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Research Article

# Vulnerability Assessment of Urban Floods in Lahore, Pakistan using GIS based integrated Analytical Hierarchy Approach

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**Abstract:** Urban flooding is getting attention due to its adverse impact on urban lives in mega cities of the developing world particularly Pakistan. This study aims at finding a suitable methodology for mapping urban flooded areas to estimate urban flooding vulnerability risks in the cities of developing countries particularly Lahore, Pakistan. To detect the urban flooded vulnerability and risk areas due to natural disaster, GIS-based integrated Analytical Hierarchy Process (AHP) is applied for the case of Lahore, which is the second most populous city and capital of the Punjab, Pakistan. For the present research, the flood risk mapping is prepared by considering these significant physical factors like elevation, slope, and distribution of rainfall, land use, density of the drainage network, and soil type. Results show that the land use factor is the most significant to detect vulnerable areas near roads and commercial areas. For instance, this method of detection is 88%, 80% and 70% accurate for roads, commercial and residential areas. The methodology implemented in the present research can provide a practical tool and techniques to relevant policy and decision-makers authorities to prioritize and actions to mitigate flood risk and vulnerabilities and identify certain vulnerable urban areas, while formulating a methodology for future urban flood risk and vulnerability mitigation through an objectively simple and organizationally secure approach.

**Keywords:** Vulnerability, Urban Flood, Drainage, Analytical Hierarchy Approach, Lahore.

## 1. INTRODUCTION

The globally human population is at risk due to natural disasters and climatic changes. Doubtlessly weather-related phenomenon is significantly increasing both in terms of intensity and frequency [1-2]. Urban flooding is an emerging risk to the human population residing in developing countries of the world [3-5]. Yet, there is no proper technique and a defined method to gauge this growing urban risk due to the uncertain nature of the occurrence of urban flooding in geographic context [6-8]. There are many strategies for flood management and the vulnerability valuation is one of them [9]. However, the risk is commonly measured through vulnerability in case of any possible hazard occurrence. Hazard can be defined as a phenomenon that can damage property, threaten lives in an area with a given period. In short, any event with having a probability of damage can be called a hazard and it can be measured through risk assessment [10-12]. Some of the known risk elements include transport routes, services of public, commercial activities, residential and educational buildings as well as population itself [13]. Furthermore, risk also has a crucial component that is a vulnerability that determines either the exposure to a hazard will have an outcome of disaster or not. The exposure of urban flood was thought to be a risk in the beginning as compared to other types of flood. Recently, it turned into a disaster that started to damage the properties and disrupt the social lives as well as commercial activities yearly in megacities of developing countries particularly. The emerging issue seeks attention due to its direct impact on the population. The fact is that population is triggering this phenomenon. It has been observed that the urban population becomes more vulnerable too due

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to dense infrastructure during urban flooding [12, 14]. Therefore, municipal authorities should keep themselves aware of associated vulnerabilities of an area for territorial management of urban flooded hotspots [15-16].

Several studies used models of hydraulic and hydrological to assess the runoff of flood along with runoff in areas that are flood-prone and low lying. For the assessment of flood risk, the information should be collected about the flood probability of occurrence, event magnitude, and management of flood, the depth and location of inundation [17]. Bhadra, Choudhury, & Kar [18], in their study used hydraulic models for the assessing the risk of floods along with techniques of GIS or Digital Elevation Model (DEM) for the purpose of mapping the flooded area as well as depth of inundation. Furthermore, various techniques are used to represent the maps of flood risk and vulnerability in which DEM and flood flows simulation in different periods of times used by various scholars of the world [19]. In addition, it has also been explained that for the extraction of inundation of flood extent in a cost-effective way and time the most effective technique for hilly basin of Dikrong is GIS because they are remotely located areas, where accompanying the conventional survey is very challenging [20]. Furthermore, for demarcating the hazard especially flood-prone risk zones in the region of Papanasam Taluk, GIS is used as the best technique in which areas are distributed into five major regions on the base of the varying extent of a flood [21]. Moreover, a map of flood risk has the capability to recognize the zones which are mostly in danger to the hazard of flood along with it. It also highlighted that any occurrence of flood events will affect various people.

The best methods which based on GIS are considered as highly suitable for mapping the risk of flood [22]. These are generally based on surveys of ground level and observations of the aerial base. On the other hand, when techniques become common, such type of phenomenon is considered expensive and time-consuming. Furthermore, a drawback of aerial photography is that timely photography mostly becomes difficult due to the prohibitive conditions of weather. Therefore, this study is an attempt to ensure a multi-parametric methodology for demarcating the vulnerability of flood in rapidly developing urban area through GIS-based integrated multi-criteria technique of AHP as used for policy and decision making procedure. Diverse and multiple criteria were involved in the evaluation of problems through AHP effectiveness & trade-offs measurement. Occasionally, data is limited and by using such data lead towards recognition across various fields of application [23]. Similarly, a framework is examined through the technique of analysis as multi-criteria which can deal with variables of various kinds for the documentation of the essentials for the decision of complex problems.  Furthermore, in the structure of categorized nature, such a technique organize all elements and examine the associations among problematic components [24]. However, such a technique is still not renowned in the management of flood risk perspective [25].

Based on topographic and morphometric data, this study has the aim to create a map of flood risk areas that is easily detected by using the approach of AHP-GIS from available geodatabase. For the risk mapping of an urban flood, analysis through multi-parametric is commonly done that creates map of the composite index for provoking risk. Later, by assigning weights, the urban flood causative criteria are chosen. For current study, research questions are considered: (a) what risk criteria will be more suitable for integration of urban flood risk assessment in an urban environment; (b) how different selected weighted criteria can alter the percentage value of flood risk and its corresponding spatial distribution in an urban area.

