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Temporal Trends and Patterns of Rainfall Variability from 1980 to 2018 in Lahore, Pakistan

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ABSTRACT

This study was conducted to investigate the effects of climate change on the variability of rainfall patterns of Lahore. The dataset was acquired from the Pakistan Metrological Department Lahore, over the past 38 years; the study period was from 1980 – 2018. The trend of variability was assessed through the nonparametric Mann Kendall test and linear regression models. The results are revealing a decreasing trend, negative skewness of data as an overall beta value remained -4.13mm/year. Similarly season-wise, negative skewness was observed in summer, spring, and winter seasons while a positive skewness have been observed in autumn. This research has concluded that the variation of rainfall patterns is the outcome of climate change in the city of Lahore. This can pose a severe risk on water management, urban flooding, urban agriculture, microclimate, and human health/wellbeing and at the same time a real threat to resilience of the urban ecosystem of the city. The Nature Based Solution (NBS) can minimize these vigorous and enormous impacts of climate change through multiple ways for instance by minimizing the rate of evapotranspiration. Therefore, this study can be useful for future research regarding climate change, urban designing, urban flooding, and city management by keeping in view the variability trends of rainfall.

KEYWORDS: climate change, rainfall variability trends, Lahore, urban designing

INTRODUCTION

Rainfall is a significant factor for the economy of agrarian countries like Pakistan where 70% population relies on agriculture (Peerzado & Magsi, 2018). It affects the crops, vegetative cover, biodiversity, ecosystem services of the region, and micro matte even the functions, structure, and living conditions of agro-ecosystems are highly affected by extreme climate changes (Adhikari et al. 2015). For decades not only the magnitude of precipitation but the seasonal distribution of rainfall is influenced and altered by climate change (Feng et al., 2013).

Loo et al., (2015) studied the impact of climate change on seasonal monsoon in Asia and variability of monsoon rainfall patterns of Southeast Asia evinced a positive correlation between global climate change and monsoon rainfall, which is also proportionately influenced by a multitude of weather systems (e.g. Arctic Oscillations (AO), Southern Oscillation (ENSO) and SST, etc.) as well as the rugged topography of Asian landmass. Schewe and Levermann (2012) also predicted a constant shift and frequent changes in Monsoonal pattern up to 70% below normal levels in the early 22nd and late 21st century. Likewise, West African Monsoon rainfall patterns indicated an increasing trend since the 1980s

(Kendon et al. 2019) this trend was caused by inclination in mean intensity of earth (Lodoun et al. 2013), rainfall extremes (Sanogo et al. 2015) and mesoscale convective systems (Taylor et al. 2017). In addition, many West African countries experience wetter season with delay in cessation of rainfall (Brandt et al. 2019). Congo Basin's precipitation seems to follow no usual trends (Zhou et al. 2014; Cook and Vizy 2019) but spring rains now arrive before time suggested by one finding (Taylor et al. 2018). In such ways rainfall variability analysis, prediction and accurate trends are utmost important for the environment, economy and development of any country for instance if changing trends of rainfall is predicted accurately can be helpful to manage and minimize the climatic disasters: flooding or droughts (Loo et al., 2015)

The Intergovernmental Panel on Climate Change (IPCC) has documented in its 6^{th} assessment report (AR6) that the hydrological cycle will be altered by the climate change hence impacting regional freshwater resources. Further extremes in regional water resources are expected: for instance wet regions are likely to be wetter and dry to be drier with few exceptions. Many Subtropical and Mediterranean climatic regions have anticipated and experiencing a decline in freshwater resources but an increment in water resources is predicted in the regions with high rainfall. However, it is worth considering that at the same time human-altered land use has the tendency to either boost or hinder the consequences of climate change on hydrological resources (IPCC; 2019 chapter 2). Therefore, this can help to generate a viable land and resource management system, which can help to reduce the competition between human and natural water system of earth. Climate change and desertification are strongly correlated on the basis of the amount of rainfall (less rainfall will ultimately result in the reduction of soil moisture hence hampering the plant growth) in a region but the literature on the interdependence of both these variables is still insignificant (IPCC; 2019 chapter 3)

