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Quantifying the Trend Patterns of Rainfall over Baluchistan, Pakistan

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ABSTRACT
There is significant variability in the occurrence of rainfall in different parts of Baluchistan province. In this study, the climatic conditions were analyzed using observed rainfall time series data ranging from 1975-2016 for nine metrological stations in Baluchistan. Mann-Kendal Trend test and Sen's slope methods were used to find trends and per-year change in the rainfall time series of the metrological stations. The methods show that the stations have negative trend and slope values except for the stations of Kallat, Nokkundi, and Sibbi. Furthermore, the lag-1 autocorrelation method was used to check the serial dependence between the current and lag values of the time series. In the results, the negative values indicate that there is a decreasing tendency of rainfall while the positive values mean that rainfall is increasing for the three stations. While only Ormara station has a significant decreasing trend using Z-test at a 5% level of significance. Similarly, the results show positive lag-1 autocorrelation except for only the Jiwani station. It means that the current and lag values move in the same direction i.e., decreasing tendency in the overall pattern of rainfall in the area. Hence, it is concluded that Baluchistan is facing a decrease in rainfall amount and the government should make proper arrangements of water resources in the region.

INTRODUCTION

In this era of changing climate, the researchers strongly focused on studying the effects of air temperature and rainfall all over the world (Karmeshu, 2012). Climate change is a global issue however its effects vary from one region to another region (Trajkovic & Kolakovic, 2009). Hence, studying changes in climatic variables signifies the task for the detection of climate change. Climate change has a strong influence on ecosystems, regional economy, and social behavior which affects the hydrological pattern that may lead to water scarcity, and increasing frequency of droughts and floods (Khan et al., 2022). Climate change also has severe impacts on the disorder of monsoon rainfall spells, distribution and frequency of rainfall, melting of glaciers, and occurrence of droughts and floods (Ullah et al., 2022). Global warming brought strong changes in the distribution of rainfall occurring at global and local scales (Goswami et al., 2006). A better understanding of climate change may lessen the unwanted effects of climatic extremes like droughts, floods, and heat waves which can further help in food security in a region (Khan et al., 2022).

A series is termed a time series when data points are observed in chronological order with a regular interval of time. Time series data is important when studying changes over consistent intervals of time to attempt future forecasting using past data (Piyoosh & Ghosh, 2017). The spatiotemporal variability in the distribution of rainfall influences groundwater, runoff, soil moisture, the occurrence of drought and flood, and crop production (Kumar et al. 2010). This spatiotemporal variability of rainfall might be settled using trend analysis for a longer series of rainfall data observed over time. The trend analysis for longer periods is important to understand the temporal variation in rainfall series over time (Hussain et al., 2022). Several statistical tests are carried out to study trends and assumptions like normality, identical distribution of the data points, and independence (Piyoosh & Ghosh, 2017). Due to lack of independence or non-randomness, autocorrelation occurs in time series data (Kundzewicz and Robson, 2004) while non-stationarity is mostly because of climate change (Madsen et al., 2014).

Pakistan has been strongly affected by climate change in the form of greater frequency of droughts and floods which are directly related to rainfall in the country (Ullah et al., 2022). The drought from 1998 to 2002 is one of the worst in Pakistan. In addition, significant changes occurred in the shape of sudden rainfalls, lack of water sources, droughts, seasonal changes, and many more in the country (Ullah et al., 2021). The country has major climatic variability in different regions of the country (Ullah et al., 2019; 2020). The province of Baluchistan is a highly affected region that received the least amount of rainfall in the past (Ullah and Akbar, 2020; 2021; 2022). On the other hand, global warming and climate change brought massive changes in spells of monsoon rainfall that caused heavy floods in Baluchistan, Sindh, and other parts of the country in the year 2022. The damages of the megaflood of 2022 included thousands of people and animals died, crops and infrastructure being destroyed, and millions of people were migrated. Hussain et al., (2022) used the Mann–Kendall test and Sen's slope estimator for seasonal and annual precipitation trend analysis in Pakistan.