## 2. MATERIAL AND METHODS

### 2.1 Study Area

The central part of Lahore is one of the cultural attractions not only from Punjab but from all over the country. Geographically, a selected area of Lahore city (as a study) extend from74 degree 12 minutes and 30 seconds E to 74 degrees 29 minutes E longitudinaly and latitudinal extends from 31 degrees 26 minutes N to 31 degree 39 minutes 30 seconds E [26]. This area is hypothesized for the emerging problem of urban flooding as per media reports. UN humanitarian agencies issued a warning that “In the province of Pakistan, Punjab, the heavy rainfall triggered flash flooding in Sialkot and

Kasur districts and also urban flooding in central Lahore and other big cities of Pakistan" as reported in Monday UN News, August 11, 2011. In the same year, an official claimed urban flooding is claimed as a chief cause for the outbreak of dengue fever in central Punjab in the month of September 2011, in Monday Foreign Policy-the global magazine of news and ideas, September 19, 2011.

Later, government efforts have been witnessed i.e. a MOU was signed between the Government of Punjab and Google to get cooperation in the IT sector to monitor several activities in Punjab. Under the agreement term and condition, Google provided technical assistance to the Arfa Software Technology Park. This cooperation between the Punjab government and Google was a good initiative even in providing relief to the people affected by the floods in Punjab in combination to add assistance to other sectors as reported in Pakistan Today, February 7, 2012. The paralyzed situation in Punjab cities in the month of August due to devastating rains is reported. All activities were disrupted due to persistent and heavy rain. This situation caused streets and roads into virtual rivulets in the entire city. In addition, deep rainwater covered the low-lying areas paralyzing the city. Knee-deep water was seen at Anarkali, Lakshmi Chowk, GhariShahu, Waris Road, Barkat Market, The Mall and Johar Town as reported in Dawn, September 10, 2012; Dawn, July 21, 2013; Dawn, August 15, 2013; dawn August 26, 2016.

In news, officials of WASA ensured the supervision of drainage operations. It has also been emphasized that Pakistan has a dire need to take structural and non-structural measures for hazardous events. It has been demonstrated that non-structural such as awareness campaigns found useful. A flood cannot be completely controlled or prevented however, damages can be reduced by concerned stakeholders working together as reported in Nation, August 7, 2015. Media reported for the urban flooding situations till 2015 was found in general perspective but in 2016 to onward, very keen interest has been seen on urban flooding in detail. Each event was recorded, for instance, 3rdJuly 2018 and 16th July 2019 were heightened by WASA for long hours rain and its adverse impacts to disrupt the city life.

### 2.2 Data and its Sources

Keeping in view, the purpose of the study, different sources of data have been incorporated, including topographic sheet, satellite imageries, land use and land cover base maps, drainage system capacity and rainfall. Later, ground-truthing has been done with the help of geo-tagging during field surveys to check the accuracy.

### 2.3 AHP as a Multi-Criteria Decision Analysis Tool

In a flooding place, the extent of susceptibility is determined through the process of mapping the vulnerability of flood. This process includes the selection of factors which are bio-physical as well as socio-economical; these factor as a combining form along with the preferences of decision-makers allow the user to create an index of composition sustainability. As a result, this process gave the problem of multi-criteria or multi-parameters making of the decision. In the mapping of urban flood vulnerability, integrate AHP with analysis of GIS, the proposed approach presents in Fig. 1 with a schematic outline. In Figure 1, steps compromises on primary data, with manipulation of data in the environment of GIS, analysis for multi-criteria decisions, and analysis for the sensitivity of the model. Such steps are further categorized into two stages of primary and secondary for the process. In addition, Figure 2 shows different datasets for the prediction that show in a hierarchal structure.

### 2.4 Flood Vulnerability Mapping Variables and Analysis

Elements of topographic and morphometric along with analysis of variables are present in this section, which become notable factors for developing decision making by AHP-GIS. Notably, for AHP that is multi-parametric, the variable selection depends upon the types of flood. Furthermore, in this unit the selection of different variables that are utilized in vulnerability analysis along with their classification into classes of intensity and risk. An analysis of decision making, the spatial reference is a profound and important step for criterion choice. Criteria of this study are undermined according to their significance in causing the flood. Such factors include slope and elevation, types of soil, the