According to the Intergovernmental Panel on Climate Change (IPCC)'s fifth assessment report (AR5) South Asia is expected to experience an average annual increase of 2^{o} C by the mid of 21^{st} century as compared to 20^{th} century, with a significant rise in sea level. Pakistan's Leadership for Environment and Development Organization (LEAD) published a report titled "The IPCC's Fifth Assessment Report; what's in it for South Asia?" with the collaboration of Climate Development Knowledge Network (CDKN). The purpose of the report was to highlight the significance of South Asia in AR5 and mentioned that the food security, health, and wellbeing of the people all across South Asia including Pakistan is at the verge of disaster and threats of climate change is on a continuous rise. Report further suggested urban flooding and urban heat islands (UHI) as consequences of climate change (LEAD Pakistan, 2015). In Asia, rainfall variability has been increased yearly and season wise since the last few decades. It is also observed that coastal areas and arid plains of Pakistan are having a decrease in the rainfall patterns (IPCC, 2009).

Seasonal and inter-annual rainfall variability cases of Africa, indicate severe threats to the society (Muthoni et al., 2019) because of increasing natural disasters coupled with climate change. Rainfall is weather and climatic parameter, which is highly variable in many parts of the world, both in time and space. It may cause floods or droughts, having serious impacts on agro-based communities of the world both socially and economically. In many parts of the earth, extreme weather events like droughts are resulting in the scarcity of food, loss of life, famine hydroelectric rationing, heavy flooding, and many more miseries. African continent, is in the worst situation, due to extreme variability in rainfall pattern and needs to improve its monitoring for the weather forecast of severe climate events for better planning and management (LN Njau, 2010).

Climatic change and variability have extremely negative effects on the rainfall pattern which were studied in Kenya during 1979-2017. This research revealed significant variations in the trend and magnitude of the different regions at different timescale. Rainfall decreased at the rate of 1.58 mm/year during boreal spring which is crop growing season, observations were made from 27/33 stations. On the other hand, in boreal autumn, rainfall patterns indicated the increasing trend at the rate of 1.48 mm /year from 29/33 stations, this season have only 26.7% contribution to annual rainfall. However, the rate of the annually decreasing trend was 0.93 mm/year (Mumo, L., Yu, J., & Ayugi, B., 2019).

Salma et al, 2012, concluded in their research, after examining the rainfall trends of Pakistan from 1976 to 2005 employing analysis of variance (ANOVA), that in general, there is a declining trend in rainfall but its consequences in the form of heavy floods and droughts have adverse impacts on water management, agricultural areas and human settlements. In recent years, precipitation patterns of northwest regions of Pakistan, have become more extreme, which are generally regulated by monsoon from July to September (Hartmann and Andresky, 2013).

Keeping in view, the geographical location of Pakistan is more susceptible to climatic variations as our country is agriculture-dependent for its revenue, employment of the people, and most importantly for ensuring the availability of food. As all means of irrigation, are directly associated with the activeness of water resources, anything that disrupts the means of water can cause tremendous harm to its economy. Since Pakistan is an underdeveloped country, and financially, it is not stable, therefore, it lacks technology and advanced equipment to cope with the vulnerabilities inbound with the climate crisis, for instance, insufficient monitoring system. Forecasting the imminent intensities is not available in Pakistan. (Mapping vulnerability to climate change and its repercussions on human health in Pakistan). Due to global warming and ozone depletion, heat stress has increased as results of which there is a change in the rainfall pattern and arid areas have become ultra-arid resulting in droughts. Besides knowing that rainfall is crucial to the survival of plants and vegetation, due to overuse of water, Pakistan is facing problems like waterlogging and salinity, causing a scarcity of water (Malik, Awan, & Khan, 2012).

Rainfall the changing pattern of Punjab Province was studied for 45 years (1961-2005) by analyzing precipitation data. This spatial and temporal variability was observed in major areas of Northern and Southern Punjab. Moreover, in rainfall data, an increasing trend was observed between 1976-80 but it was reduced, from 2001-05. This research illustrates the shifting of rainfall patterns towards north east and southern west of the province (Cheema& Hanif, 2013). There are many examples of rainfall variation like floods and droughts, during different years which are indicating the intense weather conditions in Pakistan (Parthasarthy and Kothwale, 1995).

