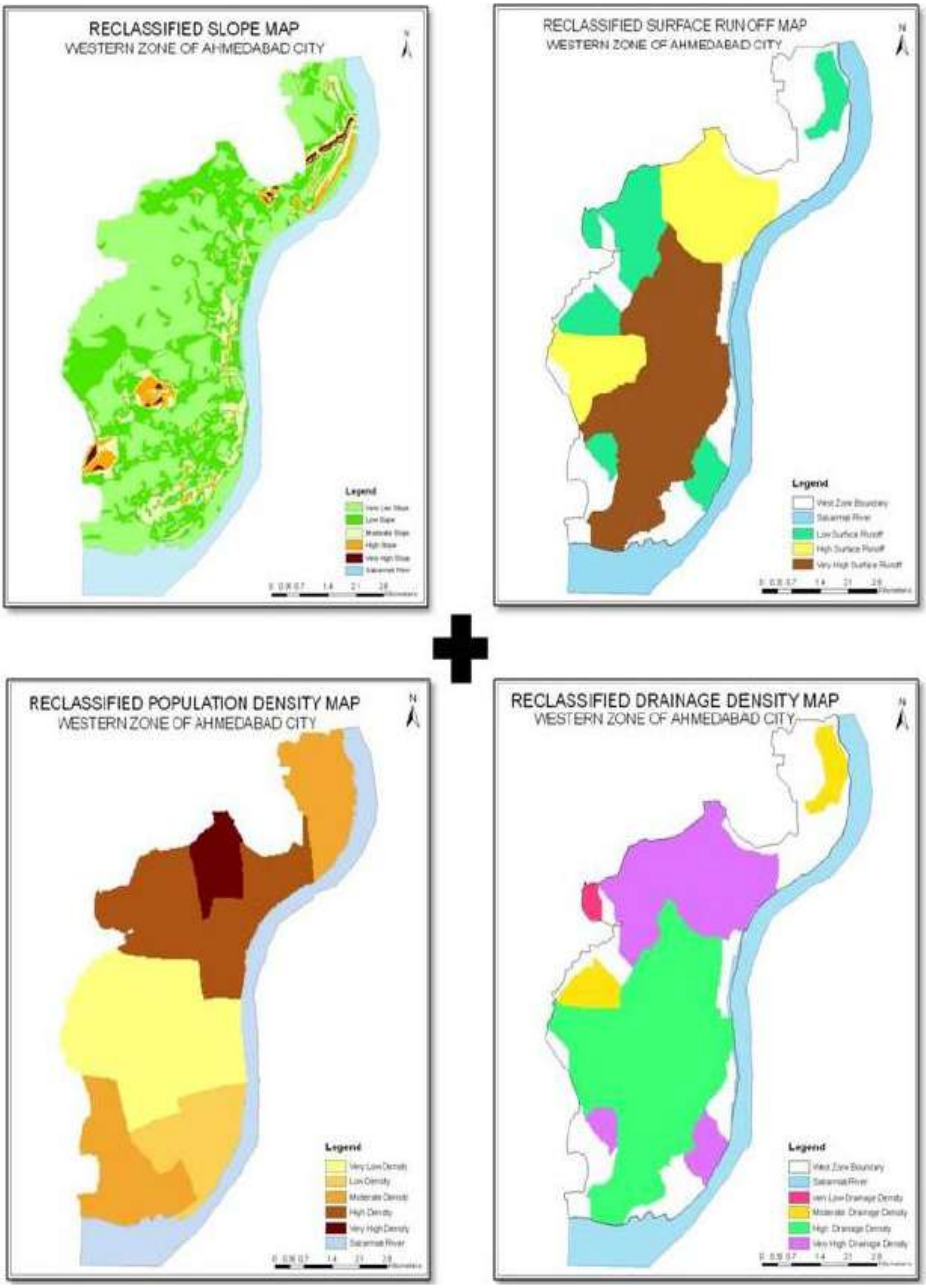


Figure3. *Overview of Reclassified Maps*

4. RESULTS AND DISCUSSION

The flood vulnerability map generated by integrating the thematic layers like Surface runoff, Slope, Population density and Drainage density. The factors affecting the flood prone area and their weightages assigning based on experts opinion and previous case studies. The summary of assigning weightage to factors is shown in Table 4.

