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Spatio-Temporal Analysis of Areas Vulnerable to Urban Flooding: A Case Study of Lahore, Pakistan

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Abstract: Identification of existing hotspots is one of the principal steps for evolving strategy to mitigate urban flooding, an emerging problem in mega cities of developing countries. Therefore, this paper aims to provide a framework of assessing the spatio-temporal hotspots of urban flooding incidents in Lahore district, Punjab, Pakistan. For this purpose, a database was created by gathering information of sore points by a governmental body, Water and Sanitation Agency (WASA) to execute spatio-temporal analysis of urban flooding through hotspot analysis in spatial analyst tool box in Arc GIS. Results show that urban flooding occurs in each town of Lahore excluding Wahga town. Among all affected towns of Lahore, Data Gunj Bakhsh town is noted as a highly affected area accounting 27 percent of urban flooding incidents during monsoon period from 2012-2017. Temporal study also shows an overall increasing trend for incidents of urban flooding during 2012-2017. Moreover, detailed study shows that month of August is noteworthy for urban flooding which is consistently increasing.

Keywords: Sore points, spatial and temporal hotspots, urban flooding, Lahore.

Introduction

Floodplains and coastal regions all over the world are highly vulnerable to flooding every year due to natural causes such as low elevation, high water flow during intense rainfall etc. (Jonkman, 2005). In other words, flooding is a situation of high flow of rainwater or storm water, which overtop land areas due to excessive runoff and less infiltration capacity of soils after or during intense rainfall events (Abaje and Giwa, 2007; Aladelokun and Ajayi, 2014). Lessening absorbent capacity of soil is merely due to anthropogenic activities which encroached natural environment. Over the last few decades, due to rapid urbanization, urban flooding has emerged as an alarming issue in different parts of Asia (Dutta et al., 2003; Schreider et al., 2000). For instance, in an urbanizing area like metropolis or megapolis cities, the infiltration capacity is reduced by the replacement of pervious surfaces with impervious urban surfaces, which gives rise to excessive runoff (Huang et al., 2018; Huong and Pathirana, 2013; Liang et al., 2017). It has been witnessed that rapid urbanization and growth of population in an area, is merely due to fertile soil of cities which make these areas suitable for agriculture, transport and communication. But at the same time, urbanization transforms pervious surfaces to impervious which prevent infiltration of rainwater into soil at the time of abnormal rainfall.

Excessive pond on lands are generated by urban flood, which can cause significant property damage, traffic obstructions, nuisance, and health hazards (Rashid, 2000). This type of flooding is termed as urban or pluvial flooding (Aladelokun and Ajayi, 2014). Handmer et al., (1999) defines urban flooding as a continuum of events from insignificant to catastrophes because of its differential effects on different environments. However, it is now emerging as fundamental environmental challenge whenever urban area receive intense rainfall event especially in developing countries (McMichael et al., 2006). It is becoming increasingly crucial issue day by day especially for inhabitants, authorities, insurance companies and government in developing countries (Aladelokun and Ajayi, 2014; Schmitt et al., 2004; Villordon and Gourbesville, 2016). Therefore, the objective of this study is to investigate data about urban flood for Spatio-temporal analysis of urban flooding situations in Lahore district from 2012, 2016.

Material and Methods

Lahore district is located in the north-eastern part of Punjab province, Pakistan and located at 31°15′ to 31°43′ N latitudes and 74°10′ to 74°39′ E, E longitudes (Minallah, 2019). As a growing region, it is a prestigious cultural and academic region of Pakistan. Physiography of Lahore covers with low lying alluvial soil at its west side to upland area up to the Indian border in the east of the district. Its western side along with river Ravi inundated by low to medium risk flooding every year during Monsoon (GoP, 2016). Likewise, other mega cities of the world, this area is becoming more prone to urban flooding as compared to flash flooding. This type of flooding has been caused by blocked drainage and sewage system due to rapid infrastructural transformation of Lahore during last few years (Güneralp et al., 2015).

According to Pakistan's administrative setup, Lahore district was designated as a city district, and divided into nine towns, which in turn consists of a group of union councils (GoP, 2016). However, study area is particularly narrowed down to urban union councils (UCs) of Lahore district due to absence of sewage lines in its rural union councils (UCs) for the specified study of urban flooding. In past years, urban flooding has been imprinting adverse impact on city life i.e. severe traffic congestion, power break down etc. For instance, on 4th September, 2014, 177 mm recorded rainfall caused many streets to become inundated, power breakdown, and leading to severe transport jam in city. Similarly, on 28th of August, 2016, Lahore district was inundated by urban flooding. City administration recorded 12 hours 30 minutes intense rainfall of 59 mm which lashed the city (Randhawa, 2016).

