Int. J. Econ. Environ. Geol. Vol. 12 (2) 13-20, 2021
Journal home page: www.econ-environ-geol.org
Open Access
ISSN: 2223-957X

Urban Floods and Suitability Analysis of Rainwater Harvesting Potential Areas in Lahore City, Pakistan

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Received: *05 February, 2021* ***Accepted:*** *22 April, 2021*

Abstract: There is a growing threat of urban flooding, particularly in Pakistan that needs attention and requires effective management strategies. The chief trigger for urban flooding is the rapid and unplanned urbanization in areas where impermeable surface inhibits rainwater diffusion and changes the natural water flow. In many developed countries, a technique of rainwater harvesting is implemented as a sustainable strategy to manage urban stormwater. Most studies and projects chiefly focused on the potential use of the Rainwater harvesting technique for water conservation in arid and semi-arid climates. In the present work, GIS and remote sensing methodologies are utilized for the suitability of rainwater harvesting structures. This study was conducted in Lahore, the second most populated city of Pakistan and the capital of Punjab. Generally, the water harvesting technique depends on topographical areas with water accumulation, where there is an availability of open spaces in the form of green areas and barren lands, rainfall, drainage network density, and rainfall distribution, particularly in the urban environment. The SRTM DEM data were used for finding high water accumulated areas, and the Landsat OLI image is used to retrieve land use information i.e. vacant land and open green spaces, existing drainage network density, and rainfall distribution. All these layers were integrated through AHP to detect the potentially suitable sites for the construction of rainwater harvesting structures. Results concluded 94 suitable sites with categorization from highly to critically suitable for the construction of rainwater harvesting structures in which 6 were highly suitable areas in Data Gunj Bakhsh Town and Ravi Town. Besides, residential areas are having a maximum site suitability percentage, followed by roads, agricultural and open spaces in the area under consideration. Considering the suitable sites, further rainwater harvesting methods can be identified in the study area to alleviate urban flooding and improve the urban environment.

Keywords: Suitability analysis, rainwater harvesting, rainfall, urban flood, Lahore.

Introduction

Rapid urbanization and Climate change is undoubtedly a global problem and thought to be the main reason for the increase in the intensity and frequency of urban flooding disasters throughout the world and particularly in developing countries like Pakistan (Marsalek et al., 2008; Franci et al., 2015; Zhang et al., 2015; Khalid et al., 2017). Likewise, in other cities of the world, Lahore is urbanizing which resulted in a shift from the rural population to the megacity of Pakistan. Conventional management was mainly dependent on drains to rapidly evacuate the overflow. On the other hand, modern urban designs are emphasizing sponge-type of management practices such as dry retention basins, rain gardens, underground reservoirs, etc. Consequently, as a result of increasing urban flooding, the establishment of rainwater harvesting systems provide a valuable solution to preserve water in urban areas. The use of a rainwater harvesting system has also been found suitable to treat surface runoff from extreme events of rainfall and the subsequent control of stormwater and volume of flood in an area (Zia and Shirazi, 2019; Javaid et al., 2016). Several studies concluded that the construction of rainwater harvesting containers might be an efficient support system to curtail the peak and frequency of floods. In England, Freni and Liuzzo (2019) stated a time series modeling approach i.e. Gerolin's method which contributes to flood reduction by RWH tanks, and tested its usefulness at three different locations. Likewise, in the residential district of Nanjing (China), Zhang et al., (2015), observed that the system has reduced the urban waterlogging problem by constructing and installation of RWH tanks. Results showed a remarkable reduction of flood volume up to 13.9%, 30.2%, and 57.7% while observing daily maximum rainfall, average annual maximum rainfall, and critical rainfall, respectively.

According to the population census in the year 2017, 100 percent population of Lahore is residing in urban areas. Consequently, the increase of impervious surfaces in the form of metalled roads, commercial and residential buildings caused frequent urban flooding throughout the rainy season, particularly from July to September. In the year 2012-2017, 37 union councils of the city experienced urban flooding, and 55 areas of the city experienced adverse impacts of inundated streets which damaged their properties and badly disrupted the social life. Furthermore, recent indicators are that urban flood events are becoming more frequent with a 4 percent increase annually from 2013-2017, and an estimate of 2 million people per year are at risk in the central area of Lahore. These trends are attention-getting of the local government to initiate a nationwide urban flooding safe campaign program. This program started in 2017 to report the issues of urban flooding. Rainfall with the increase of 1.16 mm annually, collectively with the growth of impervious surface by 8 percent, and semi-combined drainage network often result in urban flooding of Lahore (Zia and Shirazi, 2019).

