RESEARCH PAPER

THE EFFECT OF URBAN GREEN SPACES IN REDUCING URBAN FLOODING IN LAHORE, PAKISTAN, USING GEOSPATIAL TECHNIQUES

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ABSTRACT. Urban Green Spaces (UGS) curtails all environmental issues and ensure an eco-friendly locale. Similarly, the emergence of UGS is very helpful to cope with emerging urban flooding in cities by setting up the world standard of green space ratio (20 to 25 percent of the area) and green per capita (9m^2) in a geographical area. Therefore, the present study is conducted to evaluate the causal effect relation of UGS with the frequency of urban flooding. For this purpose, 69 selected union councils are taken as a study area in District Lahore, Pakistan. The relation between UGS and the occurrence of floods is evaluated using geo-statistical and geospatial analysis techniques during the monsoon rainfalls from 2013 to 2019. Furthermore, the data sets of sore points (inundated areas), occurrences of urban flooding (number of event occurrences), green per capita, and green ratio are used. Results revealed that selected union councils in Lahore don't have enough urban green spaces. There is only a 51 sq km area with adequate UGS that accounts for only 18 percent of the study area. The rest of the area does not meet the world standards of green area. There are some areas including Ravi town, Gulberg town, and Samanabad town with green per capita more than 4 green per capita. On the other hand, there are only 02 union councils including Race Course and Model Town that are comprised of a 20 percent green area. The findings of the study will be helpful for proper urban planning and strategies i.e. with greener structures.

KEYWORDS: hydro-meteorological disasters, nature-based solutions, green space, flooding mitigation, Lahore

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INTRODUCTION

Rapid urban expansion has produced massive changes in the urban and regional environment (Kim 2021; Nasar-u-Minallah et al. 2021). Specifically, in high-density urban centers, there are a large number of impervious surfaces made by roads, parking lots, and large-scale architecture because of the new developments (Foster et al. 2011). As a result, unexpected events may be triggered, which may drastically affect human habitation (Meerow and Newell 2017). Whenever the impervious surface increases, it can affect the store-ability of flowing water, causing greater flooding at hazardous sites (Liu and Jensen 2018). Urban flooding is a key issue in the cities of the developing world and is mainly caused by natural hazards such as riverine floods, coastal storm surges, sea-level rise, poor absorptivity, and urban management. These challenges were faced by city planners while dealing with the mitigation of flood disasters. Pakistan is inclined to many geological and hydro-meteorological disasters mainly due to climate change and environmental degradation (Mahmood and Rahman 2019) including floods which have severe impacts on human losses and destruction of built-up areas and property. It is mainly caused due to inability of city drainage and sewage systems to deplete rainfall water during the period of excessive rainfall. Due to climate change, increasing precipitation by 40-45% flood zones will develop at the end of the 21st century. However, infrastructure is not designed to adapt mitigation to predict urban flooding hazards and eventually make cities vulnerable (Gimenez-Maranges et al. 2020; Mohtar et al. 2020).

Urban development raises the risk of floods in cities because of hydrogeological and meteorological conditions caused by increased flood hazards, vulnerability, and the association between runoff and flooding has seemed through variations in rainfall patterns and climate change. Rising populations in urban areas are mostly initiated in developing countries which may be due to the conversion of rural areas into big cities and the migration of rural people to cities to improve their lifestyles. Urban flooding is a persistently repeating regular danger as far as the number of lives lost and the general expense of harm to property, public works foundation, and normal assets (Shuster et al. 2005). The rate of urban flooding is increased with the growing population and change in climate (Hammond et al. 2015). The condition will worsen due to the migration of people from rural to urban areas which result in an increase in impervious surfaces which causes serious effects on the water cycle and an increase in flood hazards.

The benefits of urban green space include reduction of rainfall-runoff primarily for affected cities from intense flooding and hazards (Gordon 2007). However, its efficiency in mitigating its effects is not fully determined (Duffy et al. 2008; Wong and Brown 2009). To protect and manage the urban environment from severe flood events, a common method is a green infrastructure (Ballard et al. 2015; Bowen and Lynch 2017) which mainly includes ponds, swales, rainwater tanks, vegetated filter strips, wetlands to gather a certain quantity of rain, with the help of either storage devices or groundwater recharge (Afriyanie et al. 2020) including green roofs, rainwater capture or harvesting and permeable paving/surfaces (Zia et al 2021a). Therefore, the objective of this study is to correlate the existing green space ratio and frequency of urban flooding at the union council's level of Lahore from 2013 to 2019. Correlative analysis was based on the frequency of urban flooding and its hotspots. This research study is conducted to find the exact ratio of green space that is triggering urban flooding and hazardous environmental conditions. This study will help to trace the actual situation and to conclude in which areas green spaces are needed to curtail urban flooding.

MATERIALS AND METHODS

Study Area

The strategic political and administrative role of the study area is Lahore, comprised is the second largest metropolitan city after Karachi in terms of population (GOP 2017). The latitudinal and longitudinal extent of the Lahore district lies between 31° 15′0″ N to 31°43′0″ N and 74° 10′0″ E to 74°39′0″ E in the Punjab province of Pakistan (Figure 1). The total area of district Lahore is 1772 km^2 (GOP 2000). It is bounded on the north and west by the Sheikhupura District, on the east by Wagah, and on the south by Kasur. The total population of Lahore has increased from 6.31 million in 1998 to 11.12 million in 2017 (GOP 2017; Nasar-u-Minallah 2020). The current population density is 6300 persons per km^2 which are projected to be increased to 16.88 million by 2030 (United Nations 2018). Lahore ranked 26th among the most densely populated cities in the world (United Nations, 2018) with a total population of 11.12 million (GOP 2017). District Lahore is governed through 151 UCs and one Cantonment area out of which 69 UCs are selected which are influenced by urban flooding.