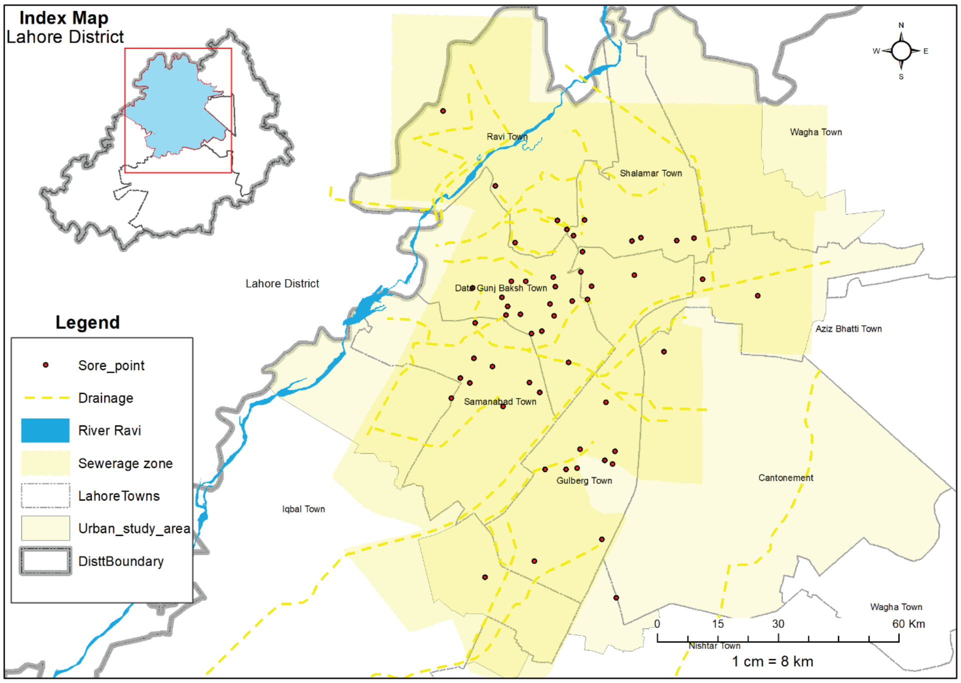



**Fig. 1.** Depicting geographical location of the study area (Central Lahore)

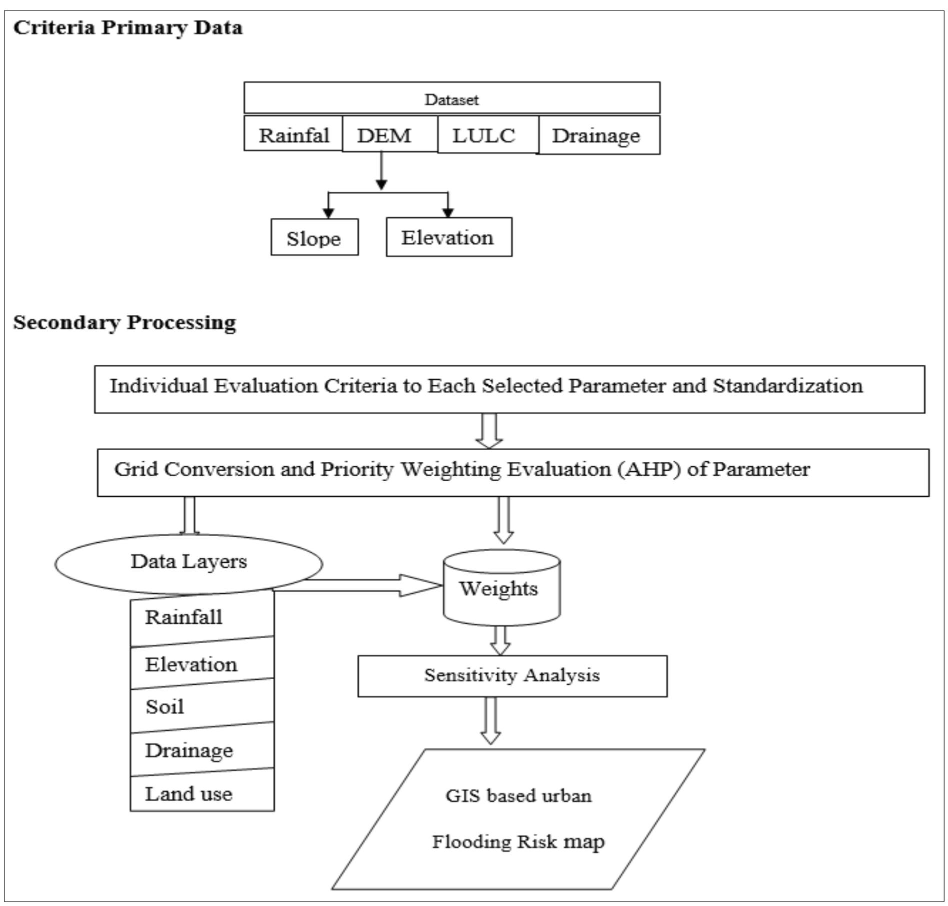



**Fig. 2.** Depicting the detailed Methodology flow chart

annual distribution of rainfall, density of drainage, and information of land use patterns.

## 3. RESULTS AND DISCUSSION

### 3.1 Elevation Profile

The elevation profile is a chief factor to measure urban flood risk. Generally, slope gradient determines direction of flow, duration, and infiltration rate of surface runoff. Both types of elevation profiles, either flat or steep, create environmental disturbances. However, role of human intervening cannot be ignored here for example, construction of metalled roads in plain areas and deforestation on steep slopes i.e. mountains. A flat surface allows rainwater to flow slowly and causes urban flooding in case of metalled roads. On the other hand, steeper slopes are also susceptible to surface runoff, if deforested. These slopes without dense trees, will lead to destabilize the soil and increase the chances of landslides. In present case study, Excessive storm water always gathers in depressions. For example, hotspots of urban flooding are natural local depressions. These local depressions can be generated by DEM. Those cells of DEM that are having a lower height than the nearby ones would be further significant for gathering excessive rainwater. These depressions are known as accumulated areas and have been shown in Figure 3.

A map through the model of digital elevation was prepared along with the use of tools related to hydrological software like Arc-GIS. For the projection of the inundated area, the tool of accumulation with raster data as input is used for the specific study area. Results show that accumulation flow obtained through applying the value of these hold that is 1.5 for selected cells which show the highest flow. Furthermore, results also clarify that mostly sore points lie near or within the area of high accumulation below the image in five classes is reclassified through selecting zone of high accumulation and assign them a value which ranges from 1 to 5 for raster cells that having less tendency of flow flat terrain or steepness identified with a tool of a slope which calculated the slope condition in the affected area. If the value of the slope is low, then cells clearly indicate that area is covered with flat terrain. On the other hand, the high value of raster cells indicates steep slopes.