Climate is the major determinant of vegetation. Plants in turn exert some degree of influence on climate. Both climate and vegetation intensely affect soil development and the animals that live in an area. Pakistan is a developing country with poor human development indicators including health. It is highly susceptible to the unpleasant effects of climate change as apparent in rising temperatures, augmented variability of monsoon, and an increase in the frequency and intensity of extreme weather events and natural disasters which produce adverse effects on the vegetation along with a severe threat to water security and the hydrological cycle of the country (Iqbal et al., 2019). As climate changes, and it becomes hotter it enhances the chances of drought, which results in loss of vegetation, and many areas are turning into deserts, as there is no way to relishing dwindling water scarcity. Furthermore, at times during the monsoon seasons when heavy showers occur, that water, do not help in crop irrigation due to poor management sources and the use of primitive and traditional farming methods. Thus, most of the water drains off into canals and river’s overflow, many times that overflows create havoc in the surroundings. The aquatic life is greatly affected due to the decrease in annual rainfall over the years. As, many fishing locations in the rivers have experienced a decline in fish catch per year owing to the less aquatic vegetation, which got affected due to high temperature and less rainfall. Climate change has direct impacts on agriculture, because the intense effects of global warming influence the crop yields and soil development.

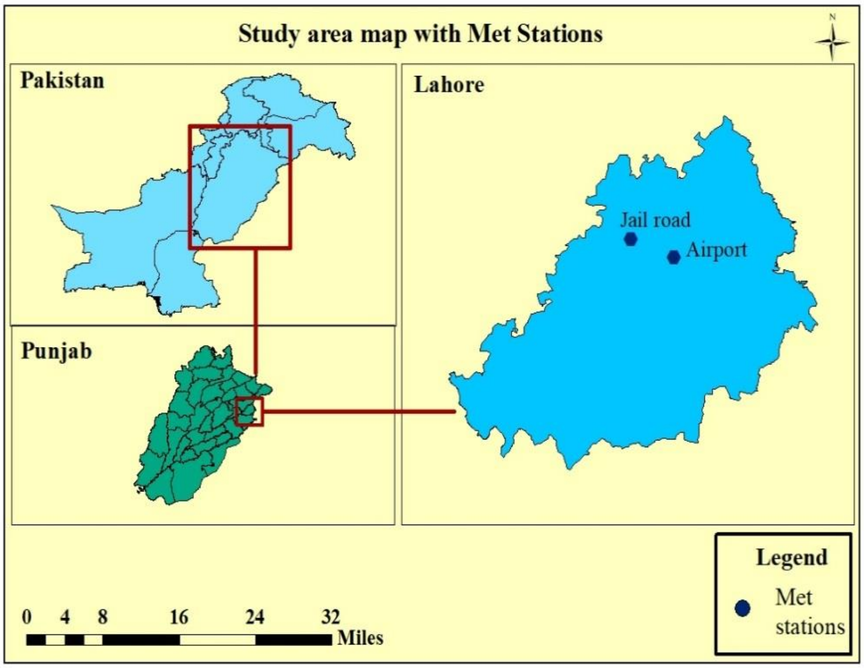
The subsequent loss of arable farming land is due to the rising temperature, which makes it harder for farmers to sow Kharif crops in the summer seasons as high-temperature results in increasing amounts of evapotranspiration in such situations farmers hesitate to grow crops and look for other options. Monsoon season brings flooding so water cannot be used efficiently by the farmers, also because the monsoon showers are variable and infrequent. Similarly, during winter, the growth of Rabi crops and other vegetation is very inadequate because of insufficient and low rainfall (SCHULDT, KONRATH, & SCHWARZ, 2011), (Farooqi, Khan, & Mir, 2005), (Ahmad, Bukhari, Naveed, & Haroon, 2018).
In Pakistan, mean annual temperature has increased by 0.35°C over the period of the last 20 years. Extremes of hot weather have increased significantly since 1960, while extremes of cold weather have decreased over the same period. Projections of future temperature, show strong warming. The annual average temperature in this region is projected to increase by 1.0°C to 2.25°C by 2020. It has been further speculated that in Lahore, the temperature is rising slowly, with a rate of 1% per 50 years. Increased usage of greenhouses gases including; CO, CH4, N2O, CFCs, water vapor, and other gases from industries are trapping the radiation and the atmosphere of Lahore is getting warmer. The change of temperature, affect the precipitation of the area. As Pakistan falls in the monsoon region, Lahore tends to receive monsoon rain towards the end of summer. However, rain is invariable and insufficient which affects crop growth and nearby industries which rely on rainwater. The depletion of the ozone layer is raising temperatures in diverse parts of the world. This consequently results in severe drought in hotter areas because of the more evaporation due to the additional heat (Muthoni et al., 2019). Similarly, an increase in precipitation results in heavy rainfall and increases the risk of floods. Lahore has experienced the number of heatwaves due to significant increasing temperatures. Thus, as global warming increases, temperature rises and the amount of precipitation falls resulting in hotter days with less rainfall (Bukhari & Sayal, 2011), (Malik, Awan, & Khan, 2012).