Table4. *Summary of assigning weightage to factors*

Sr. No	Parameters	Weights
1	Surface Runoff	0.35
2	Population Density	0.25
3	Drainage Density	0.25
4	Slope	0.15

The urban flood Vulnerability is divided into four classes such as very low, low, moderate, high and very high zone generated by classifying the cumulative vulnerability score. The Figure 4 shows that, 28.1 % (890.61 Ha) of the total area of western zone of Ahmedabad City has very low and low urban flood vulnerability. The analysis revealed that, most of the area under very high and high vulnerable zones together constituted 47 % of the total area of the Ahmedabad City.

In the vulnerability zonation, 15% area of western zone of Ahmedabad City is identified as 'Very high' vulnerable to urban flood. The total area of very high vulnerable zone is 493.12 hectare. The major locations in this zone include Navrangpura, Sabarmati, Wadaj, Usmanpura, Ambawadi, Paldi, Vasna areas have very high risk. Above locations does not have proper drainage channels and the available channels are not maintained properly, if channels are present those are not sufficient for draining out the instantly accumulated floodwater because connection to the main drainage channels are lacking. Some of the identified locations have no drainage system and very compact & dense settlement type. Therefore, the special planning for storm water drainage in south Navrangpura, Stadium and Gandhigram North catchments are necessary. These locations are prime areas, where schools, banks, markets, high court, hospitals, colleges and other commercial institutions are located with high crowding. Hence, it can be observed that if any urban flood happens that will seriously affect the common public, compared with the other locations. Apart from the above observation, 32 % of the western zone of Ahmedabad City is laying in the zone, which is 'High' vulnerable to urban flood. This zone includes areas such as Wadaj, S. P. Stadium, Naranpura and Gandhigram etc identified in Figure 5.

Major part of the study area (25 %) is identified as moderate vulnerable to urban flood zone i.e. New Wadaj, some part of the Vasana and Paldi catchment area. 24 % of western zone of Ahmedabad City lies in the very low and low vulnerable to urban flood zone due to maximum storm water drainage pipeline carrying capacity.

The vulnerability map revealed that very high risks zone required immediate action plan to improve the drainage systems, which may include maintenance of existing storm water drainage and creating linkages between drainage networks.