Analysis of long-term rainfall data can help to understand better trends in rainfall data and further help in future planning in the area under study. Awareness of trends is important for risk-free decisions where several research studies examined the rainfall trends in semi-arid and arid regions (Ahmadi et al. 2018; Phuong et al. 2020; Meshram et al. 2020; Mallick et al. 2021; Xu et al. 2021). Baluchistan mostly contains semi-arid to hyper-arid areas. However, there is no such studies in literature to analyze the trend patterns of rainfall that cause drought and floods in Baluchistan province. Therefore, rainfall data of long series are selected to find the patterns of climate in the region and fill the research gap in the study area. There are two major objectives of the study. Firstly, to find the trends using statistical methods in the time series of rainfall. Secondly, to study the serial dependence within the past and current values of the time series of rainfall. These results will contribute in the better planning and climate risk assessment of the region. The results will also be helpful for water resources management, agriculture planning, and drinking water arrangement in the area.

Study area and data

Baluchistan has a diversified climate which contains mostly the arid parts of Pakistan ranging approximately from the latitudes of $25^{\circ}0'$ to $32^{\circ}0'$ N and the longitudes of $61°0'$ to $71^{\circ}30'$ E. This province of Pakistan is physically a widespread land divided into high mountains and wide deserts. The structure of the area shows unusual variability which affects the climate from humid to hyper-arid conditions. The study area has high diversity w.r.t elevation and is presented in Figure 1. Rainfall data were acquired for nine metrological stations in different parts of Baluchistan from the Pakistan Meteorological Department (PMD) ranging from 1975-2016. The coordinates and elevation of stations along with mean annual rainfall and its 95% confidence interval, are given in Table 1. Missing observations within the rainfall series were estimated through multiple regression methods like in Ullah and Akbar, (2021).

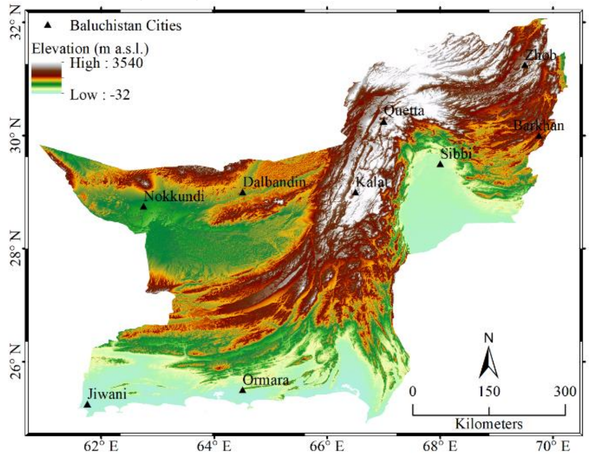


Figure 1: Geographical Location of the meteorological stations of the study area.

Methodology of the Study

The following methods of trend are used in the analysis of rainfall time series data. The details of each method are mentioned in the subsequent sections:

Mann-Kendall Trend Test

The Mann-Kendall Trend (MKT) test statistic is used to find the decreasing or increasing tendency within the time series data. It is defined by Mann (1945) and Kendall (1975) and calculated using Eq. (1).

$$\text{MKT} = \sum_{r=1}^{m-1} \sum_{s=r+1}^{m} sign(y_s - y_r) \quad (1)$$

where m represents the total number of units in a time series, y_r, and y_s are the two consecutive data values (s > r), respectively and $sign(y_s - y_r)$ is an indicator function defined as below:

$$sign(y_s - y_r) = \begin{cases} +1 & if\ y_s - y_r > 0 \\ 0 & if\ y_s - y_r = 0 \\ -1 & if\ y_s - y_r < 0 \end{cases} \quad (2)$$

The MKT has the following statistical properties.