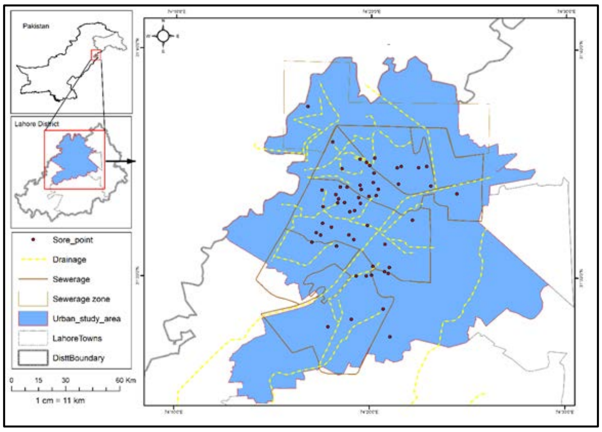

Fig.1 Map showing the study area (Lahore).

Data were collected from WASA. Generally, it contains information about 55 sore points in urban localities of Lahore district. Sore points are those points where urban flooding causes stagnant water for few hours to days after any intense rainfall event. These data were collected by WASA with the help of registered complaint calls of residents. Later, information of WASA call centres on flood incidents has been used to quantify the urban flood events in last five years. In this way, urban flooded areas are analysed spatially and temporally. Also, incident intensity can be quantified which are creating problems and disrupting the daily activities of citizens (Veldhuis et al., 2013; Veldhuis et al., 2011). However, this method is surely not complete coverage of flood occurrence. Because there is no guarantee that a call is made for every event. Call data consists of location name to indicate the problem location. Other sources, such as newspaper articles and on-line pages are used for the verification of flood occurrence information.

Spatio-Temporal Hotspot of Urban Flooded Areas

For spatio-temporal analysis, data were collected from WASA, were reorganized in nine towns of Lahore district. Firstly, all 55 sore points were classified in 9 towns of Lahore district in order to find out the highly affected town by urban flooding. Later, an aggregated result was generated that shows how many times each sore point is flooded from 2012 to 2017. All the urban flooding incident records add up to 110 data points, which are plotted in Excel. To give an overview of what this looks like for Lahore district, Figure 3 gives an idea about the distribution of all the flooding incident records town wise. Later, aggregated results were used for hot spot analysis.

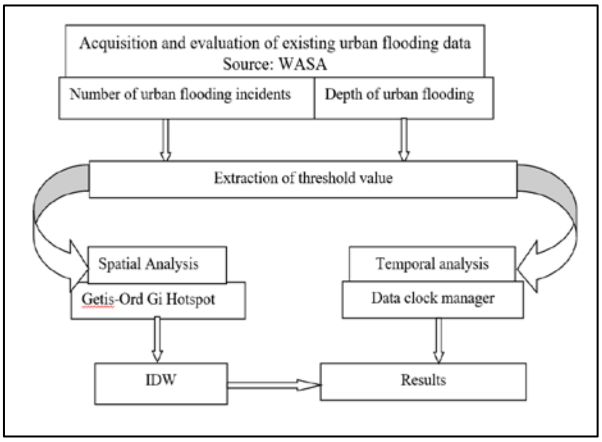

Fig. 2 Flow chart of Methodological framework.

The term hot spot has been used generically across disciplines e.g. urban development, economy and criminology to describe a region or value that is higher relative to its surroundings (Isobe et al., 2015; Lepers et al., 2005). Values indicate the concentration or the intensity of a certain phenomenon in a limited geographical context (Chainey et al., 2002; Jalayer et al., 2014). In context of natural disasters, Dilley et al., (2005) defined hotspots as a geographic area which is prone to natural disasters and are high risk zone. Thus, flooding risk hotspots can be defined as areas that are relatively more at risk for flooding. Hotspot analysis tool use Getis-Ord Gi statistic to find spatial pattern (Ord and Getis, 1995). In this study, location and degree of spatial clustering of urban flooding has been identified in Lahore with the help of hotspot analysis. The map is produced using the hotpot analysis in ArcGIS 10.5 with a given set of urban flooding depth in inches as weighted point feature and identifies statistically significant cluster with high and low values of water depth in inches. These clusters were later designated as hot and cold spots respectively.