Study Area

The central part of Lahore is one of the cultural attractions. Lahore city extends from 74° 12' 30" E to 74° 29' E longitudinally and latitudinal extends from 31° 26' N to 31° 39' 30" N (Fig.1). It constitutes 37 UCs with all observed inundated areas since 2012 to date. The central part of Lahore city is also known for the busiest traffic junction, business activities, and commercial activities (NESPAK, 2004; Nasar-u-Minallah, 2020). In this study, the growing threat of urban flooding is taking a hazardous situation since it leads to severe inconvenience for humans. It can even be a cause leading to fatalities in some cases like electrical. Furthermore, various damages to property and assets are also caused due to rainwater flooding in urban areas.

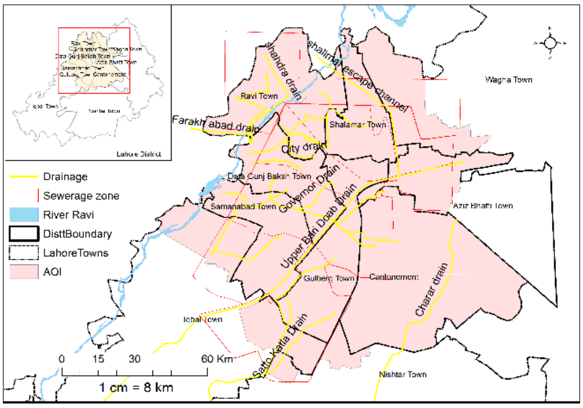

Fig. 1 Depicting the study area (Lahore City).

Materials and Methods

Although, RWH techniques have been under consideration for the last few decades due to development in advanced computer technology, GIS and RS techniques have contributed to developing new techniques to recognize appropriate sites for rainwater harvesting efficiently and effectively by creating simulations. The choice of appropriate sites for rainwater harvesting depends on numerous criteria by acquiring all relevant datasets including rainfall pattern, topographic condition, existing drainage system, LULC, availability of green and open spaces. To date, there are two identified sets of criteria including socio-economic and biophysical. In the current paper, only biophysical criteria have been selected. Several of the studies (Gupta et al., 1997; Prinz and Singh, 2000; Ammar et al., 2016) worked with biophysical criteria including rainfall, drainage network, slope, type of soil, and land use.

In 2003, the Food and Agriculture Organization (FAO) of the United Nations, documented six criteria for identifying RWH sites, which are: hydrology, agronomy, climate, soils, socioeconomics, and topography (Kahinda et al., 2008). There are four approaches including (a) RS and GIS (b) modeling of hydrological using SRS and GIS, (c) multi-criteria analysis (MCA) incorporated with HM in GIS environment, (d) MCA integrated with a GIS. In the present study, MCA integrated AHP-GIS approach is used. With the help of the analytical hierarchy process (AHP), relevant datasets are combined to set up various criteria. It is an MCA method that has been used in several studies to identify potential rainwater harvesting sites. By applying MCA, an estimated relative weight for each criterion has been given, rather than supposing the same weight for all criteria (Chandio et al., 2013). Later a comparison is made between two or more alternatives. AHP is a structured technique, based on the multi-criteria decision. It organizes the raw data and helps to analyze a complex combination of factors. Thomas Saaty developed AHP in 1970s (Saaty,1990). Hierarchical organization and representation of all selected elements, exhibiting their relationship with one another, is the essential principle of AHP. Moreover, the matrix of pairwise comparisons help to determine the weight. It also determines the relative importance of each criterion with one another while assessing the suitability.

Datasets

In the present study, four criteria are associated and evaluated through a 4-point continuous scale. Therefore, the following datasets were acquired.

Satellite imageries

In this study, two satellite data sets were used: Firstly, a 90-meter resolution SRTM DEM, secondly, Landsat 8 OLI images (path 149, row 38) with a spatial resolution of 30x30 meter.

The drainage system

Data related to the existing drainage network is also crucial to figure out the least facilitated area. Semi-combined drainage for sewerage and rainwater is set up in Lahore. There is no separate system to manage rainwater. Therefore, the sewerage system of Lahore is important to cite as an example for the present study. It is significant to mention that the existing drainage and sewage system is facilitating all towns of Lahore. The network system of drain and sewage is equipped with three drains namely: primary drain, secondary and tertiary drain. Details of each drain size are given in Table 1.

Table 1. Details of drains in Lahore

Drains	Sizes
Primary	2′x3′ to 84′x22′,
Secondary	from 4′x4.5′ to 17.5′ x10′
Tertiary	18inches to 8′x10′

Rainfall data

Rainfall data is the foremost statistical information to obtain in such case studies. There are sixteen rain gauge stations in the city of Lahore, which have been recording rainfall statistics since 2002. However, for the identification of rainfall variability, only 6 out of 16 stations were chosen.