$$E(MKT) = 0 \quad (3)$$

and variance is calculated as follows:

$$\text{Var(MKT)} = \frac{m(m-1)(2m+5) - \sum_{i=1}^{n} t_i(t_i-1)(2t_i+5)}{18} \quad (4)$$

where n represent the tied groups which is a set of the same values within time series and represents the number of ties of extent i. When the sample size is greater than 10 i.e., m>10, then MKT follows a standard normal distribution Z test statistic (Gocic & Trajkovic, 2013; Ahmadi et al. 2018) and is calculated using the following equation:

$$Z = \begin{cases} \frac{\text{MKT}-1}{\sqrt{\text{Var(MKT)}}}, & if\ MKT > 0 \\ 0, & if\ MKT = 0 \\ \frac{\text{MKT}+1}{\sqrt{\text{Var(MKT)}}}, & if\ MKT < 0 \end{cases} \quad (5)$$

If the value of Z is positive, it shows increasing trends and if the value of Z is negative, it shows decreasing trends. Trends can be tested considering the null hypothesis that there are no significant trends in time series at any level of significance i.e., α. When $|Z| \geq Z_{1-\alpha/2}$, it shows that the hypothesis of no trend is rejected which means existing significant trends and vice versa.

Sen's Slope Estimator

A non-parametric method called Sen's slope (β_{Med}) developed by Sen (1968) is used for calculating the slope of the trend of M pairs in a time series data used by Hirsch et al. (1982) and given as follows:

$$\beta_{Med} = Median\left(\frac{y_s - y_r}{s - r}\right), for\ all\ s > r \quad (6)$$

Where y_r and y_s are the pairs of data of times s and r ($s > r$), respectively. The sign of β_{Med} reveals the trend in data and its value shows the strength of increase or decrease in the trend. The positive value of β_{Med} show an increasing trend and vice versa. To check the slope of a trend whether statistically deviate from zero or not, the confidence interval of β_{Med} should be used at a specific α level of significance (Gocic & Trajkovic, 2013; Gilbert, 1987) as follows:

$$CI_\alpha = Z_{1-\alpha/2} * \sqrt{\text{Var(MKT)}} \quad (7)$$

This confidence interval follows a standard normal distribution in the form of $Z_{1-\alpha/2}$ (De Silva et al., 2015). The lower limit of the confidence interval of slope (β_L) and upper limit (β_U), are the largest of L^{th} and $(U+1)^{th}$ of the M arrayed estimated slopes of the data where $L = \frac{M - CI_\alpha}{2}$ and $U = \frac{M + CI_\alpha}{2}$ (Gilbert, 1987). The slope statistically deviates from zero if β_L and β_U have the same signs.

Autocorrelation

Time series data are records of interests collected over successive intervals in a chronological order that often shows serial dependence. Serial dependence arises due to statistical dependence of a value at one time over the other value at another time which violates the assumption of statistical independence within data. Autocorrelation or serial correlation measures the degree of relationship between the current values of a time series variable with any past or lagged values over successive intervals of time (Tabari et al., 2011). In other words, it is the correlation between the observations of a dataset at different times with its own lagged values. Just like correlation, autocorrelation can either be positive or negative and lies between -1 and +1. The autocorrelation is calculated using the following equation:

Consider $y_1, y_2, y_3, \ldots, y_m$ are m observations of a time series, then the statistical dependence using lag-k autocorrelation or serial correlation coefficient is computed as by Kendall and Stuart (1968) and Salas et al., (1980):

$$r_k = \frac{\frac{1}{m-k}\sum_{i=1}^{m-k}(y_i - \bar{y})(y_{i+k} - \bar{y})}{\frac{1}{m}\sum_{i=1}^{m}(y_i - \bar{y})^2} \quad (8)$$

The approximate confidence interval of 100(1−α) % for lag-1 autocorrelation is calculated to check the reliability of its estimate. It means that in the repeated sampling procedure, 100(1−α) % of the confidence intervals contain the value of the true unknown population parameter (O'Brien & Yi, 2016). It is calculated using the following equation:

$$\left\{\hat{\rho}_1 - z_{1-\alpha/2}\hat{\sigma}_{\hat{\rho}_1},\ \hat{\rho}_1 + z_{1-\alpha/2}\hat{\sigma}_{\hat{\rho}_1}\right\} \quad (9)$$

