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SUSTAINABLE MANAGEMENT OF RAINWATER TO RECHARGE GROUNDWATER IN CITY LAHORE

Rabia Qayyum,
Sohail Ali Naqvi,
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ABSTRACT

Lahore, Pakistan's second largest urban hub, is dealing with two major issues. The first is a decrease in groundwater level as a result of intensive groundwater extraction, and the second is urban flooding during the monsoon season. Ground water recharge has a large impact on sustainable development for water supply in many areas, but variations in rainfall pattern have had a significant impact on water supply. There are some days when winter rains occurred the water become surplus in some regions, because of low evapotranspiration and less crop water requirements. By conserving surplus water, we can reduce the stress on fresh water resources. This research aims to improve rainwater management in order to increase water supply for various domestic uses and to aid in the alleviation of water scarcity in Lahore. The rainfall pattern is changed due to the global and local climate change, Mann Kendal test and Sens Slop were applied to analyze the data. In this research seasonal potential of rainfall was characterized for water conservation. The results showed decline in average annual rainfall from 839mm to 557mm during last 4 decades and seasonal rainfall in summer and winters are also changed. These results will be helpful for better management of water supply and flood management with blue and green initiatives. This research is also providing the guidelines and recommendation for enhancing the quality and quantity of water supply in Lahore.

Keywords: MK (Mann Kendall), Urban Water Management, Lahore

Introduction

The key components of the global development program are urban resilience, access to clean water, and sustainable management of water resources. The three basic components of urban water management are water supply, wastewater treatment, and stormwater drainage. Urban water management system is considered as important as climate change mitigation and attaining resilient cities. Present system is built on conventional infrastructures, urban water management's resilience is being called into doubt (Herslund & Mguni et al., 2019). Urban water supply security can be assessed in term of water available per capita at the city level (Krueger et al., 2019). Despite significant

[1] WWF-Pakistan, Inside Ali Institute of Education Lahore, Pakistan

investment and development in water-related infrastructure, many cities are unable to provide all citizens with basic water services (Krueger et al., 2019). Urbanization and climate change have put great pressure on global water security due to growing imbalance between water demand and water availability. Global urban population is facing water scarcity due to increase in population from 933 million in 2016 to 1.6-2.3 billion people in 2050 which is nearly half of global urban population (He et al., 2021). Lack of urban planning, policy and poor drainage system have resulted in various water related issues like flooding, water shortage and water pollution.

Pakistan was water ample country and now is facing situation of water scarcity with the passage of time due to the increase in population. Surface water availability has decrease from 5000 m3 per capita to 1000 m3 per capita in last 6 decades which can be reduced further up to 800 m3 by 2025 (Zhang et al., 2020). Similarly, there are 60% losses of water due to the poor management in irrigation system and about 21 million people of Pakistan do not have access to clean water. Pakistan is the third country facing a water deficit, and by 2025, it will be severe, according to the International Monetary Fund (PCRWR, 2018). Water shortage is also accelerating the provincial conflicts over water such as between Punjab and Sindh (Tariq et al., 2020). The shrinking of Indus Delta makes the remaining water unsafe and contaminated to be use for drinking and irrigation. According to Asian Infrastructure Investment Bank (2018), groundwater is depleting at rate of more than one meter annually in the Capital of Punjab, Lahore city. With increasing population of city Lahore, water demand is also increasing. Overuse of water resources and poor practices causes increase in difference between water being recharged and water being pumped from groundwater as shown in Fig 1. A study conducted by WASA Lahore (2016), groundwater level of city Lahore has gone down up to 60 feet since 1961 and average decline rate per year is around 3 feet. Groundwater extraction is around 1.45 million cubic meters per day and difference between discharge and recharge is 427 million cubic meters per year. This caused 55 cm drop in groundwater level per year in Lahore (Qureshi & Sayed. 2014). Dryness of River Ravi and urbanization are the main reason of declining the groundwater level in Lahore. The magnitude of groundwater decline varies from area to area of Lahore that's why there is great need to determination the water associated problems by using rain water.