Flow direction and accumulation areas analysis

In hydrological studies, detection of flow directions, and accumulation areas, digital elevation model (DEM) is always found to be an accurate technique. DEM is helpful in the demarcation of catchment boundaries, drainage networks, and in the assessment of several catchment parameters such as contours, slope, stream network, aspects, etc. Flow accumulation has been calculated by Hydrologic modeling in the ArcGIS environment. Generally, the direction of a surface runoff will be towards the steepest slope. By the procedure, the direction of flow of each cell of DEM is identified. Later, projected inundated areas are determined. The sequence of stages was applied as per Tarboton's devised methodology. Whereas the calculation for DEM pixels depends on the flow routing model or D8 technique. At first, the interconnection of cells is identified to analyze the flow of direction. However, errors can be expected due to sink cells in the elevation model. These sink cells show some natural depressions in the area. In this situation, all water going into the cell won't be associated further and generate errors by holes. Thus, Jenson and Domingue (1988), eliminated all “sinks” before the determination of accurate flow directions. By using the SINK tool of ArcGIS and the functions of hydrologic analysis the sinks were recognized. Later, these identified sinks are filled by a FILL. As a product, the processed image shows a depression-less elevation model in the next step, the flow direction of this processed image is determined, and the flow accumulation for each cell location is computed. The digital stream network is determined in the last step, (stream network) by adjustment of contribution cells threshold by value <=2.

Normalized Difference Vegetation Index (NDVI)

Urban Green Space (UGS) is considered a potential first choice to reduce the risks of urban flooding. The usefulness of UGS has been emphasized in prominent urban water management in various studies several times. Therefore, NDVI analysis has been applied to obtain information about the available green area with the following formula by using Landsat 8 OLI bands of NIR and Red as shown in Fig. 2.

$$NDVI = \frac{NIR - Red}{NIR + Red} - - - - - - - - - - - - -(1)$$

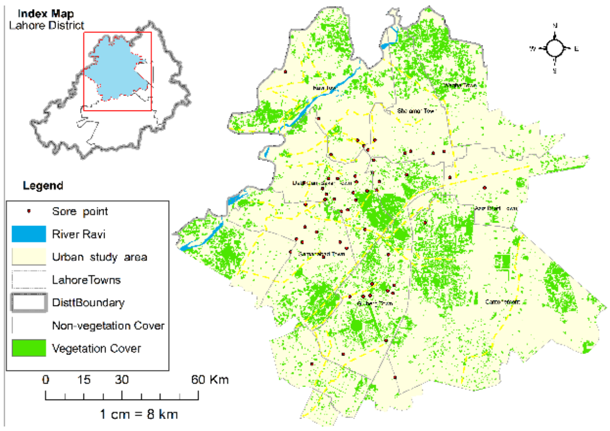

Fig. 2 Vegetation cover of Lahore (2017)

Dry Bare-Soil Index (DBSI)

Availability of barren land is one of the main features especially in urban areas with dense infrastructure. In this aspect, Landsat 8 bands suggested the use of SWIR1 and Green bands to retrieve the information of barren land or bare soil. In these bands, generally, the digital number of bare land is appeared slightly higher than the digital number of the built-up area. Thus, the following equation is used:

$$DBSI = \frac{SWIR1 - Green}{SWIR1 + Green} - NDVI - - - - - (2)$$

Surface reflectance is calculated by SWIR1 band 6 and Green surface reflectance in Landsat 8. Generally, DBSI values can be ranged between −2 to +2. Higher numbers represent more bare soil. A threshold value can be used for distinguishing bare soil and non-bare soil classes. In the present study, 0 thresholds have been used to differentiate bare soil and non-bare soil. Later, obtained results were reclassified as highly suitable and non-suitable site criteria. Higher numbers were considered as highly suitable sites and low numbers were chosen as Non-suitable sites determination as shown in Fig. 3.

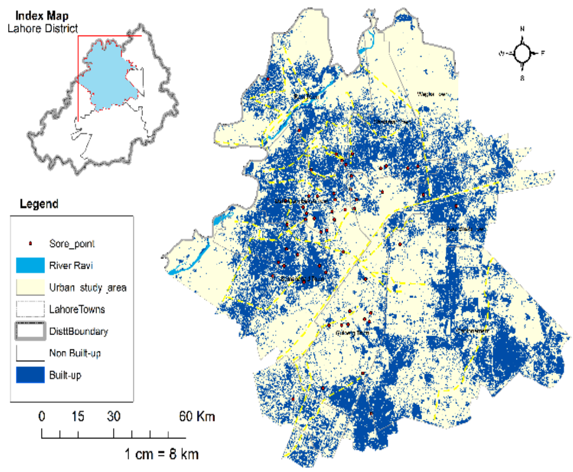

Fig. 3 Built-up area of Lahore (2017)

Drainage density

In the current study, information about the diameter of the drainage channel is used to prepare the drainage capacity layer map. The density of the drainage network is computed by the line density tool. The size of drainage channels varies from 171 square meters to 1.8 square meters. Low-density network channels were considered as highly suitable sites to install new channels and high dense network areas were chosen as non-suitable sites.