Where $\hat{\rho}_1$ is the estimate and $\hat{\sigma}_{\hat{\rho}_1}$ is the standard error of lag-1 autocorrelation, given by Box and Jenkins, (1976) as follows:

$$\hat{\sigma}_{\hat{\rho}_1} = \sqrt{\frac{1 - \hat{\rho}_1^2}{m}} \quad (10)$$

The lag-1 autocorrelation is tested for statistical significance. Similarly, the null hypothesis of zero lag-1 autocorrelation is tested for possible rejection using the rank von Neuman (RVN) ratio test (von Neumann et al., 1941) given as follows:

$$V_R = \frac{\sum_{i=1}^{m-1}(R_i - R_{i+1})^2}{\sum_{i=1}^{m}(R_i - \bar{R})^2} \quad (11)$$

Where R_i indicates the rank of i^{th} observation and $\bar{R}$ indicates the mean of ranks (Bartels, 1982).

An autocorrelation is statistically significant at a specific lag if the p-value is less than .05 and the null hypothesis of zero lag-1 autocorrelation is rejected and accepted if the p-value is greater than or equal to 0.05. Similarly, small values of RVN show likely positive autocorrelation while large values show negative autocorrelation.

Results and Discussion

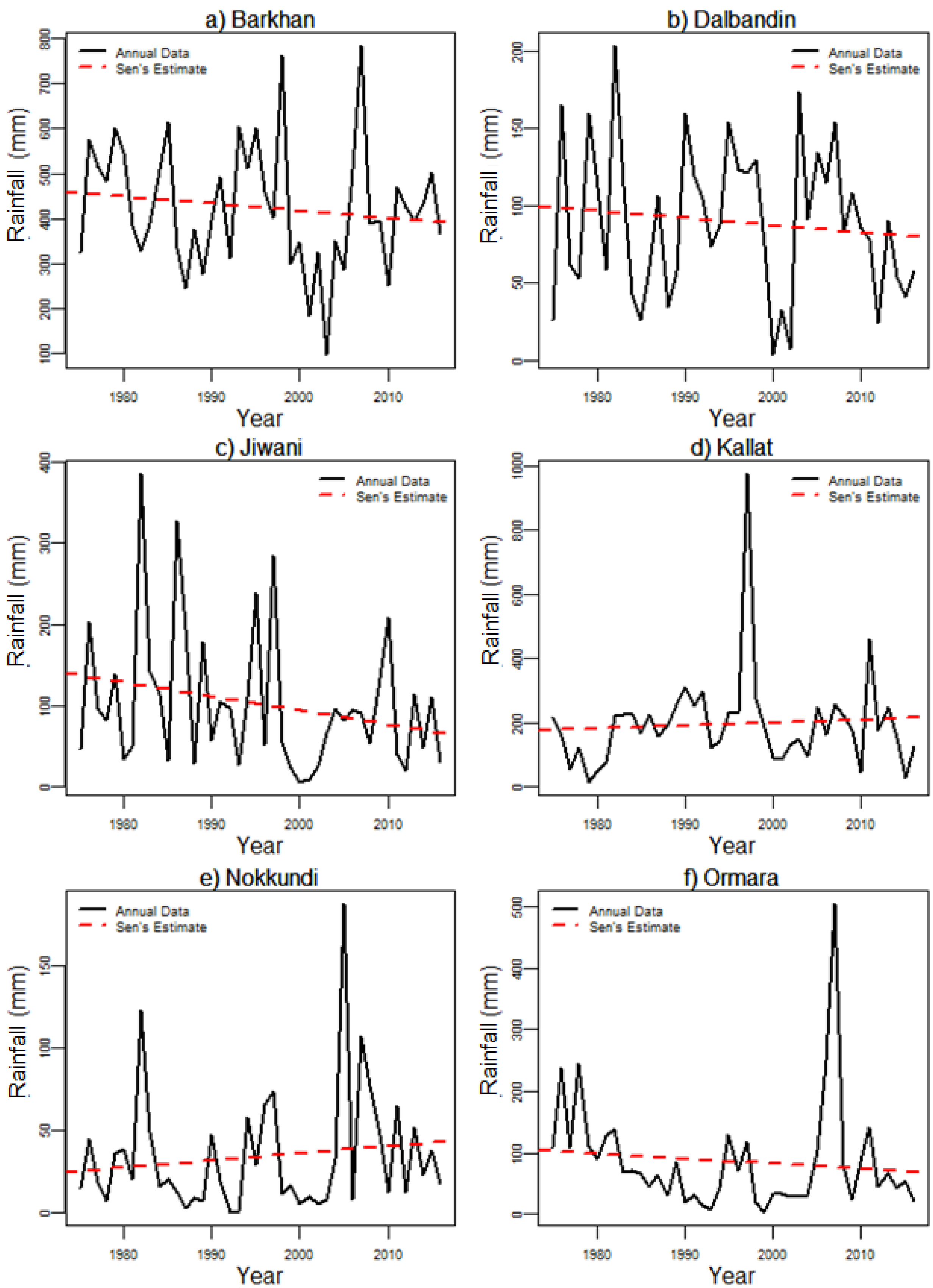
Rainfall is one of the main factors affecting climate as well as human beings of a region. In this study, rainfall time series data from nine metrological stations were selected from the Baluchistan province of Pakistan. The average annual rainfall was calculated for the stations which lies approximately from 153 to 526 mm given in Table 1. It shows significant variation within the rainfall records in Baluchistan. A point estimate does not explain the scenario more accurately, whereas an interval estimate is a better way for a more reliable estimate to show possibly a more accurate estimate of the precipitation (DiCiccio & Efron, 1996; Hazra, 2017). Barkhan