Sponge City in China is great example of sustainable urban water management (Nguyen et al., 2019). This model has potential to alleviate the flooding and water shortage by adapting to the variation in rainwater like a sponge (Guan et al., 2021). Water organizations and river basin authorities are taking actions for better management of water resources and shifting toward alternative water sources such as reuse of treated wastewater and rainwater harvesting. Rainwater harvesting has gained notable attention as alternative of freshwater

especially for urban area with limited water supply. Rainwater harvesting practice has been used as an alternative source of water in urban and sub urban region of developed countries. It reduces the pressure on freshwater resources and strengthens the urban stormwater management (Ali et al., 2020). Residential community of Lahore has potential of rain harvesting around 536 m3 per year (Siddiqui et al., 2019). It shows that rainwater harvesting technique has potential of groundwater replenishment in Lahore. The main objective of this article is to highlight the opportunity of rainwater management through blue and green infrastructure in Lahore to control urban flooding, recharging ground water, reduce the stress on fresh water, propose guidelines and recommendation for enhancing the quality and quantity of water supply and achievement of better rainwater management in Lahore city at individual and community level.

Year wise Groundwater Mass Balance of Lahore Aquifer System during 2006-2017 (MCM)

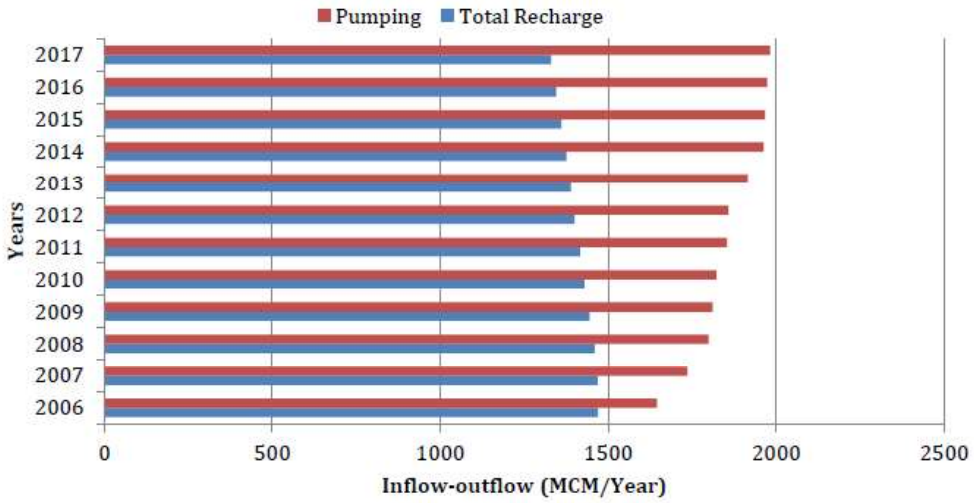


Figure 1 Year wise Groundwater Mass Balance of Lahore aquifer during 2006-2017 (MCM)

Study Area

The study area is located at latitude 31.558 and longitude 74.35071. It is capital of Punjab and the northern hemisphere with total area 1772 km2 and 11.13 million population. Its catchment area receives an average rainfall of 673 mm and around 75% occurs in the monsoon season which causes runoff in urban and rural areas of Lahore. In this study two non-parametric methods (Mann Kendall & Sen's Slope) were used to detect the Rainfall trends.