Data and its Sources

Digitization of urban green spaces (UGS) of 69 Union Councils of district Lahore acquired by using Google earth explorer (https://explorer.earthengine.google.com) which permits scientists

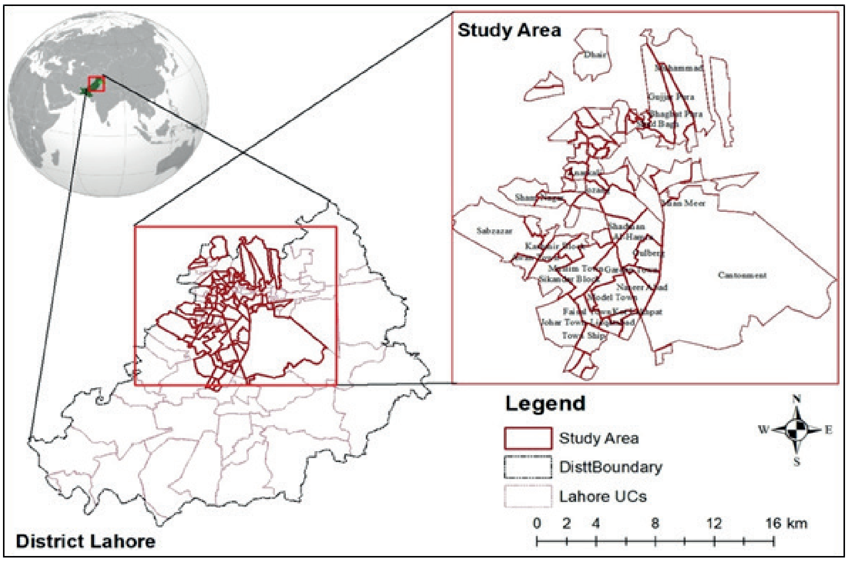

Fig. 1. Map showing the study area (Union councils of Lahore)

Table 1. Characteristics of the Landsat-8 OLI image used in this study

Date of Acquisition	Sensor	Bands	Wavelength (um)	Spatial Resolution	Thermal Resolution	Path/Row
08-05-2021	OLI	Band 1—Ultra Blue	0.435–0.451	30m	-	149/38
		Band 2—Blue (B)	0.452–0.512			
		Band 3—Green (G)	0.533–0.590			
		Band 4—Red (R)	0.636–0.673			
		Band 5—Near Infrared (NIR)	0.851–0.879			
		Band 6—Shortwave Infrared (SWIR) 1	1.566–1.651			
		Band 7—Shortwave Infrared (SWIR) 2	2.107–2.294			
	TIRs	Band 10—Thermal Infrared (TIR)	10.60–11.19	-	100m	
		Band 11—Thermal Infrared (TIR)		-	100m	

Source: http://earthexplorer.usgs.gov/

everywhere in the world to interconnect their data and examine research verdicts in an instinctive three-dimensional (3D) universal outlook (Yu & Gong 2012). The satellite imagery of Landsat-8 for the year 2021 (Table 1) is acquired from the USGS website (https://earthexplorer.usgs.gov/) obtained for path 149 and row 38.

The population data were obtained from Punjab development statistics (PDS) which is an authorized report issued by an agency named Pakistan Bureau of statistics. It is selected due to uneven census practices and the database is the only source that offers efficient projected population data at UC and town levels. The categorization of population data is in urban and rural union councils. While considering the current study, the estimated population of urban-rural union councils wise was obtained for analytical purposes (GOP 2016). The ponding point's data from the year from 2013 to 2019 was acquired from the government organization Water and Sanitation Agency (WASA). The data contains flood depth in inches and ponding points of union councils of Lahore. Considering the aim and objectives of this paper, the qualitative approach is selected to conduct explanatory research (Figure 2).

Tabulation and organization of data

Three datasets were required to achieve the objective of the current study including the area of green spaces to calculate the green ratio, population to calculate green per capita concerning available green area, and ponding points that are frequently inundated during Monsoon. For this purpose, the urban green spaces of 69 union councils of Lahore were digitized in Google earth and were converted from kml (Keyhole Markup Language) format to shp (Shape file) format which is a compatible model for calculating the green ratio as shown in the table. The selection of union councils is done on basis of those areas only where flood inundation is observed in previous years every time after a rainfall episode.