Rainfall

The average annual rainfall data ranged from 2010 to 2017 is considered for interpolation. The inverse Distance Weighting (IDW) technique is utilized to generate continuous rainfall data for the proposed study area of Lahore. High rainfall receiving areas were considered as highly suitable sites to tackle stormwater and low receiving rainfall areas were chosen as non-suitable sites (Fig. 4).

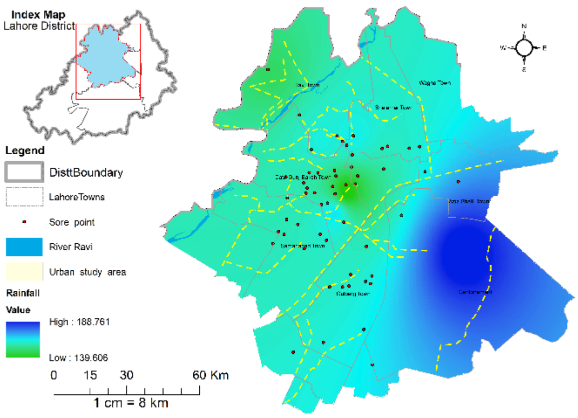

Fig. 4 Spatial rainfall Pattern

Analytical Hierarchical Process (AHP)

An analytical hierarchical process (AHP) was applied to find out the best suitable site for rainwater harvesting to cope up with urban flooding. Generally, it is applied to organize the urban flood causative rank-wise factors. The AHP is an organized technique, this method supports policy and decision-makers to discover the best way while considering the relevant input. It helps to explore all probable solutions to deal with the research problem. In the present work, all certain parameters are organized and reclassified on a similar scale to execute the analytic hierarchy process with the help of a pairwise matrix (Table 2).

Results and Discussion

Total 93 sites were found suitable for the construction of rainwater harvesting structures including highly suitable to critically suitable (Table 3, Fig. 5).

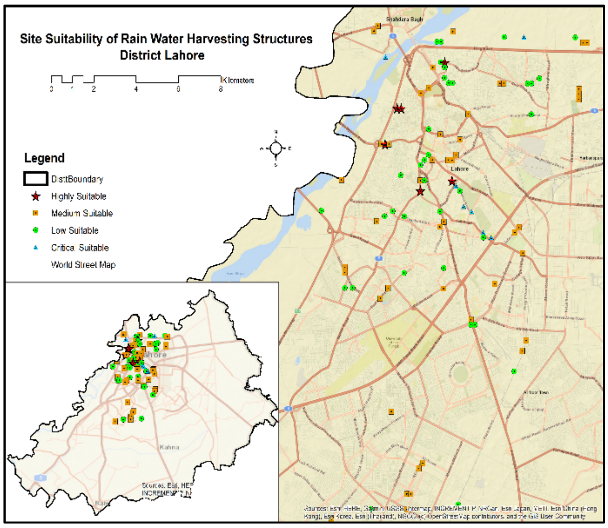

Fig. 5 Site suitability map of RWH structures in Lahore

Fig. 6 Residential areas having a maximum site suitability percentage, followed by roads and agricultural and open spaces.

Table 2. Pairwise matrix comparison.

	Water accumulation	NDVI	DBSI	Drainage capacity	Rainfall	SUM	nth_root	Priority Vector	Percentage
Water accumulation	1	2	3	4	5	15	0.68	0.387597	38.76
NDVI	0.5	1	2	3	4	10.5	0.48	0.271318	27.13
DBSI	0.33	0.5	1	2	3	6.83	0.31	0.176572	17.66
Drainage capacity	0.25	0.33	0.5	1	2	4.08	0.19	0.105512	10.55
Rainfall	0.2	0.25	0.33	0.5	1	2.28	0.1	0.059001	5.9
Sum	2.28	4.08	6.83	10.5	15	38.7	1.76	1	100
sum PV	0.885	1.108	1.207	1.108	0.885	5.192	0.24		

Table 3 Summary of suitable sites.