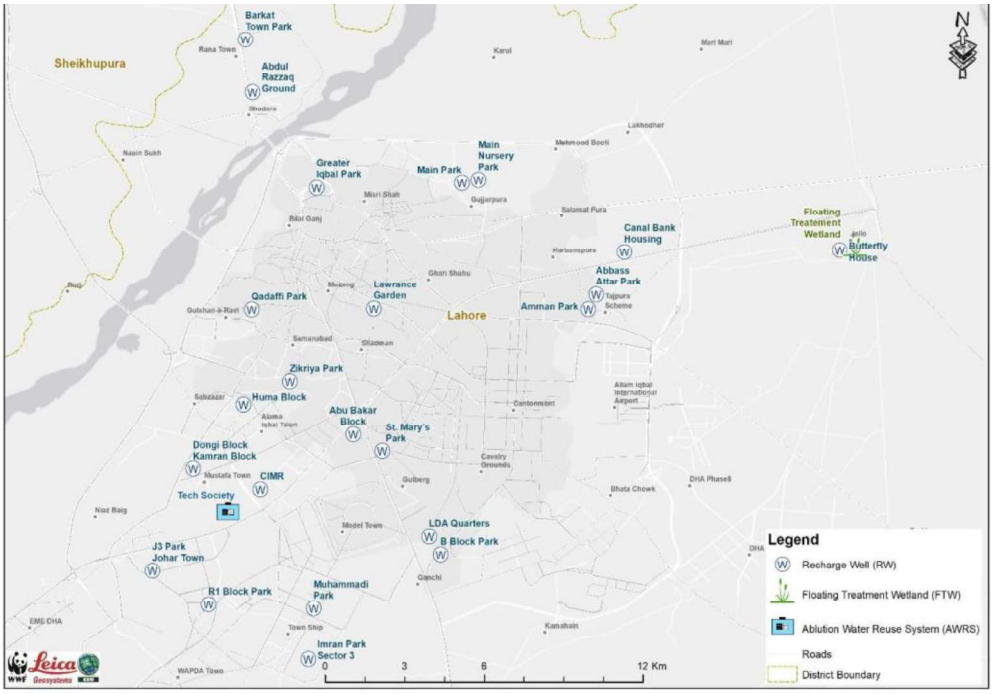


Figure 2 Project Area of Lahore

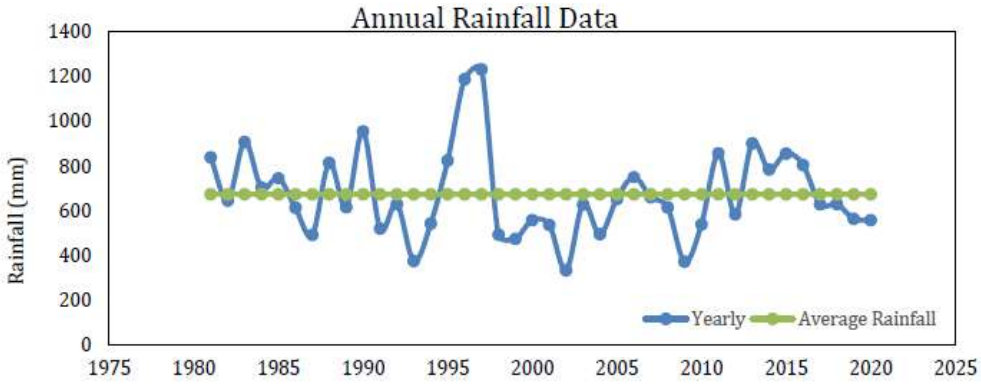


Figure 3: Annual Rainfall (mm) of Lahore from 1975 to 2020

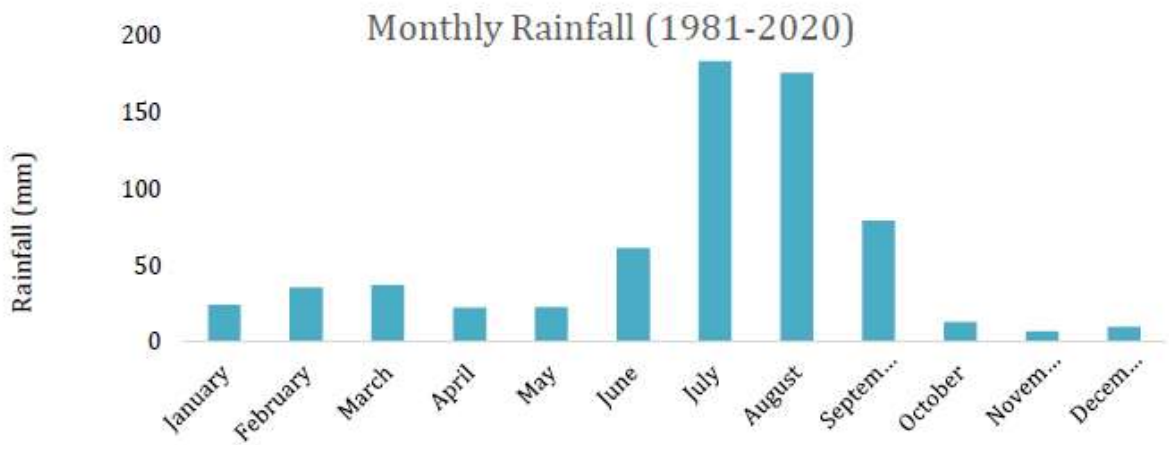


Figure 5. Average Monthly Rainfall (mm) of Lahore from 1981 to 2020

Mann Kendall Tests

The Mann-Kendall test is used to determine whether or not there is a linear monotonic trend in a given time series data. It is a non-parametric trend closely related to the concept of Kendall's correlation coefficient. The null hypothesis, H0, states that there is no monotonic trend, and this is tested against one of three possible alternative hypotheses, Ha: (i) there is an upward monotonic trend, (ii) there is a downward monotonic trend, or (iii) there is either an upward monotonic trend or a downward monotonic trend. It is a robust test for trend detection used widely in financial, climatological, hydrological, and environmental time series analysis.