MATERIALS AND METHODS

Study Area

Lahore is situated in the northeastern part of Pakistan. It is the capital of Punjab province and the 2nd largest city of Pakistan in terms of population and still is expanding so rapidly in size as well as in population. Its geographical extension lies between 74° 10' to 74° 39' E longitude and 31° 15' to 31° 43' N latitude. Lahore is bounded by Wagha boarder (Indian border) on its eastern side, the northern and western side is bounded with the Sheikhupura District and it shares its southern boundary with Kasur District. It was famous as the city of gardens and colleges. Lahore is a commercial, cultural and educational hub of Pakistan. According to the UN World Urbanization Prospects, (2018) the population of Lahore is 12,642,423 which is estimated to be 17 million until 2030 (World population review). Lahore has been burdened beyond its fair share in terms of population, urbanization, and exploitation of natural resources (Rana and Bhatti, 2018). The area occupied by the city is 1772 square km with 9 administrative towns and one cantonment area (GOP, 2018). Lahore is having a hot semi-arid climate; summers are always long and terrifically hot starting from April and last until September. The temperature of Lahore is extreme in the months of May, June, and July. It can rise to 40–48 °C. Maximum temperature 48.3 °C was recorded on 30th May 1944, and again on 10th June 2007 which was 48 °C.

Monsoon season starts in the late of June and remains until mid-September. December and January are the coldest months. Lahore experienced the lowest temperature of -1.1 °C on 13th January 1967. The city receives its maximum precipitation during the monsoon season. On 13th August 2008 maximum rainfall for 24 hours was 221 millimeters (8.7in). It is noteworthy that substantial urbanization and large scale migration along with asymmetrical expansion has altered the local climate of the city adversely (Sajjad et al., 2015).



For this study, rainfall data was acquired from Pakistan Metrological Department (PMD) for the past 38 years from 1998 to 2018. In order to locate two Met stations in Lahore one at Allama Iqbal International Airport and second at Jail road was used. Mann Kendall method, linear regression techniques were exercised for the analysis. In several studies the different non-parameter of statistics for estimation are found (Hollander and Wolfe, 1973), MK Test is famous and the finest method among all of these methods (Mann, 1945, Kendall, 1975). It is favored by most of the researchers (Jain and Kumar, 2012). Variability trends of rainfall in Gandaki river basin of Nepal were determined through non-parametric Mann Kendall and Sen's method by Panthi et al., (2015), Spatio-temporal variability trends of rainfall in South Korea and rainfall trends analysis of district, Chakwal was also examined by using MK tests by Shin et al., (2019) and (Hussain et al., 2015) respectively. Likewise long term trends (from 1866-2006) in Standardized precipitation Index (SPI) and Standardized temperature Index (STI) was evaluated by applying Linear regression analysis and Mann Kendall test for northwestern Himalaya by (Bhutiyani et al., 2010). In order to study rainfall/precipitation variability in Pakistan also, MK test and Linear regression is the most preferred and ideal choice by researchers (Latif et al. 2018, Ullah et al. 2018, Iqbal and Athar 2017, & Bocchiola and Diolaiuti, 2013 etc) because it has ability to handle outliers and ideal choice by WMO (Iqbal et al., 2019).