Besides, the area of green space is also retrieved from satellite imagery and details are mentioned in the 3.4 section. Moreover, the population data were obtained from Punjab Development Statistics of Lahore Union Councils. Likewise, the ponding points and their frequencies of flooding events were obtained from Water and Sanitation

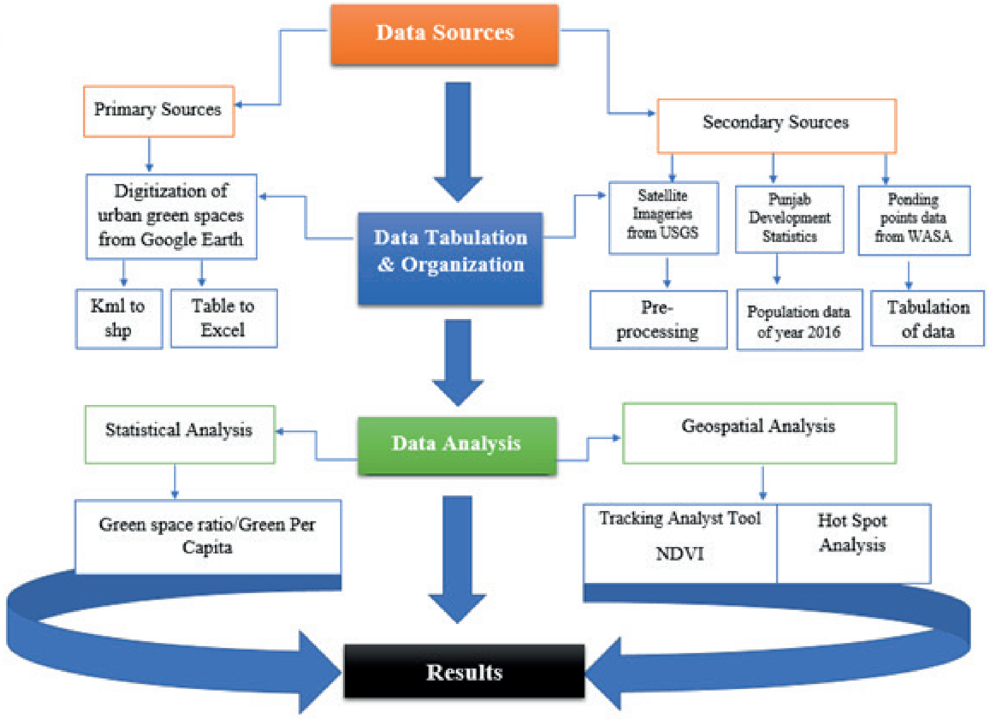

Fig. 2. Methodological Framework of the study

Table 2. Selected Union councils in each town in District Lahore

Town Name	Number of selected Union councils
Aziz Bhatti Town	2
Cantonment	1
Data Gunj Baksh Town	12
Gulberg Town	13
Iqbal Town	6
Nistar Town	4
Ravi Town	12
Samanabad Town	10
Shalamar Town	7
Wagha Town	2

Agency (WASA) and tabulated in an Excel spreadsheet for 69 union councils of District Lahore. The frequency of urban flooding is defined as the occurrence of an urban flood at one point after any rainfall event.

Image preprocessing

The satellite imagery acquired from Landsat 8 of 2021 for the Lahore District was further processed for the classification of the Normalized Difference Vegetation Index (NDVI). While the investigation of NDVI can deliver observation of vegetation fluctuations in contrast to other vegetation indices by using Landsat imageries based on variations in absorption and reflectivity of energy resulting from vegetative cover in the red and near-infrared bands (Fung and Siu 2000). This technique hires the Multi-Spectral Remote Sensing data method to discover Vegetation Index, land cover organization, vegetation, water bodies, open area, undergrown area, mountainous areas, agrarian areas, and forests with limited band fusions of the remote sensed data, particularly to interpret exterior structures of the noticeable areas which are significant for policymakers while making strategies by using formula as (NIR-RED)/(NIR +RED) whereabouts NIR denotes reflectivity which discharges in the near-infrared frequency band of satellite (Gandhi et al. 2015) to access the vegetative area in union councils.

Geo-statistical Analysis

Statistical data analysis mainly includes various statistical formulas and functions. The current study involves the use of the statistical technique for calculating Green per capita using a formula stated as the total area of green space (sq. m)/ Total Population of the city as green per capita common quantifiable measure to evaluate urban green infrastructure.

Geospatial Analysis

The geospatial analysis includes various Geographic Information System tools and techniques. Keeping in view the objectives of this study, the Tracking Analyst tool (Data Clock Manager) in ArcGIS was used to monitor and associate spatiotemporal variable data from several sources which use path evidence to access the positions of time-enabled and spatially variable scatter data via an amalgamation of trajectory alteration and spatial interpolation (Gad et al. 2018). Hotspot statistical analysis in ArcGIS was used as recognition of present hotspots is considered as one of the primary steps for developing policy to alleviate urban flooding which uses Getis-Ord Gi statistic to discover spatial variations (Zia and Shirazi 2019; Zia et al. 2021).

RESULTS AND DISCUSSION

Green space per capita

The current study involves the use of the statistical technique explained in the previous section for calculating green per capita. According to World Health Organization (WHO), the availability of 9 m^2 value to 50 m^2 per capita of green space per person is an ideal urban green space (UGS) that plays a pivotal role in maintaining a healthy urban environment. This is considered standard because the rate of urbanization is increasing and causing severe impacts on the urban environment by contaminating the biosphere and consequently harm to biodiversity making the city an urban heat island.

Observing the data, it is revealed that a higher proportion of urban towns and respective union councils that falls in extremely low green per capita on average include all towns of District Lahore shown in Table 3. Values shown in Table 3 are derived by excluding the outliers that exist in the area of Model town, Racecourse, and Al-Hamra of Lahore. These are three areas where green per capita is 27, 20, and 14 sq. meters per person respectively. The data is further categorized into three groups to evaluate the situation in each union council of Towns in District Lahore including (a) Extremely low (0.080 to 2.464), (b) Moderate (3.256 to 9.310), and (c) High (14.083 to 27.866).