The number of annual values of the data series is denoted by n. The differences of annual values x were determined to compute the Mann-Kendall statistics. The Mann-Kendall statistic(S)is computed using equation1.

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn\left(x_j - x_k\right) \qquad (1)$$

Where $sgn\left(x_j - x_k\right)$ is an indicator function that takes on the values 1,0 or -1 according to sign of difference $\left(x_j - x_k\right)$, where j>k:

$$sgn\left(x_j - x_k\right)\begin{cases} 1 & if\ x_j - x_k > 0 \\ 0 & if\ x_j - x_k = 0 \\ -1 & if\ x_j - x_k < 0 \end{cases} \qquad (2)$$

The values of x_j and x_k are the annual values in the year j and k respectively.

The variance S is computed by the following equation:

$$VAR\ (S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p-1)(2t_p+5)\right] \qquad (3)$$

Where q is the number of tied groups and tp is the number of data in the group. Before computing VAR(S) the data is checked to find all the tied groups and number of data in each tied group.

S and VAR (S) are used to compute the MK test Z as follows:

$$Z = \begin{cases} \frac{s-1}{[VAR\ (S)]0.5} if\ S > 0 \\ 0 \quad if\ S = 0 \\ \frac{s+1}{[VAR\ (S)]0.5} if\ S < 0 \end{cases} \qquad (4)$$

The trend is evaluated using Z values. A positive value of Z indicates an upward trend while negative values shows downward trend (cooling trend). The statistics Z has a normal distribution. For the present study, the significance trends are evaluated with α≤0.1.

Results and Discussion

Rainfall trend analysis of Lahore city has been done in this study with 40 years of rainfall data from 1981-2020. Mann Kendall and Sen's Slope estimator has been used for trend analysis. Fig 2 Represents average annual rainfall from past 40 years with maximum rainfall (99.1 mm) in 1996 and minimum rainfall (15 mm) in 2016.

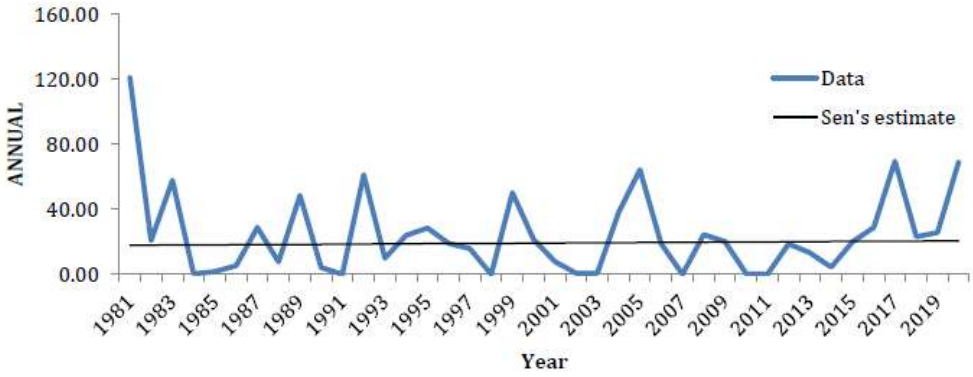


Figure 6. Annual Trends of Rainfall Data from 1981 to 2020

In addition, annual and seasonal rainfall variability time series data were investigated. The study area has four season Spring (March to May), Summer (June-Aug), autumn (Sept to Nov) & Winter (Dec to feb). Mann Kendall test has been used to observe the trends and Sen's Slope for measuring the reliability. There is significant decrease observed from 1981 to 2020 (Z=-0.64). A slight increase is observed in Spring (Z=0.08) and sharp decline was observed during Summer (Z=-1.39). Furthermore, again a slight increase is observed in Autumn

(Z=0.24) and decline is observed in Winter (Z=-0.64) from 1981 to 2020. The Mann Kendall and Sen's slope show an increase and decrease in the rainfall trend, however there is no statistically significant data.