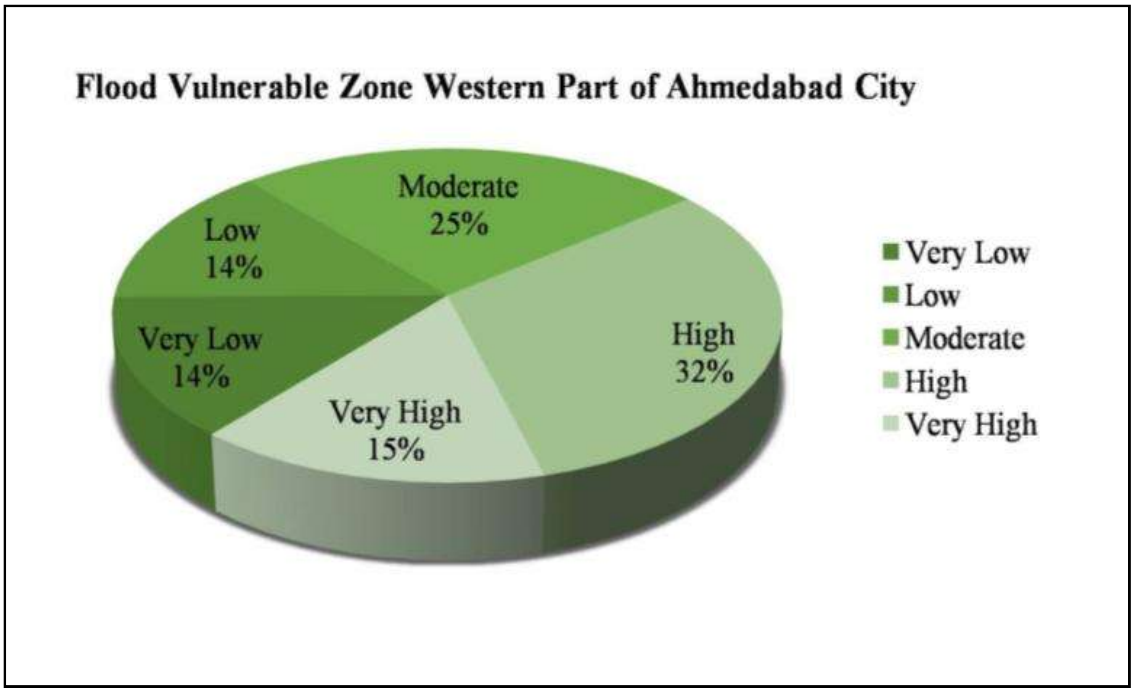


Figure4. *Flood Risk Zones*

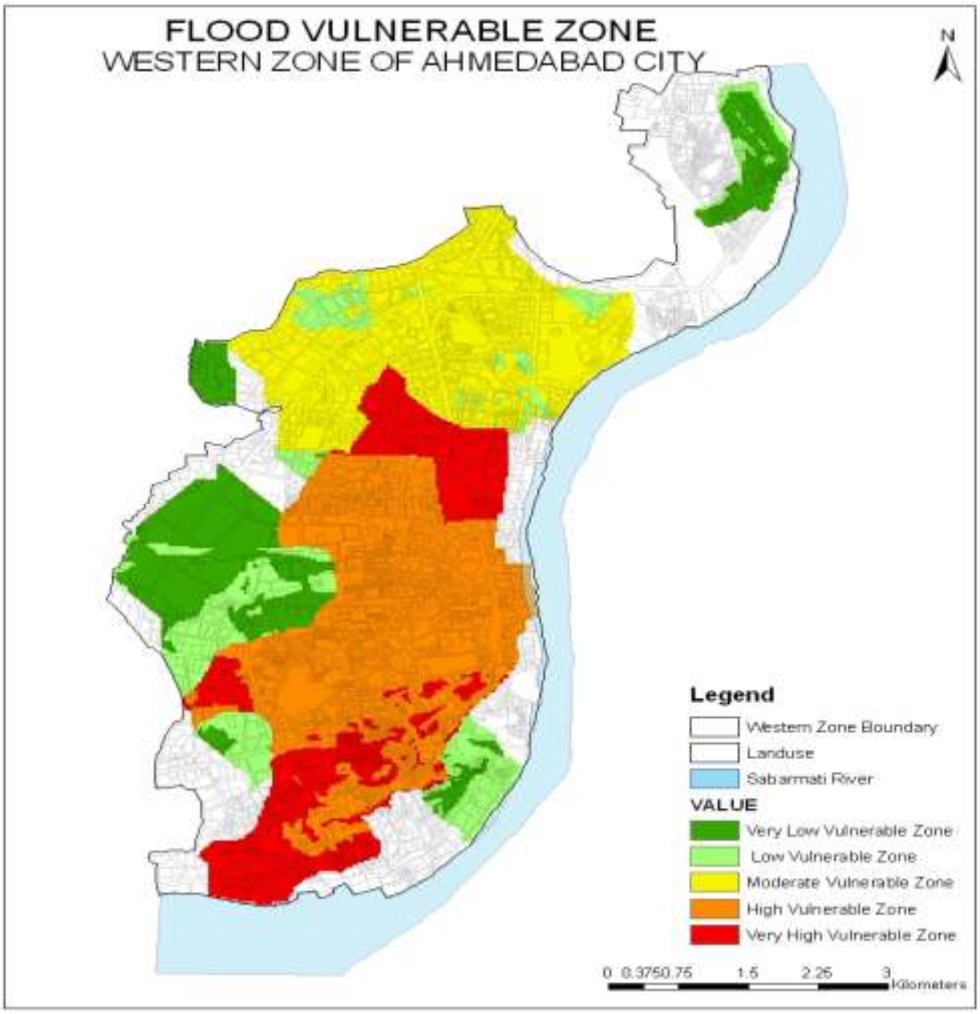


Figure5. *Flood Vulnerable Zone in Western Zone of Ahmedabad City*

5. CONCLUSION

This study represents exploratory steps towards developing a new methodology for inexpensive, easily read, rapidly accessible charts and maps of flood vulnerability analysis based on morphological, topographical, demographical data. The study demonstrated the use of GIS and spatial technology for analysis to identify the various vulnerable areas and places can be used to take various measures of pre and post-disaster management in Western zone of Ahmedabad city. Flood affected areas of different magnitude has been identified and mapped using GIS Software.

The study reveals that due to closeness to river Sabarmati, pattern of land use, low relief and housing compactness; some areas in the study area were found to be very high vulnerable to flood and these areas included Navrangpura, Sabarmati, Wadaj, Usmanpura, Ambawadi, Paldi, Vasna etc. The analysis is helpful for local planning authorities and planners for identification of risk areas and taking proper decision in right time. The flood vulnerability map can give planners insures and emergency services a valuable tool for assessing flood risk.

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