Observing the data reveals a higher proportion of Urban Towns and Union Councils that falls in extremely low green per capita including 58 union councils out of 69. This result shows that 224 sq. km out of 285 sq. km selected study area comprising 78 percent of the area is deprived of green spaces. The second criteria of moderate values range from 2.464 to 14.083 which includes only 8 union councils in the study area comprising only 15 percent of the study area.

Likewise, the class showing high green per capita range from 14.083 to 27.866 sq. m includes only three union

Table 3. Green Per capita in the study area

Town Name	Green Per Capita (World standard 9m^2 to 50m^2 per person)
Cantonment	0.10
Nistar Town	0.37
Data Gunj Baksh Town	0.70
Wagha Town	0.75
Samanabad Town	0.80
Shalamar Town	0.86
Ravi Town	1.11
Aziz Bhatti Town	1.15
Iqbal Town	1.97
Gulberg Town	2.20

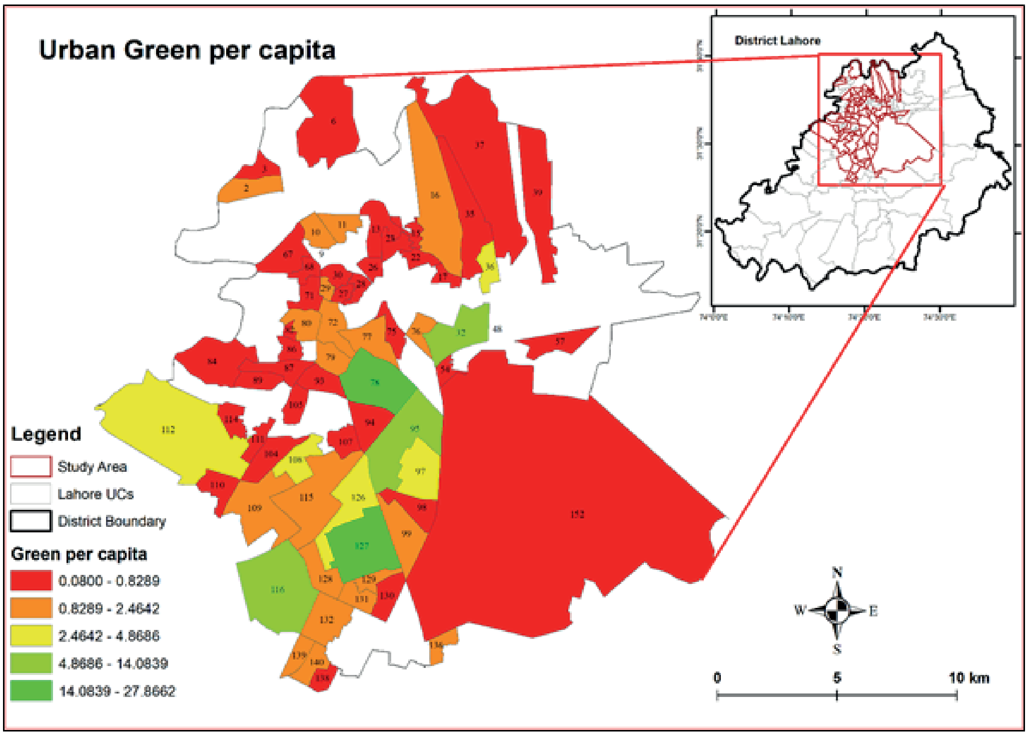

Fig. 3. Green per capita in the study area

councils. However, this range approximately covers 18 percent of the study area. The spatial distribution of green per capita is shown in Fig 3. In past studies, green spaces played a significant role in maintaining a healthy urban environment because the rate of urbanization is increasing and causing severe impacts on the urban environment by contaminating the biosphere and consequently harm to biodiversity making the city an urban heat island (Alam et al. 2014; Hanif et al. 2022).

The Green Area Ratio (GAR)

The Green Area Ratio (GAR) score narrates to rise in the amount and value of ecological presentation of the urban site. Data is categorized into five categories to evaluate the green area ration includes: (a) Very Low (0.03-0.85), (b) Low (1.08-1.99), (c) Moderate (2.00-5.79) (d) High (7.54-15.25), (e) Very High (20.0-23.74) shown in Fig 4. The world standard recommended a minimum of 25 to 30 percent of green open space in an urban locality. However, results reveal that only two Union Councils lie in the Very High category including Model Town of Data Gunj Baksh Town and Racecourse of Shalamar Town ranging from 20.0-23.74 shown by green color. On the other hand, the union councils lie in a very low category including union council Muhammad of Data Gunj Baksh Town Rehmatpura of Shalamar Town ranging from 0.03-0.85.

Ong (2003) provided a piece of evidence that for the sustainability of cities the application and preservation of green areas in the urban setting have been preferred as plants are not just ecological but also recreational and appealing.