The tool takes input feature having information about urban flooded incidents in last five years for all 55 sore points. Analysis produced a new clustered map with a z-score, p-value, and confidence level, bin (Gi_Bin) value for each sore point present in urban localities of Lahore. High or Positive score and small p-value shows spatial clustering of high value of feature. However, a low or negative z-score and small p-value indicates less clustering in an area. While, the Gi_Bin value identifies statistically significant hot and cold spots. Values of Gi-Bin of either +3 or -3 are statistically significant at the 99 percent confidence level. Values of Gi-Bin with either +2 or -2 indicates a 95 percent confidence level and values in the +/-1 Bin shows 90 percent confidence level. Whereas, the clustering for features with 0 for the Gi Bin value is not statistically significant.

Based on probability and intensity of events, values are classified into three confidence levels both for cold spots, hot spots and class with no significant value. On the other hand, temporal pattern has been observed through data clock management tool in ArcGIS 10.5. This tool provides a data clock chart, which is a circular in shape and divided into cells by a combination of concentric circles and radial lines. Intensity of events occurrence can be seen by different colors. For example, darker to lighter shades will indicate the highest to lowest intensity of urban flooding respectively.

Results and Discussion

Sore points of urban flooding have been shown in Figure 3 town wise for Lahore district. Results show that the western area along with Ravi river is more prone to urban flooding than the eastern side, because, this study area of district has been changing rapidly by anthropogenic activities since British rule. The total area affected by urban floods in Lahore district is 72.997 sq. km. out of 1772 sq. km. All the towns are affected by urban flooding. However, nearly 29 percent of urban flooded areas are found in Data Gunj Bakhsh town.

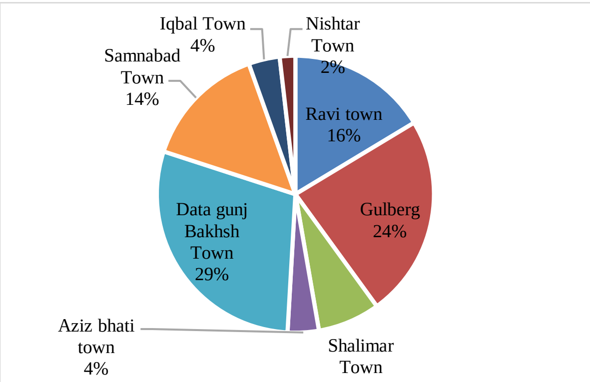

Fig. 3 Observed sore points town wise for Lahore (2012-2017) data

Spatio Analysis

Figure 4 is representing the spatial hotspots of urban flooding in study area of Lahore district. The flood probability map produced by hotspot analysis shows spatial- incidents of flood in urban localities of Lahore district. The grey color represents the cold spot and hot spots are represented with red colors. The density of colors represents the occurrence of the flood i.e. the darker color shows the highest confidence level for the cold or hot spot. Similarly, the number of events is represented with graduated circle i.e. Larger the circle representing more occurrences of urban flooding. Based on the hotspot analysis, the highest probability of flood occurrence is found in Data Gunj Bakhsh town; whereas, Gulberg town ranked at second followed by Ravi and Samanabad town in Lahore.

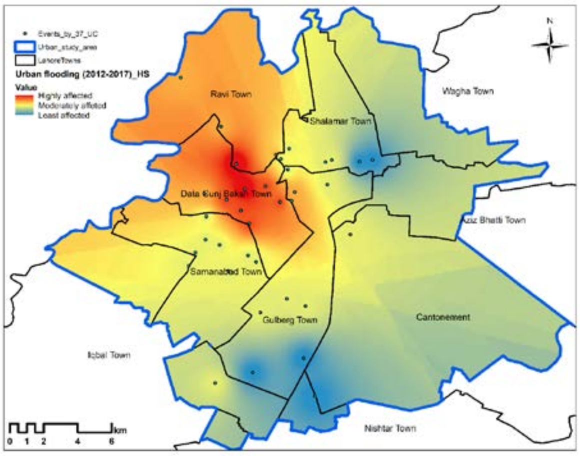

Fig. 4: Hotspots of urban flooding incidents in Lahore (2012-2017)