### 3.2 Rainfall distribution

An intense amount of rainfall in a particular area for very long time became a reason of the flooding of all types. With heavy rain, flood mostly occurs due to the low capacity of flow channels either they are natural or manmade for drainage the excessive amount of water. Urban flooding mainly has an association with the amount of rainfall, in such areas water cannot infiltrate in soil and start to flow as runoff that gave the result of inundation which spread over the whole region. Thus, in a region it can be described that amount of rainfall clearly indicates the rate of runoff. In this study, it is observed that flooding in urban areas has a major cause that is local rainfall. As a result, it was concluded that the risk and hazard of urban flooding occur through the events of heavy rainfall. That is why events of rainfall that occurred at the local level are integrated by analysis. For the period of eight years such as from 2002 to 2017, take into consideration the amount of mean annual rainfall. For the study area, raster continuous data of rainfall was created with the help of Invasive Distance Weighting (IDW) for the process of interpolation. By using the equal interval, resulting layers of raster data are reclassified into five classes, in which the least rainfall class has a value of 1 while the highest amount of rainfall class is denoted by 5. Figure 5 highlights the outcomes of the raster layers of rain, data layers of interpolated IDW as well as data of rainfall as reclassified.

### 3.3 LULC Management

In the present research of urban flooding, land use consider as significant aspects. The current situation of land is represented with this factor, along with its pattern also discovered which developed with activities of humans in that area. Land use land cover has a relationship with the rate of infiltration in the soil during the time of the intense event of rainfall due to which consider as significant. Soil cover either the land is barren or cover with agriculture, always has a noteworthy influence on its aptitude in which soil act as an absorbent of water before as well as after the events of rainfall. Soil that presents in barren land openly always increases the rate of infiltration due to the runoff rate become