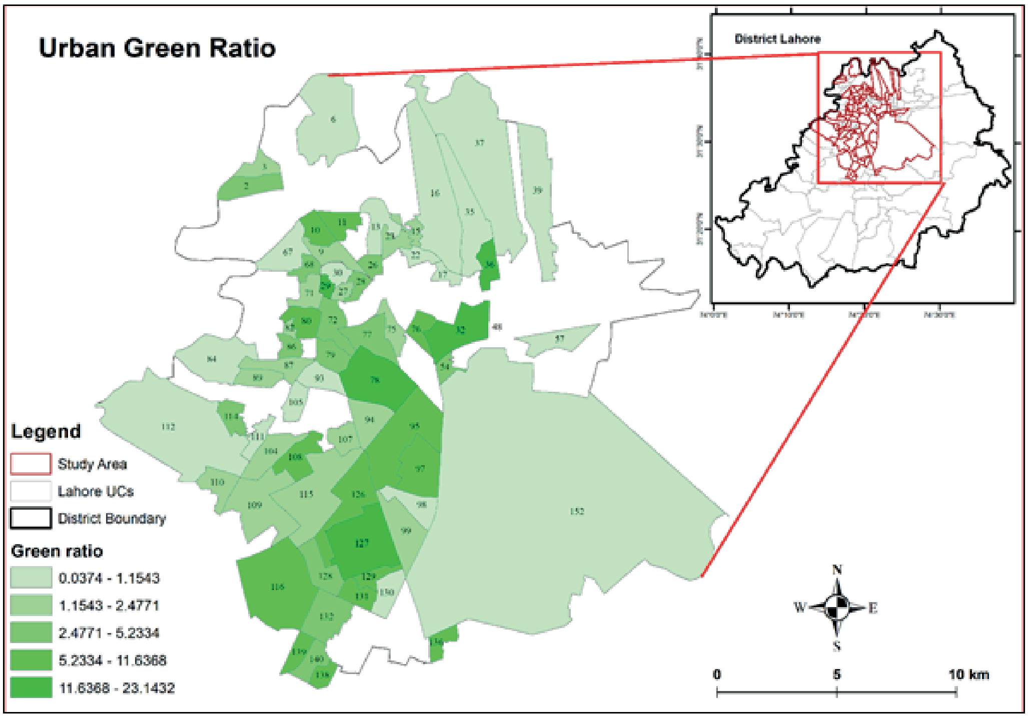

Fig. 4. Urban green area ratio in the study area

Normalized Vegetation Difference Index (NDVI)

To illustrate the current scenario of vegetation (Figure 5) in the study area Normalized Vegetation Difference Index (NDVI) in selected 69 urban union councils of district Lahore was used. Land Assets are effectively interpreted by processing their standardized difference vegetation for land cover arrangement by Gandhi et al. (2015). The names of union councils are shown by different numbers assigned to 69 union councils such as 1 to Mughalpura, 2 to Rehmanpura, and so on, and are grouped into three categories: Low (0.1 or less), Moderate (0.2-0.5), High (0.6-0.9) designated with different colors. The urban union councils which lie in the low category constitute 100 union councils and 66% of Lahore shown by the color red, moderate constitutes 30% and 46 union councils shown by yellow color The third category high constitutes 3% with designated color green includes only 5 union councils. The analysis showed that the situation of NDVI in Lahore does not meet the standard of vegetation (Figure 5).

Occurrences of urban flooding

Temporal analyses were used to quantify incidents of rainwater that couldn't be drained due to poor sewage systems during the spell of heavy rainfall and the least reported events of urban flooding are in the years 2013 and 2019. For this purpose, the Data Management Tool in ArcGIS which offers a data clock chart, which is circularly alienated into cells by the grouping of concentrically circles and radiated lines was used to show the annual average depth and trend of water during the monsoon period from June to September in 2013–2019-time span. The study years are shown by rings, while each wing is showing monthly data. The average depth of urban flooding is observed from 1 to 485 inches (0.08 to 40.08 feet) in the study period classified into 6 classes based on no concentration of rainwater to more stationary/stagnant water up to 40.08 feet depth of urban flooding. The data management tool is used to reveal the situation of urban flooding for the monsoon period which uses a novel Direction based Trajectory Tracking Analyst (TTA) that can track and connect spatiotemporally factor information from different sources using multiple sensors (Gad et al. 2018).

Different colors are designated to show the intensity of urban flooding temporally. Orange to blue color is showing highest to lowest averages in inches of urban flooding correspondingly. Though grey color is depicting omitted months from this study as the monsoon period was not practiced during these months. Results of the study indicate that urban flooding in Lahore occurred throughout the monsoon period from 2013-to 2019 with variable intensities and incidences such as fewer events reported in June, and July can be considered as an intense month for urban flooding events, August showing consistency in the occurrence of flood events. However, September is considered as least intense month in the recording of flood events because it is the last month of the monsoon period (Figure 6).

Spatial hotspots of urban flooding

Spatial hotspots of urban flooding events were identified in the study area of 69 Union Councils in the Lahore District. For this purpose, values are categorized into three confidence levels shown by different colors such as red for the hot spot with +3 and 3 Gi-Bin value through 99% confidence level, blue for a cold spot with +2 and -2 Gi-Bin value with 95% confidence level and yellow for clustering of features with no significant value based on the susceptibility of flood events by Dilley (2005) state hotspots as topographical areas where the dangers