RESULTS AND DISCUSSION

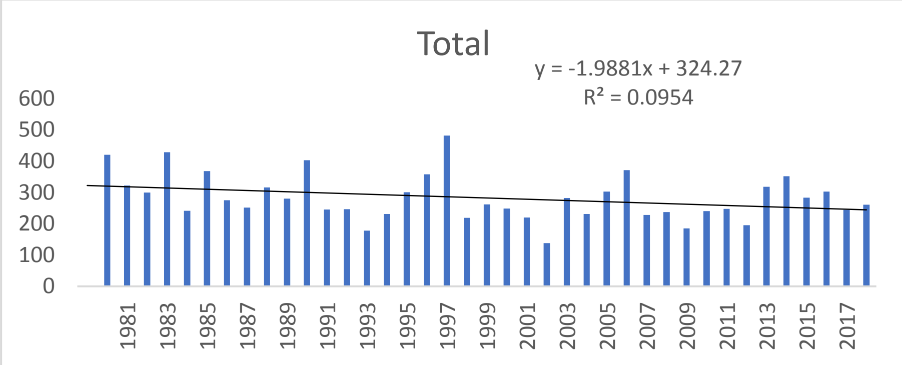
Climate change effects on the study the area were preliminarily analyzed by computing the minimum, maximum, mean, standard deviation, and coefficient of variation of annual rainfall. These statistical parameters for the time period of 38 years (1980- 2018) were studied and presented below. The rainfall statistics of Lahore City, for example, mean, Standard Deviation, coefficient of variation is described in Table 1.

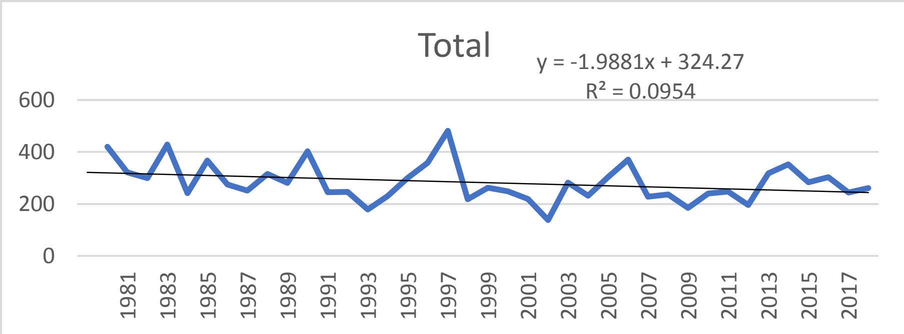
Table 1: STATION - LAHORE-PBO----RH = MONTHLY HIGHEST RAIN IN A DAY (MM)

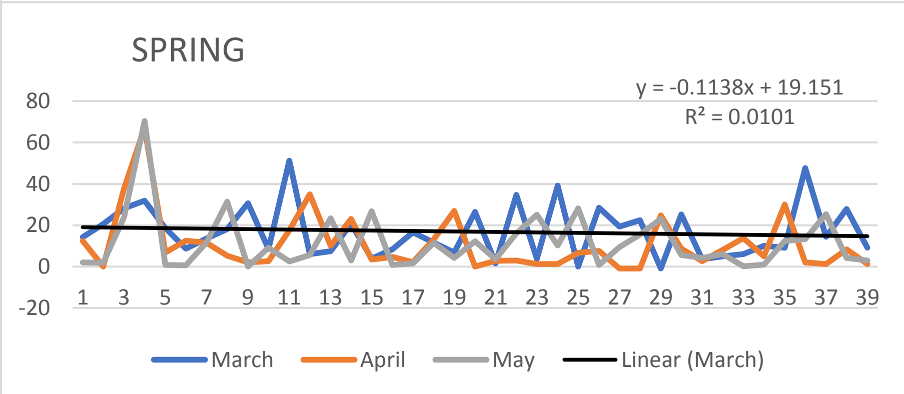
YEAR	Max	Min	Mean	standard deviation	CV (%)
1980	207.6	2	35.042	58.25112	1.6623
1981	125.5	0	26.817	39.72333	1.4813
1982	67.5	0	25.008	20.65146	0.8258
1983	93.8	0	35.733	31.98759	0.8952
1984	60.6	0	20.117	22.23404	1.1053
1985	117.4	0	30.642	38.85129	1.2679
1986	65.3	0.3	22.892	21.88472	0.956
1987	59.1	0	20.942	17.86411	0.853
1988	76.9	0	26.333	26.7098	1.0143
1989	123.1	0	23.375	34.9689	1.496
1990	83.1	1.9	33.542	32.39923	0.9659
1991	75.7	0	20.467	23.95042	1.1702
1992	69.6	5.7	20.525	19.91492	0.9703
1993	55.1	0	14.867	15.83485	1.0651
1994	49.4	0.5	19.25	18.38322	0.955
1995	76.8	0.8	25.017	27.98785	1.1188
1996	189.7	-1	29.867	53.08222	1.7773
1997	151.1	1.3	40.158	46.50651	1.1581
1998	59	-1	18.225	18.96327	1.0405
1999	88.2	-1	21.842	30.53131	1.3978
2000	110	-1	20.733	33.14698	1.5987
2001	87	-1	18.317	25.53817	1.3943
2002	29.4	0	11.475	11.73612	1.0228
2003	84.2	0	23.542	26.46533	1.1242
2004	58	0	19.275	18.94793	0.983
2005	136.8	-1	25.25	37.71654	1.4937
2006	114.6	-1	30.917	33.89765	1.0964
2007	49.4	-1	18.992	18.17103	0.9568
2008	80.7	-1	19.733	25.76891	1.3059
2009	49.4	-1	15.458	16.52763	1.0692