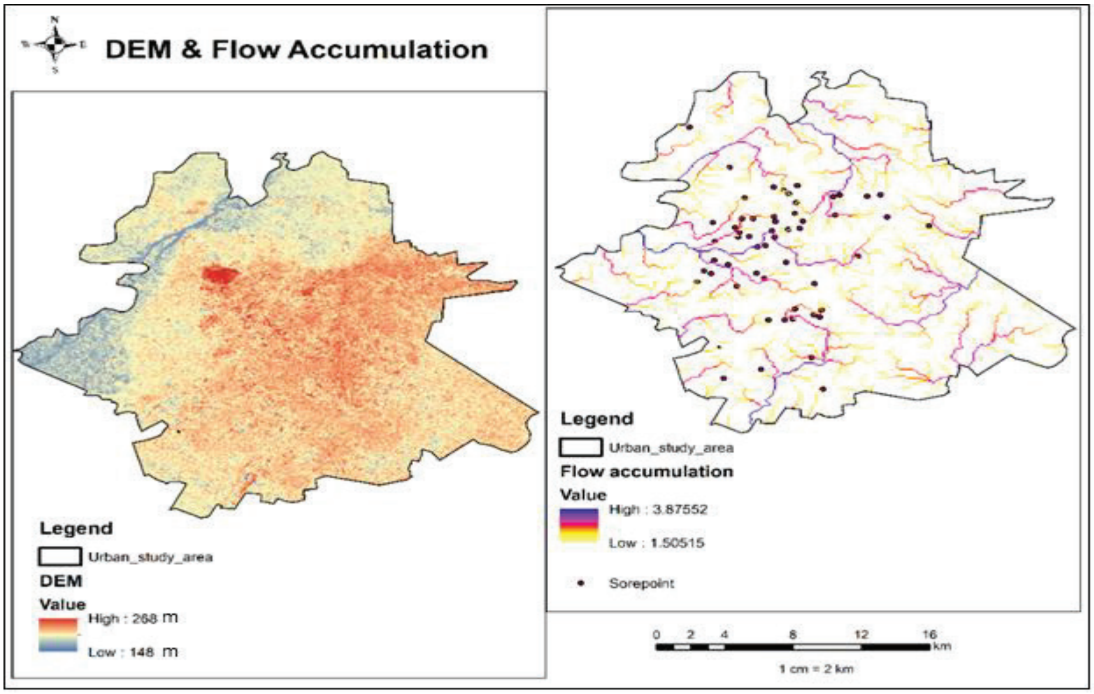



**Fig. 3.** DEM and flow accumulation

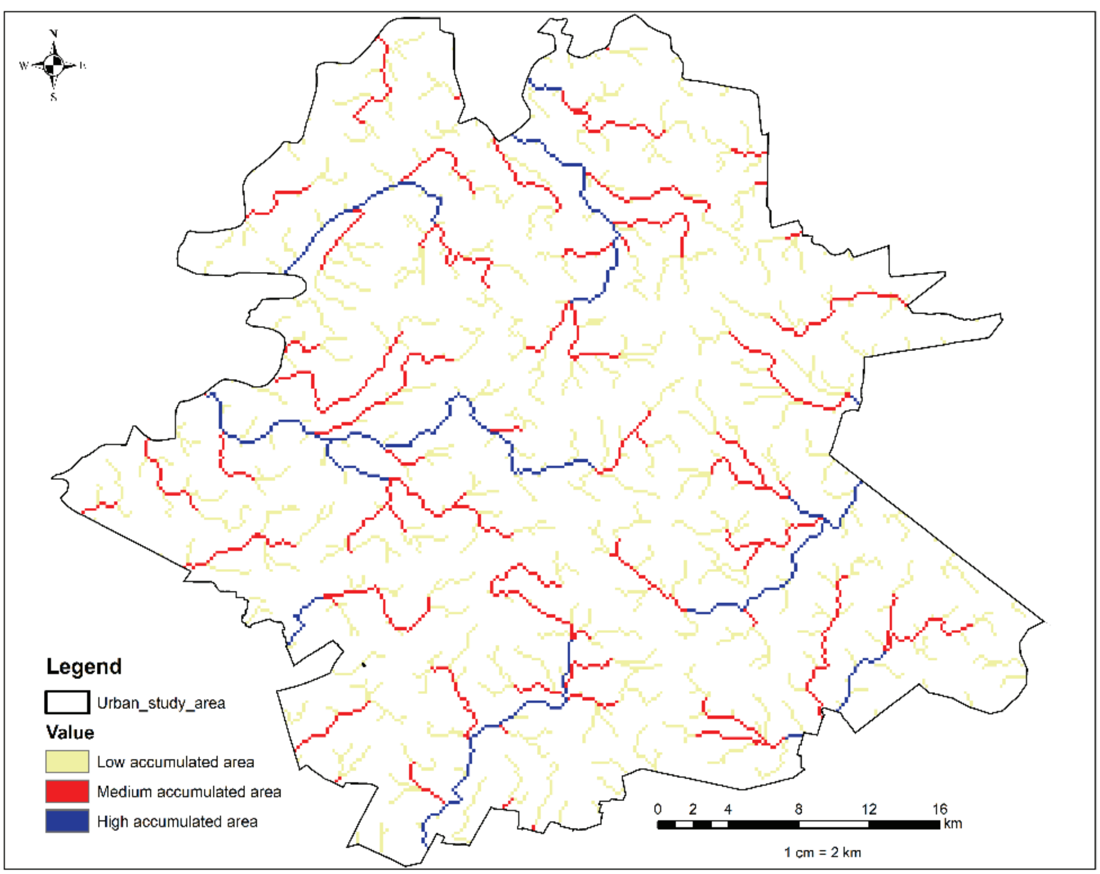



**Fig. 4.** Projected accumulated area extracted by DEM

low. Meanwhile, building roads which made up of concrete material and consider as impermeable land cover cause diffraction in storm water.

As an outcome, streets in the urban areas remain inundated usually during a season of monsoon. Land uses such as roads, buildings, areas of slums decrease the capacity of rainwater penetration in soil or increase the rate of inundation during intense rainfall. Similarly, types of land use always behave as an agent either the land cover with resistant or cover with absorbent. If the land has resistant quality than holing time decrease due to which chances of flooding also enhance. So that it is concluded that land use land cover is a significant element in determining the chances of events like urban flooding.

With the help of a map based on land use, the classes of land use were prepared for the study area. Map of land use is reassigned through categorizing into two types of land use pervious and impervious. Obtained raster classes of land use were classified again in five classes that move from a high value of absorbent toward land use of least absorbent and this division occurs based on their capacity by considering the land use type. For example, concrete roads are categorized as the least absorbent category. Figure 6 shows the results of the analysis done for land use and land cover.

### 3.4 Drainage and Sewage Network

In-network of drainage, the capacity of drainage and holding is a chief factor which controls the flooding in the urban area, the density of the drainage network predicts the chances of flooding in urban areas. From this, it is measured that if drainage has the highest capacity for draining the water of storm then probability becomes low about the occurrence of flooding in the urban regions. Maps related to the capacity of drainage originated from drainage map which has information related to the channel diameter of drainage, the tool of density used in the tool of spatial analyst through density is calculated related network drainage based on the pipe's size. Channels of drainage have a varying size which moves from 171 sq. km to 1.8 sq.km. After that, the layer of drainage density is reclassified further into subgroups which are three. Those areas which