Suitability status	Number of expected suitable sites
Highly Suitable	6
Medium Suitable	45
Low Suitable	35
Critical Suitable	7

Highly Suitable Sites

Two towns out of eight in Lahore district are found as highly suitable sites including Data Gunj Bakhsh Town and Ravi Town. Union councils of Data Gunj Bakhsh Town including Ameen Pura, Ganj Kalan, Kasur Pura, Mozang, and Qila Gujjar Singh contain highly suitable sites. Each Union council has one suitable site. In contrast, Siddique Pura of Ravi Town spots a residential area for a rainwater harvesting structure (Table 4).

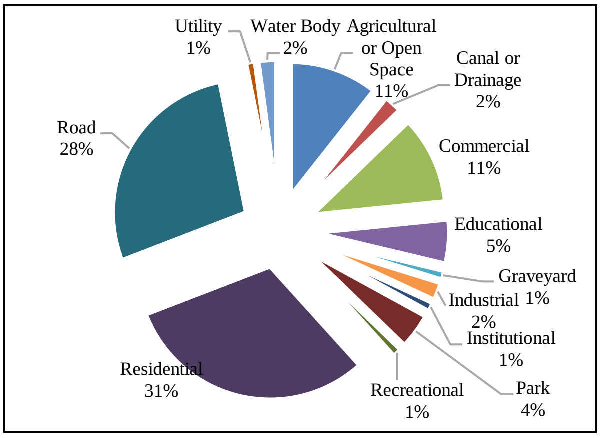

Fig. 6 Overall potential of RWH suitability by area size (sq. meter) in different Land use.

Table 4 Details of Land-use type and area (sq. Meter) for highly suitable sites.

Town Name	UC Name	Land-use type	Area in sq. meter
Data Gunj Baksh Town	Ameen Pura	Residential	1227.75
	Ganj Kalan	Commercial	4755.88
	Kasur Pura	Residential	1971.99
	Mozang	Road	187377.67
	Qila Gujjar Singh	Residential	85057.04
Ravi Town	Siddique Pura	Residential	6149.04

Medium Suitable Sites

Medium suitability for rainwater harvesting projects have been found in all towns of Lahore. Results revealed Wagha town as the most suitable for proposing rain harvesting structures in an area size of 27 sq. km, followed by Samanabad with 2 sq. km area availability and Gulberg town with 2.33 sq. km. Furthermore, according to land-use type, residential areas are found more suitable, followed by areas along roads and agricultural or open spaces (Table 5, Fig. 7a, b).

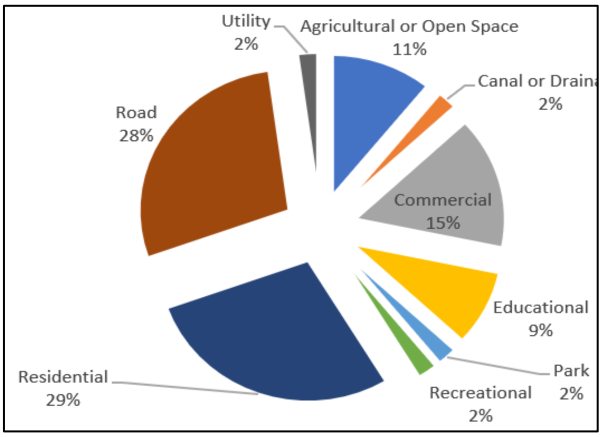

Fig. 7(a) Potential of RWH medium suitable sites in different land-use types of Lahore.

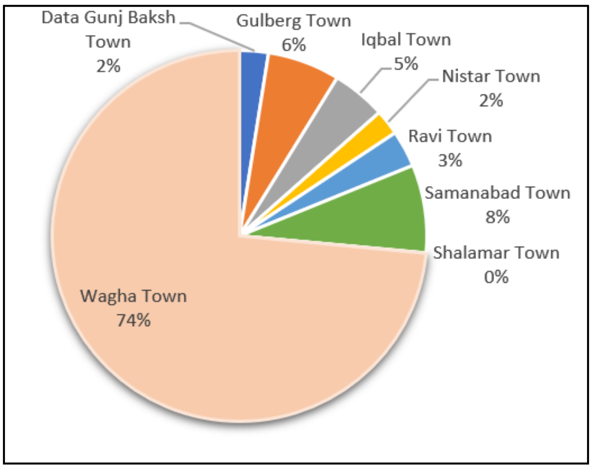

Fig. 7(b) Medium suitable Rainwater harvesting area percentage in towns of Lahore.

Low Suitable

There were 35 medium suitable sites identified through AHP (Table 6, Fig. 8a, b).