station has the narrowest confidence interval of rainfall among the selected stations which shows lesser variability among the observed rainfall records. Similarly, Quetta station has the widest interval among the stations with possibly more variability among the observed rainfall records for the same sample sizes. This indicates that Barkhan station has more consistent estimates due to lesser variability. The narrower the confidence interval of an estimate, the more reliable the estimation will be (Hazra, 2017). The structure of the area shows large variation over short distances w.r.t elevation, shown in Figure 1. This unusual variability in geography strongly affects the climate of the province from semi-arid to arid, and to hyper-arid (Ahmed et al., 2016). The province has low and unequally distributed rainfall where the amount of rainfall differs over space and time in various seasons (Ahmed et al., 2014). Elevation also plays a significant role in the rainfall and climate of the stations (Da Silva et al., 2015)

Table 1: Site Characteristics and Climate data information of the Meteorological Stations.

S#	Station	Site Characteristics					
		Longitude	Latitude	Elevation	MAR	MAR(LCL)	MAR(UCL)
1	Barkhan	69°45′	30°00′	1097	153.45	107.04	199.86
2	Dalbandin	64°30′	29°00′	848	228.07	159.09	297.05
3	Jiwani	61°45′	25°15′	56	162.29	113.21	211.37
4	Kalat	66°33′	29°00′	2015	271.31	189.26	353.36
5	Nokkundi	62°45′	28°45′	682	267.33	186.48	348.18
6	Ormara	64°30′	25°30′	7	314.55	219.42	409.68
7	Quetta	67°00′	30°15′	1600	526.46	367.24	685.69
8	Sibbi	68°00′	29°30′	133	495.98	345.98	645.99
9	Zhob	69°30′	31°15′	1405	412.70	287.89	537.52

Note: MAR stands for Mean Annual Rainfall, LCL and UCL stand for Lower and Upper 95% Confidence Limits of observed rainfall records.