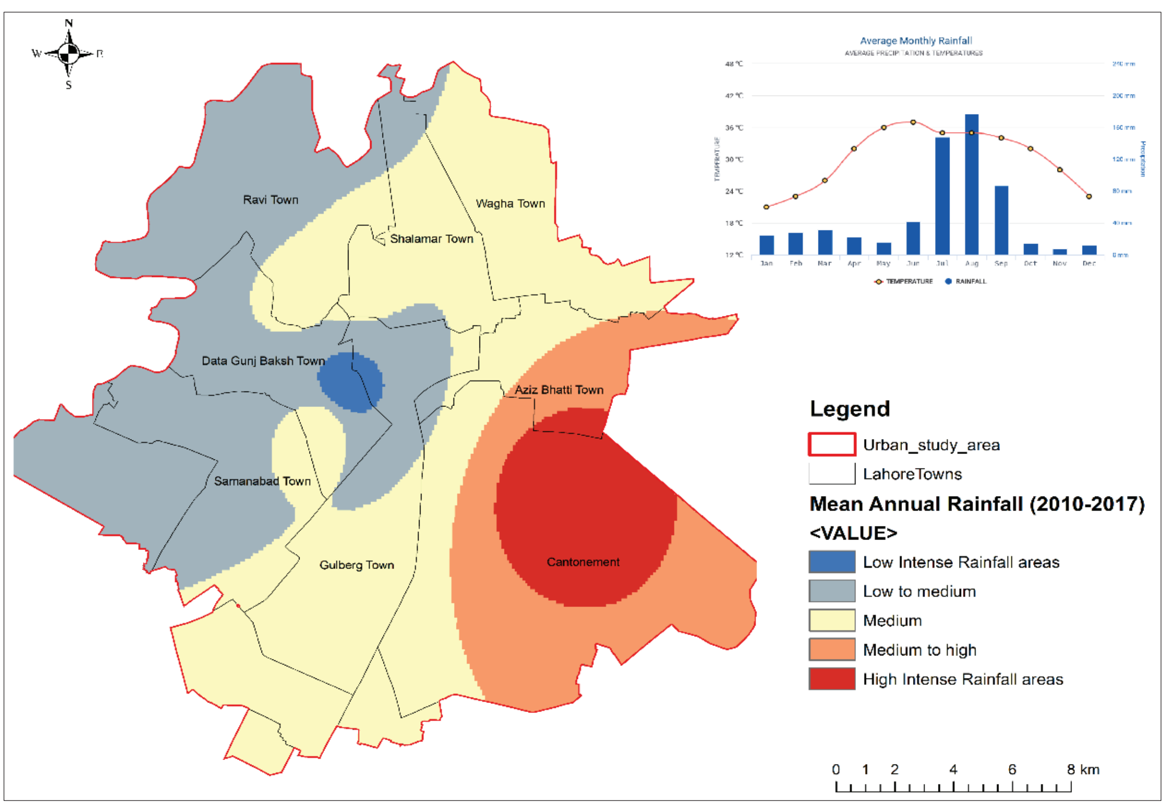



**Fig. 5.** Spatial rainfall pattern of Central Lahore (study area)

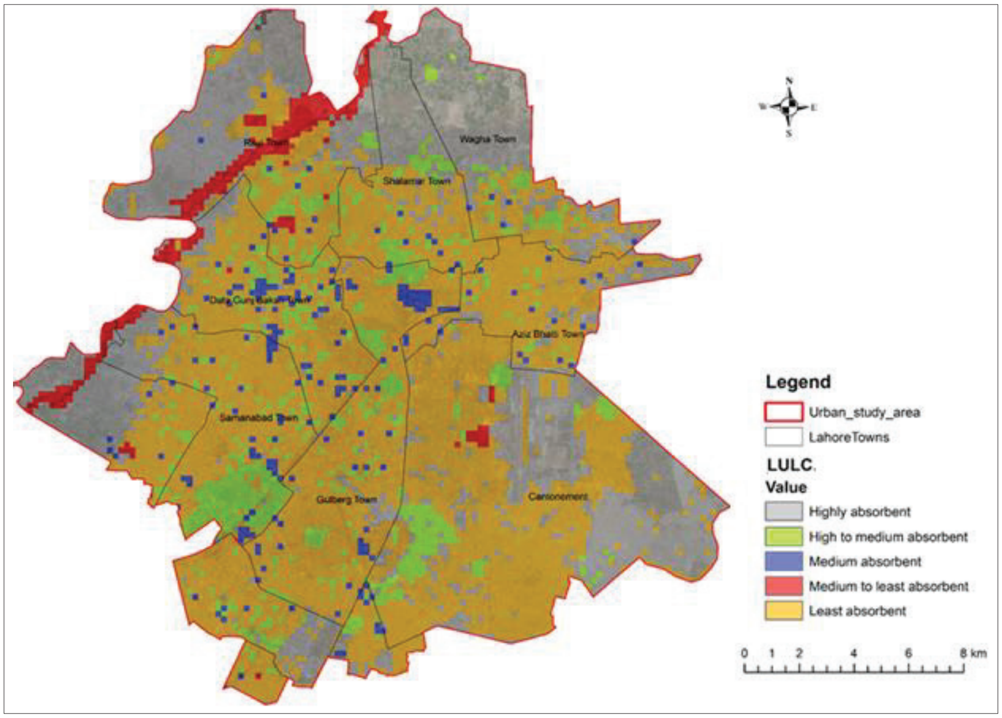



**Fig. 6.** Spatial rainfall pattern of the study area

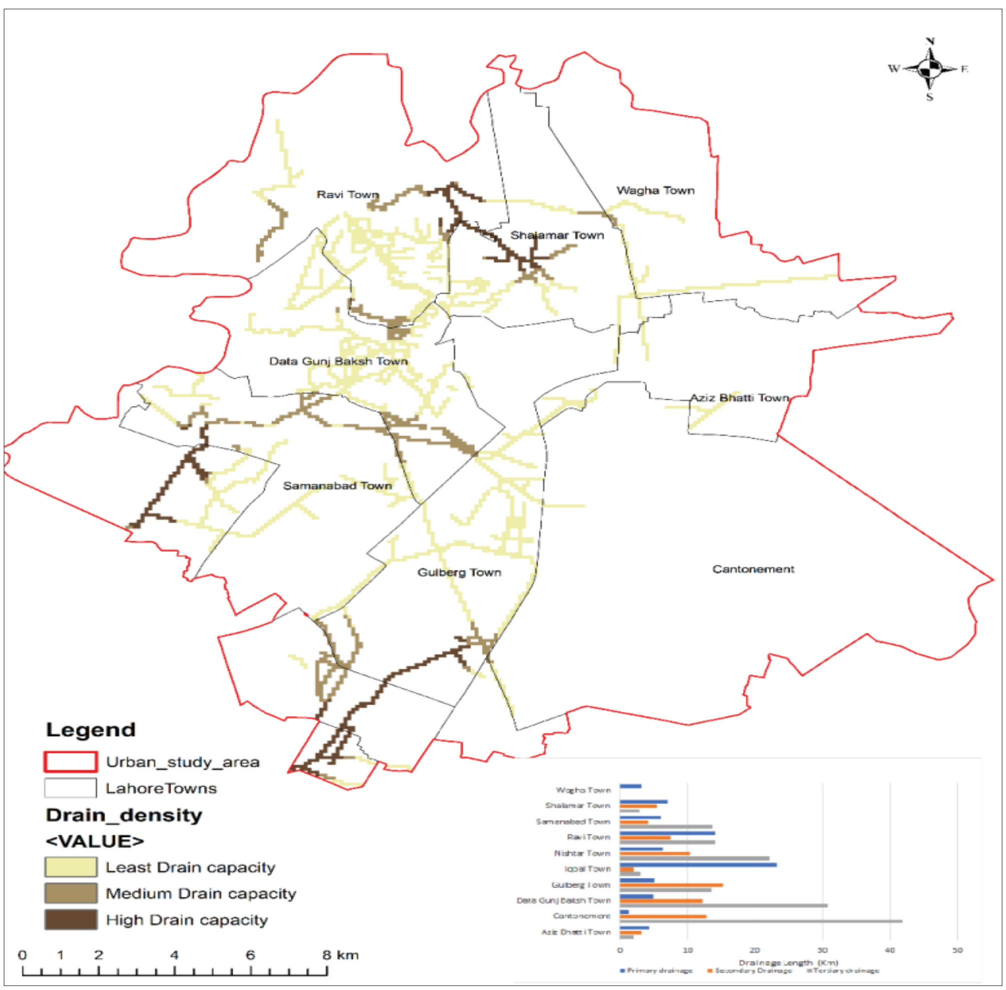



**Fig. 7.** Drainage network density

are having a low density of drainage are explained as 5. While those areas which show a high value of drainage density representing 1. The main step is ranking and prioritization in AHP.