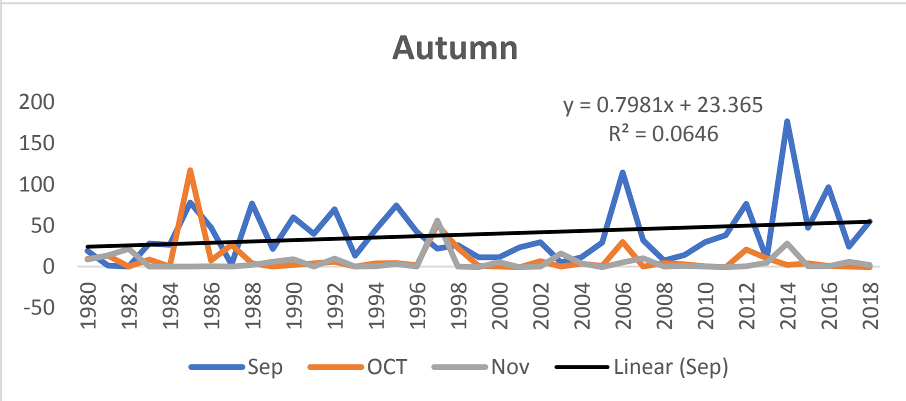
2010	122	0	20.058	36.44264	1.8168
2011	86	-1	20.667	27.96001	1.3529
2012	76.4	0.2	16.308	20.34804	1.2477
2013	113.1	1	26.517	35.7614	1.3486
2014	177	0	29.35	47.99624	1.6353
2015	67	-1	23.608	22.37545	0.9478
2016	96.6	0	25.225	30.88316	1.2243
2017	54.4	0	20.342	17.39313	0.855
2018	139	-1	21.775	40.2907	1.8503

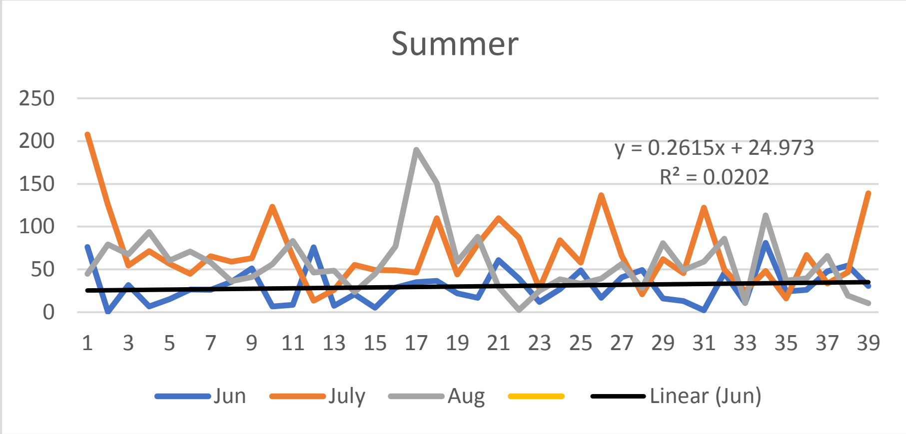
Annual and seasonal trends and variability of rainfall Computed generated tables showed the average range of monthly rainfall is **11.475 mm to 40.15833 mm** from 1980 to 2018 and coefficient of variation (CV %) ranging from **0.825783 % to 1.850319 %.** The highest value of the coefficient of variation was found for the year 2018 that is, **1.8503**. Fig shows the annual changes from **1980 to 2018.** Figure 2 is showing the general linear trend of annual rainfall in the studied region, where the linear regression equation is showing Linear slope value **(*a* = 0.0055)** and the R^2 value comes about **0.0477**. R^2 which is the coefficient of determination value explains that 4% of the variability in the annual rainfall is explained by this linear regression model. The trend for rainfall in autumn months (September to November) showing an upward trend from starting to end the season **(*a* = 0.7981) and** R^2 value comes about **0.0646.** Similarly, the trend line showing a downward tendency from 1980 to 2018 during spring and summer months whereas almost unchanged trend was observed in winter months. The value of $\boldsymbol{R^2}$ **0.0954** shows unpredictable trends i.e. rainfall in the previous year could not be able to judge the expected rainfall in subsequent year similar unusual trends were found in a study of Congo Basin’s precipitation by Zhou et al. (2014); Cook and Vizy (2019). Though a longitudinal data of many years could be able to predict an overall situation. Data shows the highest rainfall in 1996 and the lowest in the year 2002. Description of data showed negative skewness of data as an overall beta value remained -4.13mm/year similarly season-wise, negative skewness was also observed in all of summer, spring, and winter seasons while a positive skewness could be observed in autumn only as shown in the figure below.