Safdar et al. (2019) explored the shifts in Monsoon rainfall patterns using the MKT test and concluded a decreasing tendency in the Monsoon rainfall regions in Pakistan. Similarly, Alam et al., (2021) used the MKT test for trend analysis of the precipitation series of three stations which showed negative trends in the Khyber Pakhtunkhwa province of Pakistan. Hence, the MKT test and Sen's method were used to find the increasing or decreasing tendency and slope of rainfall time series. According to the results in Table 2, the rainfall in selected stations has negative trends and Sen's slope values except for Kallat, Nokkundi, and Sibbi. The negative signs of the trend and slope estimator signify a possible decrease in the occurrence of rainfall in the future (Da Silva et al., 2015). Both measures show different amounts of increase or decrease for the series. For example, Barkhan station has an annual decreasing trend of 77mm with a downward slope of -1.579mm per year whereas the trend is not statistically significant. The same has been graphed using the historigram in Figure 2, to practically check the trend patterns which confirms the results of the MKT test and Sen's slope estimator. Hence, it shows that rainfall decreases in most of the parts of Baluchistan province. Both the statistical tests have similarities in results comparing their signs and real purpose as described in studies like Tabari and Hosseinzadeh Talaee (2011) and Gocic & Trajkovic (2013). For further analysis, the statistical significance of MKT was tested through standard normal distribution i.e., Z-test at 5% level significance where only Ormara station show significant trends. It shows that rainfall has significant chances of decreasing trends in Ormara while the remaining stations have no statistically significant variability in rainfall series.


a) Barkhan
b) Dalbandin
c) Jiwani
d) Kallat
e) Nokkundi
f) Ormara
Annual Data
Sen's Estimate
Rainfall (mm)
Year
1980
1990
2000
2010