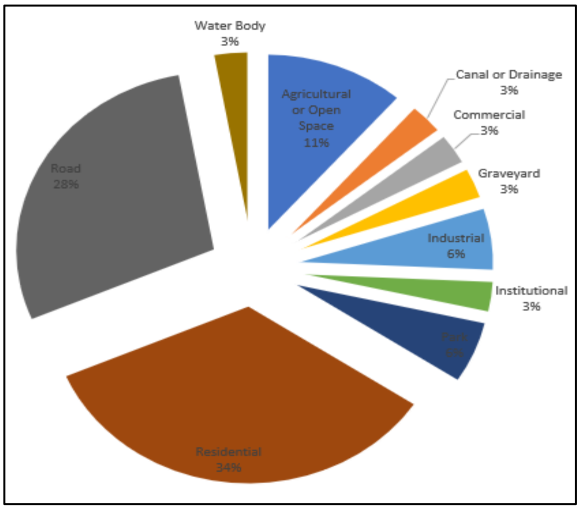

Fig. 8(a) Potential of RWH Low suitable sites in different Land use types of Lahore.

Table 5. Details of land-use type and area (sq. meter) for medium suitable sites.

Town Name	UC Name	Land-use type	Area (sq. meter)
Data Gunj Baksh Town	Anarkali	Commercial	4109.19
	Race Course	Commercial	3417.53
	Sare Sultan	Educational	33487.49
	Gawalmandi	Educational	2049.64
	Gawalmandi	Educational	21140.55
	Ganj Kalan	Road	211548.48
	Gawalmandi	Road	414319.21
	Mozang	Road	187377.67
	Ganj Kalan	Utility	49155.65
Gulberg Town	Zaman Park	Commercial	10628.17
	Makkah Colony	Commercial	576.75
	Al-Hamra	Residential	50976.58
	Al-Hamra	Residential	46978.4
	Al-Hamra	Road	1182134.85
	Al-Hamra	Road	718068.17
	Makkah Colony	Road	322653.51
Iqbal Town	Town Ship	Commercial	17400.65
	Ali Raza Abad	Residential	3821.73
	Bakar Mandi	Residential	4621.11
	Sabzazar	Residential	13930.65
	Johar Town	Road	1316566.51
	Town Ship	Road	385735.53
Nistar Town	Green Town	Canal or Drainage	817935.86
	Maryam Colony	Residential	2436.5
	Maryam Colony	Residential	3597.6
Ravi Town	Kot Mohibbu	Agricultural or Open Space	7754.49
	Jia Musa	Agricultural or Open Space	3136.17
	Qila Lachhman Singh	Commercial	581.25
	Farooq Ganj	Park	9289.04
	Qila Lachhman Singh	Recreational	481135.32
	Siddique Pura	Road	497006.41
	Aandroon Dehli Gate	Road	189605.56
Samanabad Town	Abu Bakar Siddique Coly.	Agricultural or Open Space	1660655.53
	Gulshan-e-Ravi	Commercial	1673.64
	Rehman Pura	Educational	310.4
	Bahawalpur House	Residential	5108.03
	Kashmir Block	Road	597375.59
	Kashmir Block	Road	597375.59
Shalamar Town	Shad Bagh	Residential	3029.58
	Bhaghat Pura	Residential	7651.02
	Baghbanpura	Residential	1381.61
Wagha Town	Muhammad	Agricultural or Open Space	13703361.2
	Muhammad	Agricultural or Open Space	13703361.2
	Muhammad	Residential	4758.9
	Sultan Mehmood	Residential	4930.89

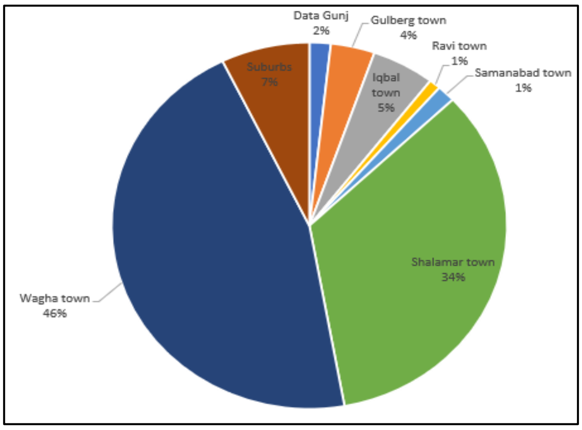

Fig. 8(b) Low suitable Rainwater harvesting area (sq. km) percentage in towns of Lahore.