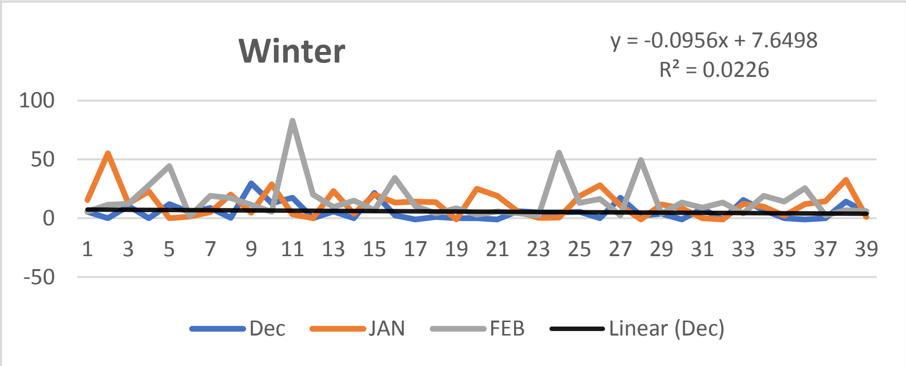

Total
y = -1.9881x + 324.27
R² = 0.0954
600
500
400
300
200
100
0
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017


Total
y = -1.9881x + 324.27
R² = 0.0954
600
400
200
0
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017


SPRING
y = -0.1138x + 19.151
R² = 0.0101
80
60
40
20
0
-20
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39
March
April
May
Linear (March)


Autumn
y = 0.7981x + 23.365
R² = 0.0646
200
150
100
50
0
-50
1980 1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016 2018
Sep
OCT
Nov
Linear (Sep)


Summer
250
200
150
100
50
0
y = 0.2615x + 24.973
R² = 0.0202
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39
Jun
July
Aug
Linear (Jun)


Winter
y = -0.0956x + 7.6498
R² = 0.0226
100
50
0
-50
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39
Dec
JAN
FEB
Linear (Dec)