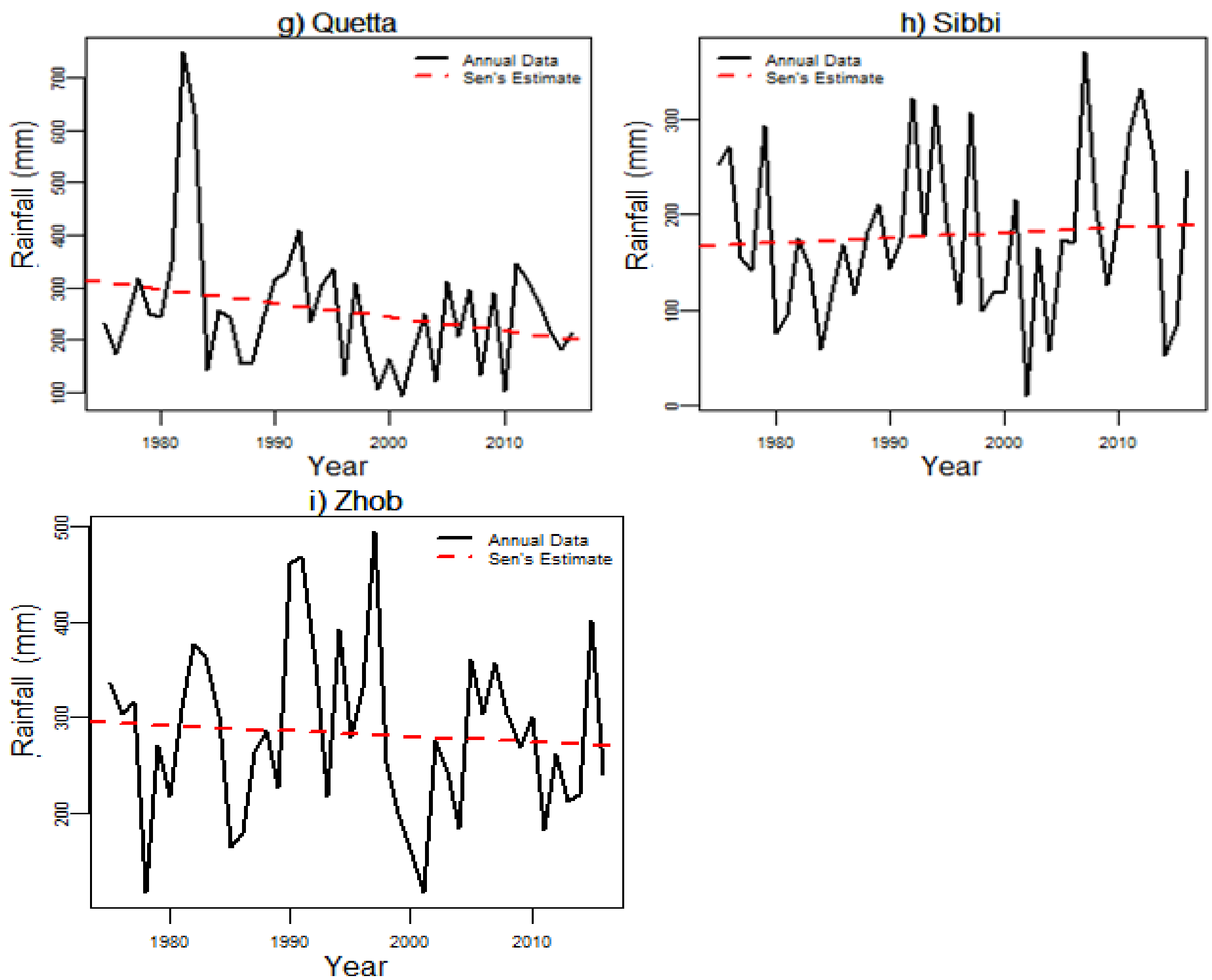


Figure 2: Graph of rainfall time series data for nine metrological stations.

Table 2: Results of Sen's estimator, MKT test, and Z-test for annual rainfall series over the period 1975–2016

S#	Station	Rainfall Time Series		
		Sen's Slope Estimator	MKT	Z-Test
1	Barkhan	-1.579	-77.0	-0.824
2	Dalbandn	-0.547	-60.0	-0.639
3	Jiwani	-0.970	-129.0	-1.387
4	Kalat	0.595	47.0	0.499
5	Nokkundi	0.183	67.0	0.715
6	Ormara	-1.400	-183.0	-1.972*
7	Quetta	-1.253	-105.0	-1.127
8	Sibbi	0.940	57.0	0.607
9	Zoub	-0.971	-81.0	-0.867

MKT: Mann-Kendall Trend test statistic
Z-Test: Mann-Kendall Z-test.
* indicates statistically significant trends at a 5% level of significance.

MKT test and Sen's slope estimator were performed to show the tendency of negative or positive trends and slope within the rainfall time series of the metrological stations. The existence of a trend and slope indicates that there is some kind of dependence on the values of a variable (Gao et al., 2020). Another important property is serial dependence which measures the correlation between the current and lag values of a time series variable. Hence, lag-1 autocorrelation is measured to check the dependence between the time series data which is simpler and used to check serial dependence (Sharma and Singh, 2017). The results are shown in Figure 3 where the stations have a positive correlation with a maximum value of Ormara followed by Quetta while only Jiwani station has a negative value. This means that the stations' current and lag rainfall values move in the same direction i.e., decreasing trend while for Jiwani this movement is in the opposite direction. The numerical values and 95% confidence intervals for lag-1 autocorrelations are calculated and tested for statistical significance using RVN statistics, given in Table 3. The results show that Kallat and Ormara stations have statistically significant lag-1 autocorrelations at a 5% level of significance. The stations with low or insignificant autocorrelations are expected not to influence the outcomes of the MKT test in a trend analysis (Gao et al., 2020)