The study region is characterized with decrease in rainfall in Summer but analysis of monthly rainfall trends show intensity is increased during period of 40 years which is problematic as this cause flooding and freshwater ends up in sewage and drainage system. The variation may influence the regional climate system as well as hydrological cycle.

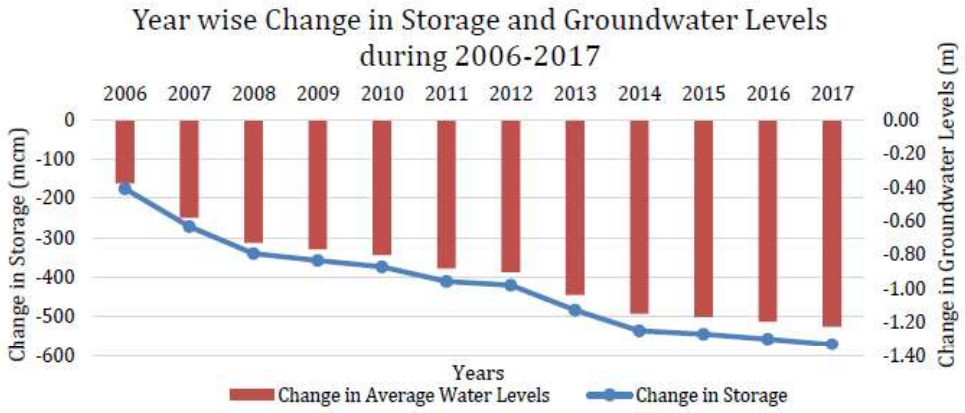
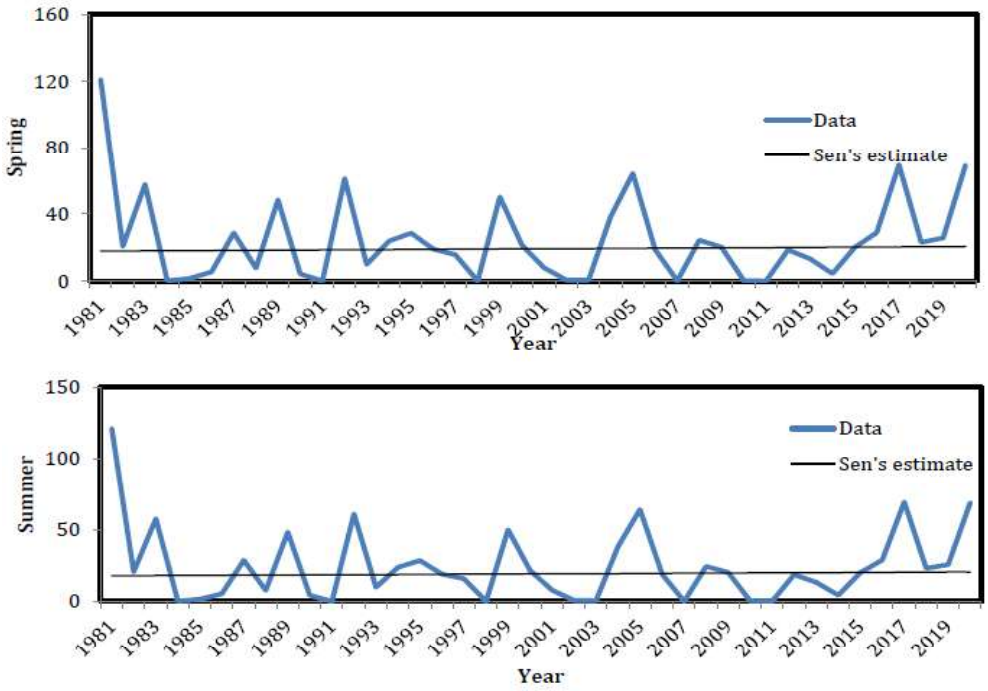