The priority-setting impacts the usefulness of the decision directly. In the present study, to define the purposes and articulate the decision to recognize vulnerable areas as cited in literature by various scholars [14, 25, 27-28]. The eigenvector is utilized to weight the consistent layers of raster to set criteria in resulting in flood hazard. The outcomes of the comparison pairwise, ranking criterion, average priority vector, and percent contributions are presented in Table 1.

The consistency check CI is calculated from Table 1 by using the formulation matrix (max λ A XX =); where pairwise matrix is (A), and eigenvector of weights is (X). From the answer of max λ, the CI is acquired through the equation number 1:

CI = (5.41-n)/(n-1) = 0.10……Equation (1)

Where n is the deciding factor and n=5

In conclusion, the consistency ratio is calculated from the random index (RI), shown in Table 2 with the following Equation (2):

CR =CI/1.12 = 0.09………………..Equation (2)

The obtained CR is 0.09 which is less than the threshold value of 0.1, and point toward high consistency in the judgments pairwise which concludes that the calculated weights are acceptable.

### 3.5 Identification of Urban flooded areas through AHP

The evaluation of the selected criteria the hierarchical model, LULC is considered as the most important criterion in site selection after ground-truthing with the weight of 5 as shown in Figure. 8. All detected points were mostly along with commercial and residential areas and validated with ground points as shown in Figure 9 (a) Roads, (b) Residential, and (c) Commercial.

Roads, residential and commercial areas are surveyed after the identification of vulnerable areas by the AHP technique. Results show 88 percent accuracy for roads, 70 percent for residential and 80 percent for commercial areas as shown in Table 3.

Therefore, WASA is performing critical activities before and during Monsoon such as setup of emergency camps before Monsoon season, continuous monitoring of the situation, ensured operation of disposal stations, functioning of channels for flow, and dewatering operations from low-lying pockets with the help of mobile squads. Massive program and media awareness campaign to educate people is also initiated last year for citizens to cop-up with flooding situations.

**Table 1.** Matrix of Pairwise Comparison

| | Rainfall | Soil | Slope | Drainage | LU | sum | nth Root | Priority Vector | (%) |
|---|---|---|---|---|---|---|---|---|---|
| Rainfall | 1.00 | 2.00 | 3.00 | 4.00 | 6.00 | 16.00 | 3.20 | 0.378698225 | 38 |
| Soil | 0.50 | 1.00 | 2.00 | 3.00 | 4.00 | 10.50 | 2.10 | 0.24852071 | 25 |
| Slope | 0.33 | 0.50 | 1.00 | 3.00 | 4.00 | 08.83 | 1.77 | 0.209072978 | 21 |
| Drainage | 0.25 | 0.33 | 0.33 | 1.00 | 3.00 | 04.92 | 0.98 | 0.116370809 | 12 |
| LU/LC | 0.17 | 0.25 | 0.25 | 0.33 | 1.00 | 02.00 | 0.40 | 0.047337278 | 5 |
| Sum | 2.25 | 4.08 | 6.58 | 11.33 | 18.0 | 42.25 | 8.45 | 1 | |
| sum*PV | 0.85 | 1.01 | 1.38 | 1.32 | 0.85 | 5.41 | | | |

**Table 2.** Random Index (RI)

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| 0.00 | 0.00 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |