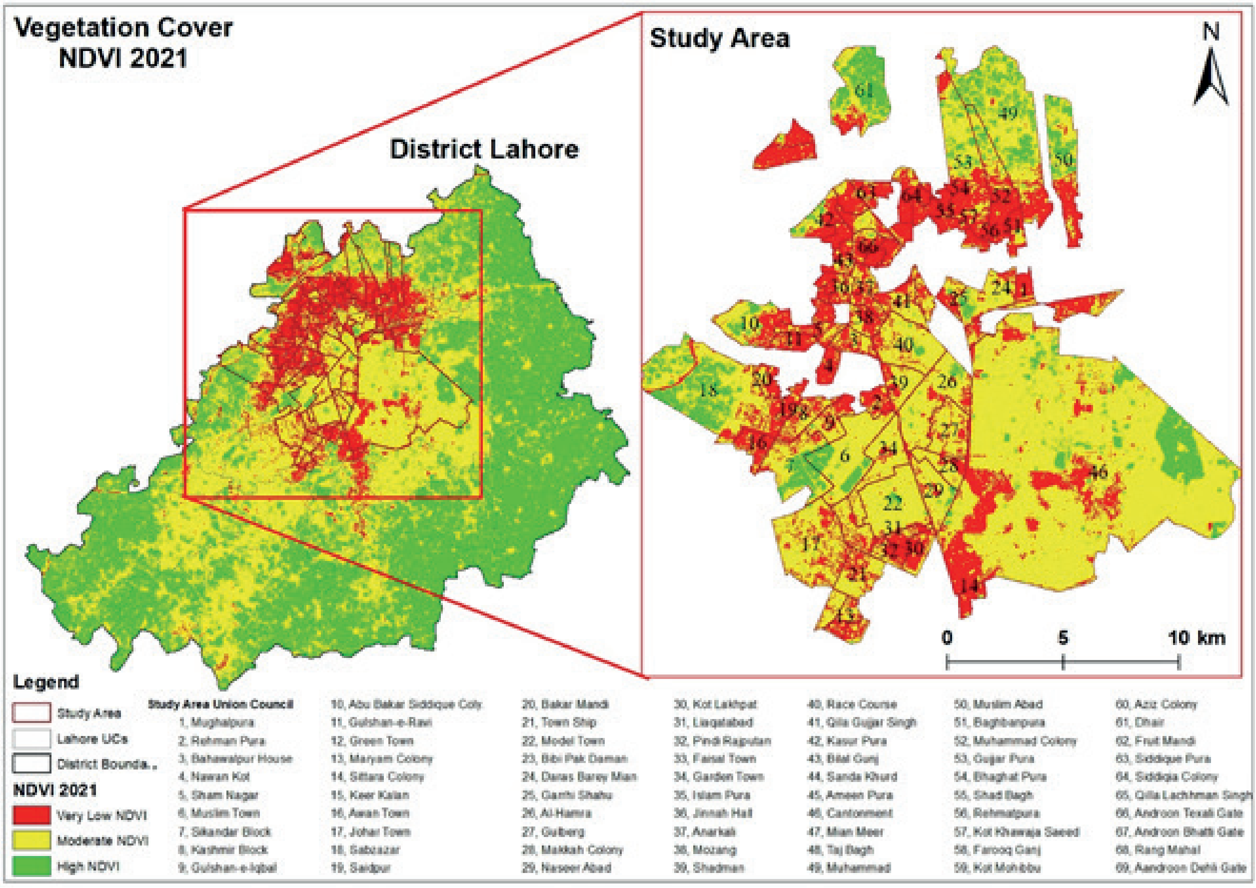

Fig. 5. The vegetation cover of the study area

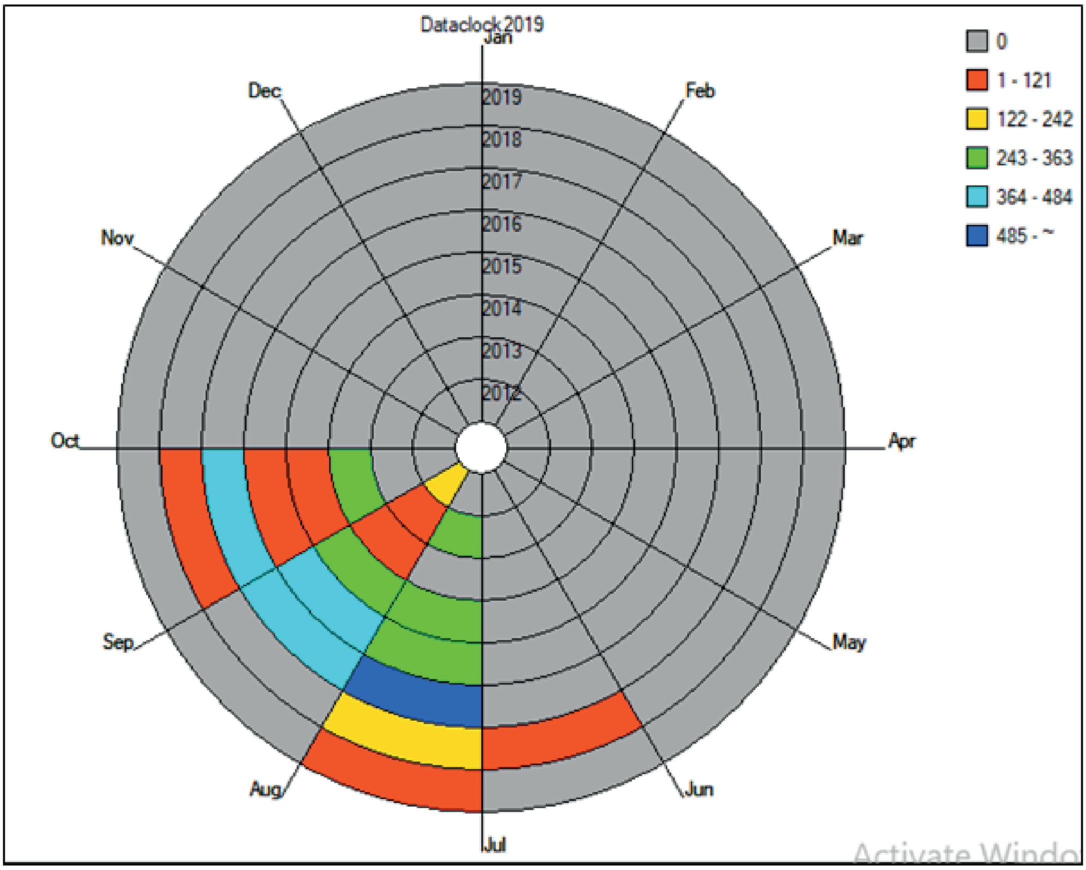

Fig. 6. The peak time of urban flooding in the study area during the monsoon period (2013–2019)