Figure 7 Year wise Change in Groundwater Storage and Levels during 2006-2017



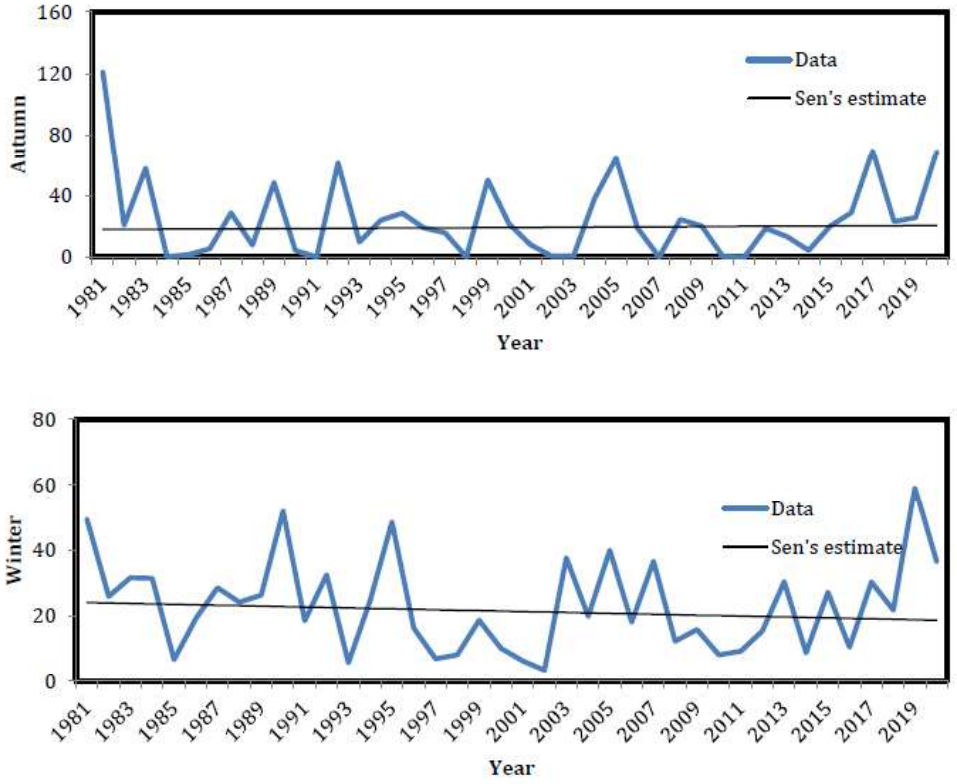


Figure 8 Tends of seasonal rainfall during period of 1981-2020

By keeping in view, the aforementioned trends some interventions are purposed for better management of rainwater by improving ground water quality, quantity and generating alternative water sources to reduce burden on freshwater.

To reduce pressure on fresh water resource, one of the interventions is "ablution water" reuse. Ablution water is relatively very clean compared to sewage, thus it can be reused for non-portable use like flushing toilets or irrigation of public gardens. A model is proposed for treatment of ablution water and its reuse in this paper. Ablution water contain mainly microorganism due to gargling which can be removed by passing water through filter media. Studies suggest that the development of a plumbing system designed to collect, filter and disinfect ablution water to be used for above purpose (Al-Alawi, et al., 2019). People in mosque shall also be educated to conserve water. By implanting this intervention at a potential site, large volume of fresh water can be saved and used for irrigation of plants. WWF has installed ablution water reuse system at 7 different sites which has capacity to replenish 36000 m3/year. By increasing in number of such systems, excess water pumping from ground can be saved.

Second intervention is groundwater recharge well which can help to improve groundwater level and prevent city from urban flooding. Rainwater is fresh source of ground water recharge and it will also help to deal with urban flood and prevent

rainwater discharge to end up into drainage system. The study show groundwater depletion rate can be reduced up to 16.5% and 39% by installing four and tens recharge wells respectively (Ashiq et al., 2020). According to WASA record, 51 locations are identified which form ponding area during rainfall and surveys conducted in monsoon season, highlighted 43 sites with a critical ponding location having depth of more than 3 inches. By installing groundwater recharge wells we can save water from being waste and control urban flooding and improve water table. Different filter media can be used in combination to treat rainwater runoff before recharging.

Conclusion The annual and monthly rainfall trends analysis in 1981-2020 has been carried out in Lahore. The Mann-Kendall and Sen's Slope estimator test results show the increase and decrease in rainfall pattern over the seasons and years. Rainfall trend show the decrease in rainfall in winter and summer but intensity is high which cause urban flooding in Lahore. Due to over exploitation of freshwater resources, groundwater level is declining. Urbanization and concrete structures have affected the natural ability to recharge ground water. Therefore, groundwater recharge wells are proposed as intervention to control urban flooding and recharge ground aquifer. Furthermore, ablution water reuse system is proposed as another intervention in order to reduce ground water pumping. These interventions can bring a very positive change to resolve water issues in Lahore.

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