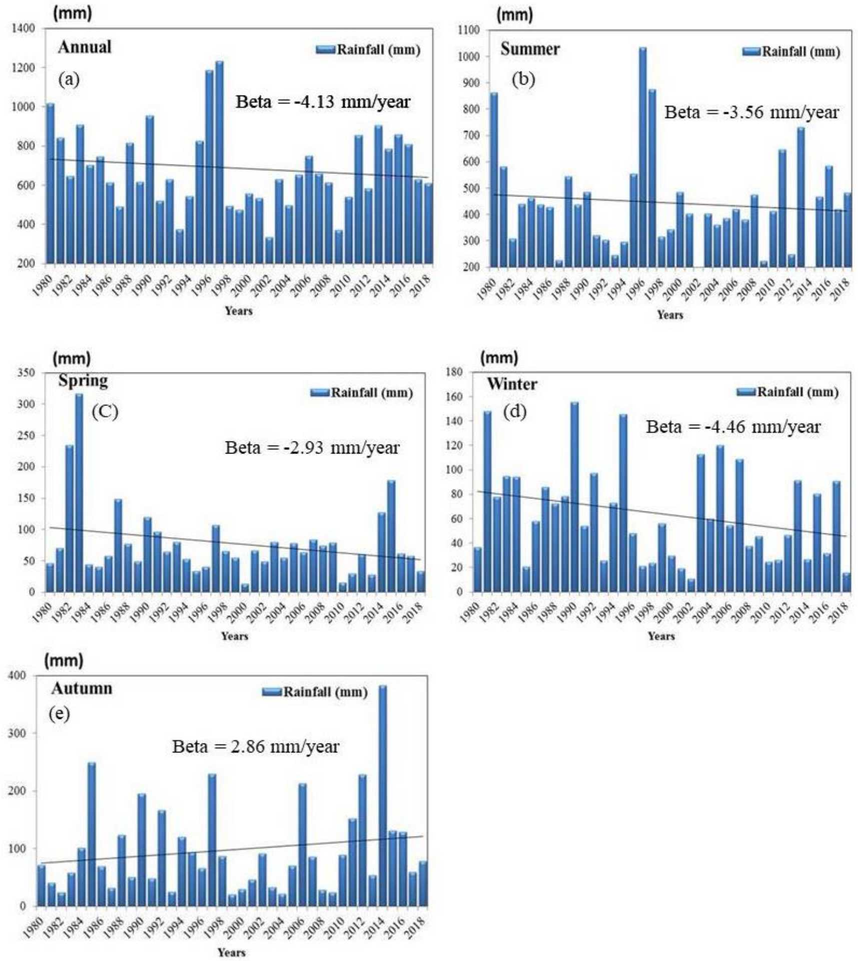


Figure 2. Annual and seasonal trends of rainfall over the Lahore, Pakistan.

CONCLUSION

This paper analyzed, the seasonal and annual, rainfall variability patterns of Lahore and this analysis has shown a consistent and significant decrease in the rainfall patterns of spring, summer and winter seasons whereas, simultaneously consistent increasing trends have been found in the rainfall data of the autumn season. Likewise, downward trends (decreasing at 1.18mm/year) in rainfall were examined by Salma et al., (2012) for Pakistan. Rainfall data from 37 climatic stations in Pakistan was gathered for the tenure 1976-2005 and applied ANOVA and Dennett T3 test. Ranade et al, (2008) had found the similar declining trends of monsoon rainfall in the main eastern Indo Gangatic plain and (Hussain et al., 2015) also found nearly similar increasing trends of rainfall in Jan, Feb, May, June, July, August and September while decreasing trends in the rest of the months, when they studied the variability trends of rainfall in district Chakwal, Northern Punjab.This declining trend in rainfall data has been supported by the IPCC, 2001, report. Pakistan has observed severe drought from 1998 to 2001, specifically, in the central and southern parts of the country, floods, and droughts are linked with extreme climate changes: extreme rainfall and low precipitation (with high temperatures) respectively (Trenberth, 2011).This research has concluded that variability in the seasonal and annual rainfall patterns is the consequences of climate change which is not only responsible for the decline in rainfall but deteriorating the urban resilience Lloret et al., (2012) also warned that if we aim to enhance the resilience of urban ecosystems, the shift of vegetation and agriculture under extreme climates need to be understood and stabilizing techniques should be formulated accordingly. This decreasing rainfall data, is a baseline data, to support the severe effects of climate change (food security, health issues (Costello et al., 2009), reduction in agricultural growth (Thornton et al., 2014), due to unplanned urbanization and the removal of vegetative cover. Therefore, this the research will be useful for future planning of the urban centers, to mitigate, climate change impacts by the adaptation of Nature-Based Solutions. NBS in the form of greens and blues are the sources of oxygen and sinkholes for the CO^2. So keeping in view the benefits of ecosystem services, plantation of vegetation, according to the area like shrubs, plants and trees and making some ponds and artificial lakes can minimize the intense impacts of climate change by evapotranspiration. The execution of NBS is the need of the hour which will enhance the resilience of Lahore. Moreover, future predictions by keeping in mind the past and present variability trends would be helpful to minimize the catastrophe of flooding or drought which is also supported by Wang B et al. (2019) as apprehension of previous rainfall trends under external forces may elucidate the future trends of climate change.

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