Critical Suitable Sites

Critical suitable sites included all those sites where rainfall is least with no extended barren lands and non-availability of green spaces. Moreover, other means of runoff evacuation are better such as more drainage capacity to cope up with urban flooding situations. Therefore, such sites were considered critical sites where biophysical features are not suitable for the quick implementation of any RWH structure plan. Results show only three towns including, Data Gunj Bakhsh Town, Ravi town and Shalimar town to be containing such critical sites (Table 7, Fig. 9 a, b)

Table 6. Details of land-use type and area (sq. meter) for low suitable sites

Town Name	UC name	Land-use type	Area in sq. meter
Data Gunj Baksh Town	Anarkali	Road	243856.49
	Anarkali	Institutional	23702.96
	Jinnah Hall	Park	1961.89
	Islam Pura	Road	167076.39
	Mozang	Residential	17106.07
	Race Course	Commercial	14725.11
	Race Course	Road	50212.04
	Race Course	Residential	3258.37
Gulberg Town	Garden Town	Road	718068.17
	Al-Hamra	Residential	10674.82
	Naseer Abad	Residential	353220.27
Iqbal Town	Ali Raza Abad	Residential	35416.48
	Sabzazar	Road	949977.74
	Sabzazar	Residential	18149.34
	Township Sector A	Road	541009.33
Ravi Town	Bhamman	Agricultural or Open Space	88315.32
	Siddique Pura	Residential	966.58
	Siddique Pura	Graveyard	15409.75
	Siddique Pura	Residential	250.46
	Bangali Bagh	Industrial	29624.9
	Bangali Bagh	Industrial	122308.57
	Androon Bhatti Gate	Park	27241.44
Samanabad Town	Abu Bakar Siddique Coly.	Road	339460.39
	Sham Nagar	Residential	6663.84
	Gulshan-e-Ravi	Road	97636.94
	Bahawalpur House	Residential	1001.19
	Rehman Pura	Residential	820.47
	Kashmir Block	Residential	4071.7
Shalamar Town	Gujjar Pura	Canal or Drainage	39636.99
	Gujjar Pura	Agricultural or Open Space	5097875.76
	Gujjar Pura	Agricultural or Open Space	5097875.76
	Rehmatpura	Road	50581.86
Wagha Town	Muhammad	Agricultural or Open Space	13703361.2
		Water Body	721298.23
Suburbs		Road	1452363.73

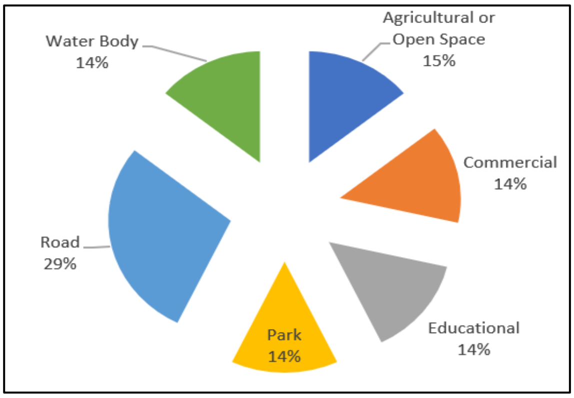

Fig. 9(a) Potential of RWH critical suitable sites in different land-use types of Lahore.

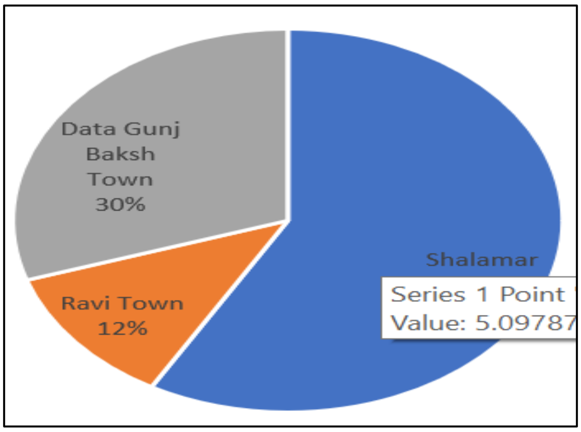

Fig. 9(b) Critical suitable Rainwater harvesting area percentage in towns of Lahore.

Table 7 Details of Land-use type and area (sq. meter) for Critical Suitable Sites of RWH.