of natural calamities are mainly high or the zones that are comparatively more expected to be visible to flooding as the demarcation of the hotspots is considered as a productive means for recognizing the regions for comprehensive risk evaluation. The density of the graduated circle represents the intensity of urban flooding i.e., the largest circle is depicting more occurrences of flood events in the study area. The name of union councils is shown by different numbers such as 1 to Mughalpura, 152 to Cantonment, and so on. The results of the hotspot analysis indicate 4 hotspot zones including number 72(Anarkali), 77(Qilla Gujjar Singh), 29(Androon Bhatti Gate), and 79(Mozang), and 2 cold spots including number 36(Baghbanpura) and 128(Faisal Town). The reference number of each union council is mentioned in Figure 5. As half of the world's population lives in urban areas, the identification of hotspots is significant in developing policies for eradicating urban flooding from megacities as it is an evolving problem due to the rapid increase in urbanization and devise different methods such as more urban green spaces in cities to overcome urban flooding to an extent (Figure 7).

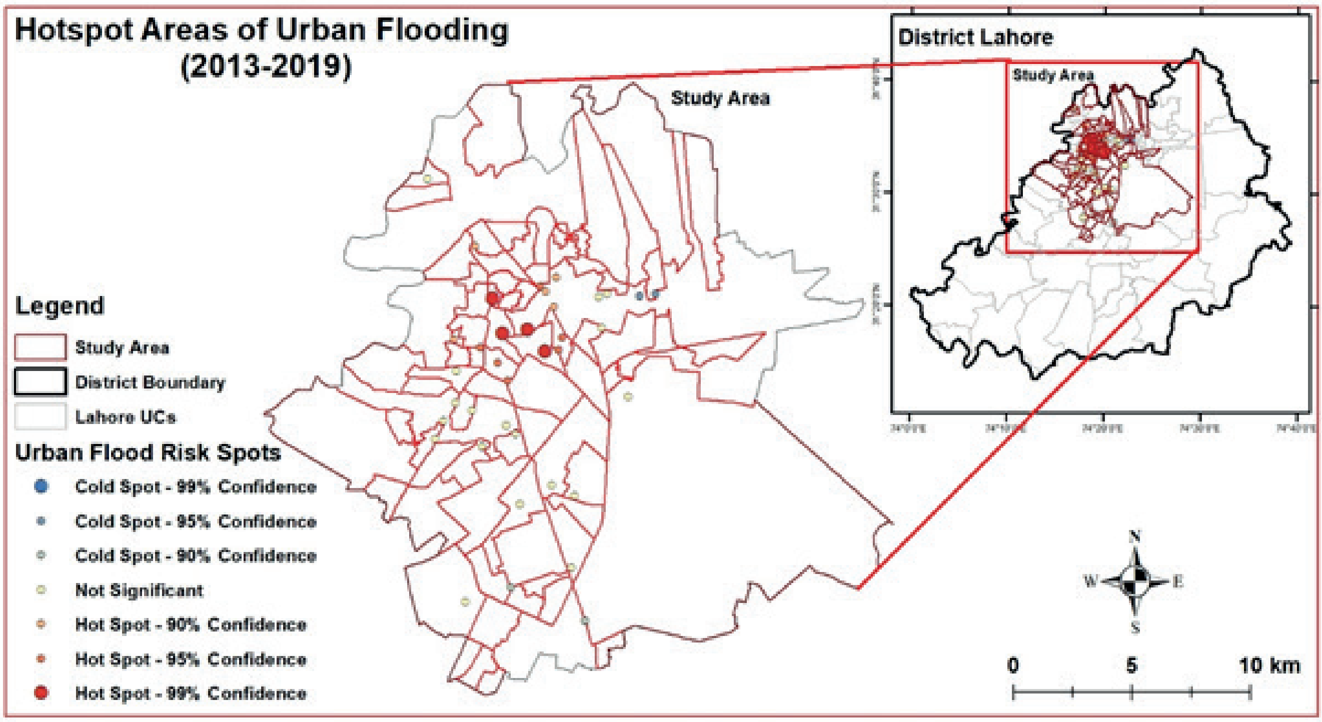

Fig. 7. Hotspot analysis incidents; 2013–2019

Correlative analysis of urban green spaces and occurrences of urban flooding

Figure 8 shows the situation or correlation between the urban green spaces and hotspots of urban flooding in 69 Union Councils of Lahore District. For this purpose, a hotspot analysis tool is used for assessing high-risk zones, and the green per capita and green space ratio is calculated for depicting green space situations in the study area. Based on the results of the analysis, four hot spots are detected including Gawalmandi, Anarkali, Qilla Gujjar Singh, and Androon Bhati gate.