Temporal Analysis

According to the temporal analysis, the incidents of urban flooding in Lahore are least in the year 2012 which intensified later. Incidents have been quantified with the help of average depth of water which could not be drained by sewage system at the time of heavy rainfall. Figure 5 shows average depth of water in response of urban flooding trend over time annually during monsoon period from July to September in 2012-2016 period. Depth of urban flooding has been shown with data clock tool for Monsoon period (July to September) on annual basis during 2012-2016. Each ring is representing study years, whereas each wing is showing monthly data. Average depth of urban flooding is observed from 1 to 10 inches (0.08 to 0.8 feet) in study time period. It has been classified into 6 classes from no concentration of rainwater to more stagnant water up to 10 inches depth of urban flooding. Different shades of blue are designated to show urban flooding over time. Dark blue to light blue color is depicting the highest to lowest depths averages in inches of urban flooding respectively. However, grey color is showing excluded months from this study, as monsoon phenomena was not experienced in these months.

According to the temporal analysis, of urban flooding in Lahore has occurred throughout the monsoon period in study time span from 2012-2016. However, variation of intensities and occurrences are found. For instance, July can be designated for intense occurrence of urban flooding incidents but not noticeable for occurrence of urban flooding annually. On the other hand, the month of August can be seen for consistent occurrence throughout the time period. Moreover, phenomenon is also showing upward trend for the month of August. Thus, it can be concluded that the temporal intensity and the temporal pattern of flooding are remarkable in this month as compared to September and July. Though, urban flooding has occurred in the month of September since 2014, as it is recorded as the month of less intense incidents of urban flooding because it is last month of monsoon.

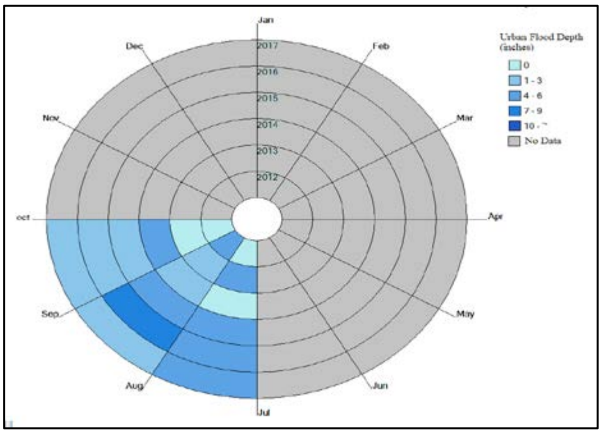

Fig. 5 Peak time for urban flooding in Lahore during monsoon (2012-2017).

Conclusion

Present study revealed that Hot Spot Analysis is an approach for evaluating statistically significant clusters of urban flooding. Unlike, traditional statistical techniques, the methodology of current study can be executed quickly with spatial statistics using GIS approach. It doesn't require detailed information, yet results can provide insight about potential further trajectories and locations of urban flooding. In recorded 110 rainy days, 57 times urban flooding has occurred all over Lahore from August 2012 to September 2017. Among all affected towns of Lahore, Data Gunj Bakhsh town is noted as a highly affected area accounting 27 percent of urban flooding incidents during monsoon period during 2012-2017. With this research study, findings show average depth of urban flooding ranging from 1-3 inches are usually experienced during monsoon as per results retrieved for the years between 2012-2017. About 1-3 inches of urban flooding can be seen for the years 2013, 2015, 2016 and 2017 excluding 2012 and 2014.On the other hand, average depth of urban flooding is increased up to 9 inches (approximately 1 foot) in month of August. As far as, September as last month of Monsoon period experience urban flooding since 2014 to onward. In 2014, urban flooding average depth was recorded up to 4-6 inches (1/2 foot). Later, likewise month of July, 1-3 inches urban flooding can be seen for the month of September during 2012-2017. Thus, it can be concluded that Lahore experiences urban flooding annually but with greater fluctuation and variations in whole monsoon period. For instance, July and September can be marked less significant for the phenomenon. But, the month of August was found significant and matter of concern for authorities to mitigate urban flooding. Some proactive measures should be taken in order to mitigate the urban floods and provide reasonable safety nets for people to survive through monsoon spells. These mitigation measures include capacity building of WASA, climate-sensitive city planning, sustainable urban development practices and creatively using geographical setting of Lahore. Furthermore, Lahore requires serious changes for future proofing in the city's current urbanization trajectory, as well as capacity building of critical agencies and departments. A master plan for Lahore's sewerage and drainage systems is needed to avoid future urban flood hazards.

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