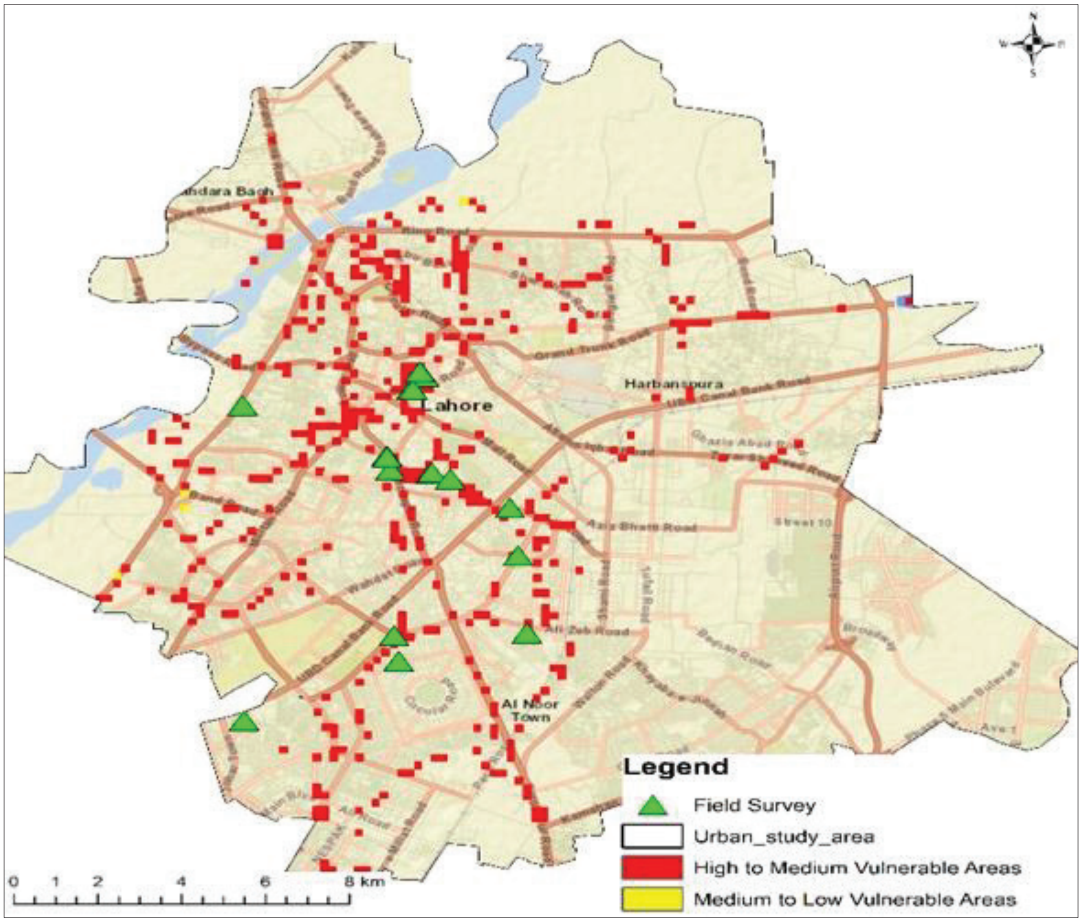
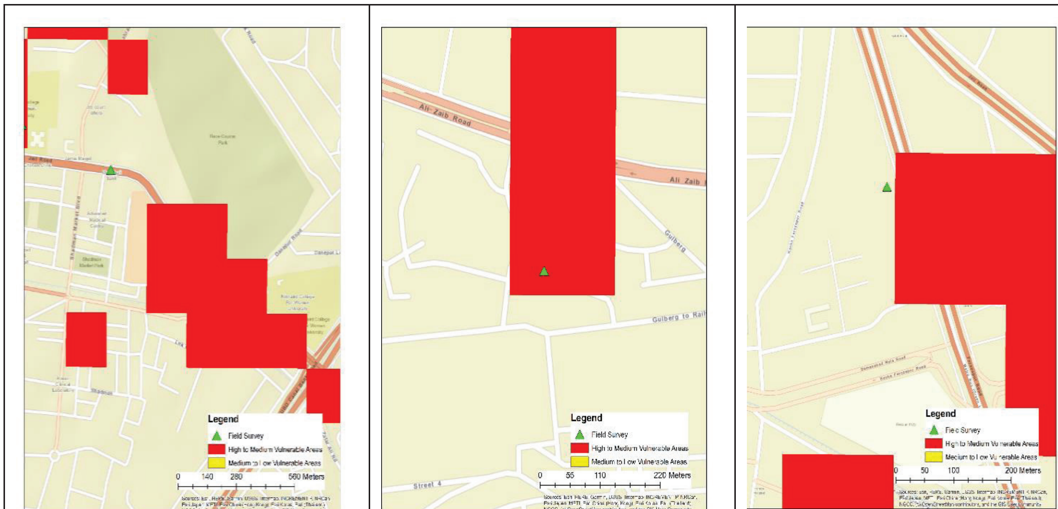



**Fig. 8.** Vulnerable areas in Lahore




(a) Roads (b) Residential (c) Commercial

**Fig. 9.** Ground trothing points

**Table 3.**

| Name | x | y | Water depth inches | Land use | Area Sq. km. |
|---|---|---|---|---|---|
| Ferozpur Road | 74.316 | 31.544 | 11 | Commercial | 0.01 |
| Jublie Town | 74.326 | 31.544 | 3 | Commercial | 0.13 |
| Jail Road Samnabad | 74.330 | 31.542 | 0 | Commercial | 0.00 |
| Efu House, Jail Rd, Main Gulberg | 74.345 | 31.534 | 4 | Residential | 0.01 |
| Block J, Gulberg III | 74.349 | 31.501 | 4 | Residential | 0.02 |
| Abdul Haque Rd, Block G, Johar Town | 74.281 | 31.477 | 5 | Residential | 0.02 |
| Pind Nizam Pura | 74.256 | 31.618 | 6 | Residential | 0.39 |
| Dil Mohammad Road, Jogi mohalla | 74.324 | 31.570 | 5 | Residential | 0.00 |
| Main Bazar Gawalmandi | 74.323 | 31.571 | 5 | Residential | 0.00 |
| Garden Town | 74.318 | 31.493 | 4 | Residential | 0.00 |
| LCWU | 74.325 | 31.543 | 3 | Road | 0.97 |
| Main blvd, Block K Gulberg II | 74.347 | 31.521 | 1 | Road | 1.18 |
| Aziz Din Road, Sandakhurd | 74.280 | 31.562 | 12 | Road | 0.25 |
| Mcleod Rd, GarhiShahu | 74.320 | 31.566 | 15 | Road | 0.41 |
| Cooper Rd, Royal Park | 74.321 | 31.566 | 4 | Road | 0.41 |
| Lytton Rd, Mazang | 74.315 | 31.548 | 10 | Road | 0.97 |
| Qurtaba chowk | 74.315 | 31.548 | 8 | Road | 0.05 |
| Main boulevard Garden town, Aibak Block | 74.317 | 31.500 | 2 | Road | 0.00 |

## 4. CONCLUSION

Urban flooding is a very timely subject for urban areas of developing countries. Solution of this growing threat is not possible without proper identification of risk areas for urban flooding. Therefore, this study employed the AHP technique, a method for evaluating statistically significant hotspots of urban flooded areas. Pair of several variables are selected and criteria is developed by assigning weights to take most appropriate decision in any other hazardous situation. Mostly focussed in the northeast of the present study area. The south eastern part is comprised of a cantonment (a developed settlement), reinforces the concept of informal settlements for causing urban flooding. Thus, Accuracy assessment for the AHP model was found appropriate with an overall accuracy of 80 percent in the case of Lahore to detect urban flooding

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