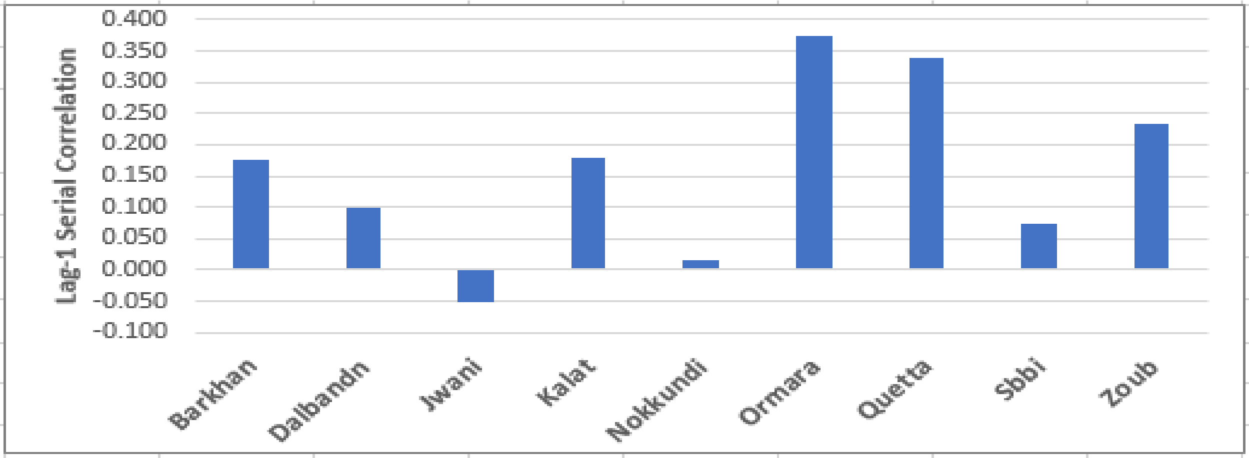


Figure 3: Graph of lag-1 Autocorrelation values for the selected stations

Table 3: 95% CI values and RVN statistics with p-values for lag 1 Autocorrelation

S#	Stations	Lag 1	LCL	UCL	RVN	p-value
1	Barkhan	0.1770	-0.1205	0.4748	1.4645	0.0772
2	Dalbandin	0.0980	-0.2029	0.3990	1.6042	0.1953
3	Jiwani	-0.0510	-0.3531	0.2509	1.9353	0.8340
4	Kallat	0.1780	-0.1197	0.4755	1.1709	0.0049*
5	Nokkundi	0.0170	-0.2858	0.3190	1.6282	0.2243
6	Ormara	0.3730	0.0928	0.6539	0.9319	0.0002*
7	Quetta	0.3390	0.0547	0.6237	1.7548	0.4252
8	Sibbi	0.0730	-0.2291	0.3742	1.7906	0.4963
9	Zhob	0.2350	-0.0592	0.5287	1.5078	0.1053

RVN stands for Rank von Neumann Test while *LCL and UCL stand for Lower and Upper 95% Confidence Limits of* Lag-1 Autocorrelation, respectively.

* indicates statistically significant lag-1 Autocorrelation at a 5% level of significance.

CONCLUSION

Baluchistan province is greatly suffering from the consequences of climate change which received frequent droughts and floods shortly. This study is conducted to investigate the trends in the occurrence of rainfall in nine metrological stations from different parts of the Baluchistan province. For this purpose, the MKT test and Sen's estimator methods are used for the rainfall time series data. Both the methods along with the graph showed that all the stations except Kallat, Nokkundi, and Sibbi have negative trends in the series of rainfall. The trend significance is tested using standard normal distribution Z-test which showed that only Ormara station has significant trends at a 5% level of significance. To check the randomness or independence properties of statistical data, lag-1 autocorrelation is used over current and lag values of rainfall time series data. The results of lag-1 autocorrelation gave positive values except for Jiwani stations which means that current and previous values move in the same direction. We can conclude from all these results that there is a decline in the overall rainfall trend in most parts of Baluchistan province. This severe climatic condition needs special attention for future planning of water arrangements in the region. There are many factors such as wind speed, humidity, land-use changes, or industrialization, that effecting climate change but this study is limited only to rainfall data of the selected stations of Baluchistan province. Also these results can only be used for planning in the study area. The government as well as the public needs to focus on the construction of dams and plantation of evergreen trees in the province. Another crucial climate variable related to climate change is temperature which will be discussed in future research work.

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