Table 4 depicts that areas with very low green ration and green per capita are more prone to urban flooding as compared to areas with higher values. The condition of green per capita and green ratio in four hotspots is 1.08% green per capita and 2.80% green ratio in union council Anarkali, 2.46% green per capita and 5.23% green ratio in Qilla Gujjar Singh, 0.968% green per capita and 14.30% green ratio in Androon Bhatti Gate, 1.05% green per capita and 5.16% green ratio in union council.

However, cold spots comprise comparatively high values of green per capita and green ratio. On the other hand, cold spots include 3.5% green per capita and 15% green ratio in Baghpanpura and 1.80% green per capita and 4.2% green ratio in Faisal Town. The correlation between urban green spaces and the frequency of urban flooding reveals that the situation is not favorable because very few union councils meet the standard requirement of urban green spaces due to which situation is worse in union councils of Lahore District.

CONCLUSION

The present study examined the effect of urban green spaces on the frequency of urban flooding in 69 union councils of Lahore District. The result shows that the union councils that lack green spaces have experienced more frequent events of a flood than those union councils that meet the standard ratio of urban green spaces as per the area. In past studies, it is evident that green spaces are playing a significant role in maintaining a healthy urban environment because the rate of urbanization is increasing and causing severe impacts on the urban environment. This research contributes to the literature from different perspectives. Firstly, this research examines the frequency of urban flooding events. For this purpose, data were collected from 22 sore points from a governmental body Water and Sanitation Agency with information on ponding points and flood depth in inches to perform hotspot analysis for identification of urban hotspots and cold spots in the study area. Secondly, statistical analysis is performed to calculate green per capita and green ratio to govern the situation in the study area which reveals that most union councils fall in the extremely low category of green spaces and no one meets the standard value of 9m2. Therefore, it is a timely need to see the actual situation and either structured or unstructured ways to create green spaces may introduce to cope with the situation. City planners should pay more attention to the role of urban green spaces in rainwater regulation and the scientific management of urban green spaces.

Table 4. Correlative assessment of urban flooding and green spaces on detected hotspots

UC Name	Events	UC area sq. meter	Park area sq. meter	Population	Green ratio (%)	Green capita per person
Androon Bhatti Gate	28	441095.51	63100	65120	14.305	0.969
Qilla Gujar Singh	29	2411458.19	126201	51212	5.233	2.464
Anarkali	46	2043795.17	57364	55167	2.807	1.04
Gawalmandi	34	877979.3595	0	66356	0	0

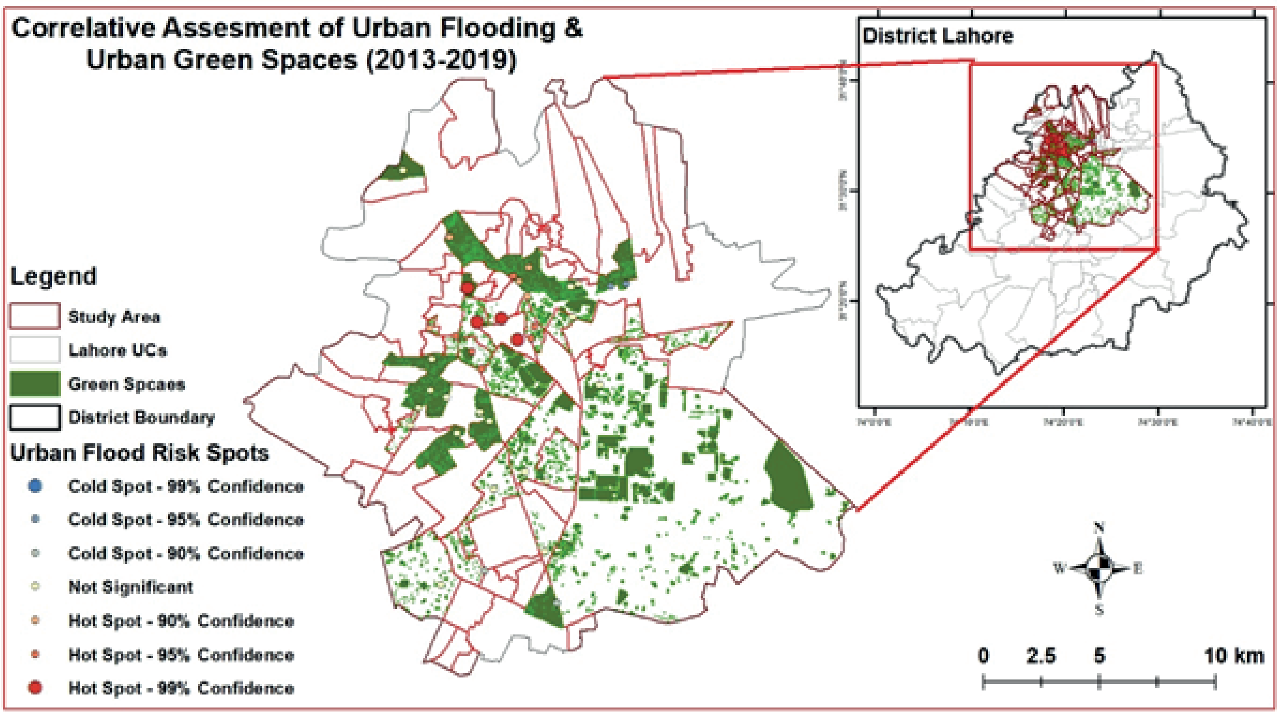

Fig. 8. Correlation between frequency of urban flooding and urban green spaces

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