Town Name	UC name	Land-use type	Area in sq. km
Shalamar Town	Gujjar Pura	Agricultural or Open Space	5.09787576
Ravi Town	Kot Begum	Water Body	1.02447195
	Qila Gujjar Singh	Commercial	0.02530462
Data Gunj Baksh Town	Race Course	Road	0.97042094
	Race Course	Road	0.97042094
	Race Course	Park	0.52111315
	Race Course	Educational	0.1410165

Conclusion

The growing threat of urban flooding in Lahore needs attention at the earliest, possible either with the aid of structure or unstructured strategies. Undoubtedly, structured strategies are costly and time-consuming. If these strategies are implemented by keeping in view long-term planning, this hazardous situation can be easily mitigated in Lahore. RHW practices are in their initial phases. The Lahore Development Authority (LDA) with its subsidiary Water and Sanitation Agency (WASA), has launched one of such structures that will collect rainwater collection to recharge the underground water table. Likewise, this study suggested 93 more suitable sites for such projects. Among all, 6 are highly suitable sites to initiate such projects that can be constructed on Abubakar road, Siddique Pura, Ravi Town, Sagiyan wala bypass Road, Ganj Kalan, Data Gunj Bakhsh town, near Bund Road in the area of Ameen Pura and Kasur Pura in Data Gunj Bakhsh town Likewise, Lower Mall road near Riwaz Garden and Queen's Road in Qila Gujar Singh area are also found highly suitable. The GIS- approach proposed in the current study is highly beneficial for water management planners to combat such hazardous situations.

References

Ammar, A., Riksen, M., Ouessar, M., Ritsema, C. (2016). Identification of suitable sites for rainwater harvesting structures in arid and semi-arid regions: A review. *International Soil and Water Conservation Research,* **4** (2), 108-120.

Chandio, I. A., Abd Nasir, B. M., WanYusof, K. B., Talpur, M. A. H., Balogun, A. L., Lawal, D. U. (2013). GIS-based analytic hierarchy process as a multicriteria decision analysis instrument: a review. *Arabian Journal of Geosciences*, **6** (8), 3059-3066.

Franci, F., Mandanici, E., Bitelli, G. (2015). Remote sensing analysis for flood risk management in urban sprawl contexts. Geomatics, *Natural Hazards and Risk,* **6** (5-7), 583-599.

Freni, G., Liuzzo, L. (2019). Effectiveness of Rainwater Harvesting Systems for Flood Reduction in Residential Urban Areas. *Water,* **11** (1389), 1-14.

Gupta, K., Deelstra, J., Sharma, K. (1997). Estimation of water harvesting potential for a semiarid area using GIS and remote sensing. *IAHS Publications-Series of Proceedings and Reports -Intern Assoc Hydrological Sciences*, **242**, 53-62.

Jenson, S. K., Domingue, J. O. (1988). Extracting topographic structure from digital elevation data for geographic information system analysis. *Photogrammetric engineering and remote sensing*, **54** (11), 1593-1600.

Javaid, A. Ghauri, B. M. K. and Nasar-u-Minallah, M. (2016) Criteria maps for rainwater harvesting in Potohar region. *Science International*, **28** (3), 2617 -2620.

Kahinda, J. M., Lillie, E., Taigbenu, A., Taute, M., Boroto, R. (2008). Developing suitability maps for rainwater harvesting in South Africa. *Physics and Chemistry of the Earth*, Parts A/B/ C, **33** (8-13), 788-799.

Khalid, M., Riaz, O., Sultan, A., Nasar-u-Minallah, M. and Hassan, M.N. (2017) Geospatial Assessment of Flood Hazard in Jhang District, Pakistan. *Journal of Basic and Applied Sciences*, **13**, 577-582. https://doi.org/10.6000/1927-5129. 2017.13. 93.

Marsalek, J., Cisneros, B. J., Karamouz, M., Malmquist, P. A., Goldenfum, J. A., Chocat, B. (2008). *Urban water cycle processes and interactions:* Urban Water Series-UNESCO-IHP (Vol. 2): CRC Press.

Nasar-u-Minallah, M. (2020). Exploring the Relationship between Land Surface Temperature and Land use change in Lahore using Landsat Data. *Pakistan Journal of Scientific and Industrial Research Series A: Physical Sciences.* **63A** (3), 188-200

NESPAK. (2004). *Integrated Master Plan for Lahore-2021*, Lahore Development Authority, Lahore. Vol. I, II, and III.

Prinz, D., Singh, A. (2000). Technological potential for improvements of water harvesting. Gutachten für die World Commission on Dams, *technical papers*, 126.

Saaty, T. L. (1990). An exposition of the AHP in reply to the paper "remarks on the analytic hierarchy process". *Management Science*, **36** (3), 259-268.

Zhang, B., Li, N., Wang, S. (2015). Effect of urban green space changes on the role of rainwater runoff reduction in Beijing, China. *Landscape and Urban Planning,* **140**, 8-16.

Zia, S., Shirazi, S. A. (2019). Spatio-Temporal Analysis of Areas Vulnerable to Urban Flooding: A Case Study of Lahore, Pakistan. *International Journal of Economic and Environmental Geology*, **10** (3), 85-89.