EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2024, 25(10), 347–358
https://doi.org/10.12912/27197050/191954
ISSN 2299–8993, License CC-BY 4.0

Received: 2024.07.28
Accepted: 2024.08.15
Published: 2024.09.01

Trends Characterization for Rainfall Time Series in Middle Euphrates Region, Iraq

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ABSTRACT

This study presents a comprehensive analysis of rainfall trends in the middle Euphrates region of Iraq, extending from 1980 to 2018, including wide region between the stations of Samawa, Al-Najaf, Karbala, Hilla, and Diwaniya. The research aims to fill a critical gap in the understanding of regional hydrological patterns and provide essential insights for sustainable water resource management. Using advanced statistical methods, such as the Mann-Kendall test and Sen's slope estimator, along with autocorrelation and cross-correlation analyses, we detected slight trends that were not previously reported. Principally, the Mann-Kendall test indicated no significant overall trends, while Sen's slope estimator identified slight positive and negative trends at specific stations, highlighting local climatic variations. the findings reveal that all stations, except Samawa, indicated stationarity and homogeneity, with a particularly strong positive mutual correlation between Karbala and Hilla stations (0.7693 at lag 0). This research contributes new insights into rainfall variability in the Middle Euphrates, in Iraq, which presents significant data to improve water resource management strategies and inform future hydrological studies in the region.

Keywords: autocorrelation analysis, Mann–Kendall test, Middle Euphrates in Iraq, rainfall trends, Sen's slope estimator, and water resources management.

INTRODUCTION

Rainfall is an essential climatic variable that rakes a significant role in the management and planning of water resources (Amer et al., 2021; Chen and Rao, 2002). Recently, there has been rising interest in studying the trends and variability of rainfall patterns, particularly in regions subject to climate change. The middle Euphrates region of Iraq, which covers five governorates, is one such area that has subjected to important changes in rainfall patterns.

Although previous investigations have studied the statistical analysis of rainfall time series in Iraq (FAO, 2003; Dawood, 2009; Osman et al., 2014; and Jaafar and Al-Lami, 2019) the literature lacks a comprehensive analysis of the trends and features of rainfall in the middle Euphrates region. For example from the Arabgeographic region and regional countries, a recent study by Amer et al., (2021) examined the variability of climate and the trends of rainfall and temperature in Algeria, but did not address the particular features of the middle Euphrates region in Iraq. Likewise, a study by Khan et al., (2023) focused on distribution of the rainfall in Pakistan, but did not provide insights into the rainfall trends and patterns in the middle Euphrates region of Iraq. In addition, the study by Alam et al., (2021) investigated rainfall trend analysis and weather forecast accuracy in selected parts of Khyber Pakhtunkhwa, but the findings may not be directly applicable to the middle Euphrates region due to differences in geographical and climatic conditions.

The time series analysis has a significant scope in hydrological modeling, researchers investigated the fundamental assumptions, and many studies have focused on the statistical tests that are mostly used to measure stationary, homogeneity, trends, no trends, and non-periodic statistics for time series

(Gao et al., 2020). Baahmed et al., (2015) analyzed the trends and change points for the hydro-climatic time series, as well, to express the role of climate on the observed trends for the time series of the annual flow in the Macta basin, in Algeria.

The study area of this research has not been the focus of a similar in-depth analysis for the same period 1980–2018. The expected findings from the research will provide enhanced insight into the climatic impacts on the region, and the changing patterns and trends of rainfall. This research addresses the critical issue of understanding rainfall variability in the region. Hence, to determine these research gaps, a comprehensive statistical analysis of rainfall time series in the middle Euphrates region of Iraq will be conducted in the present research. The research will inspect the stationary, homogeneity, and trends of rainfall time series, as well as the cross-correlation between meteorological stations in the study area. The results of this research will contribute to understanding the rainfall patterns and trends in the middle Euphrates region and probably update the management of water resources and planning policies in the area.

STUDY AREA AND RESEARCH METHODOLOGY

Study area

The Middle Euphrates region was selected as a study area that is located in the central part of Iraq, and covers five governorates, which are Babylon, Al-Najaf, Karbala, Al-Diwaniya, and Al-Muthanna as shown in Figure 1. The study region area is about 98870 square kilometer, which constitutes about 22.7% of the total area of Iraq. It is distributed between two natural regions, the western plateau and the alluvial plain in semiarid regions.

The climate of the study area varies considerably from dry, hot to extremely hot during summer, cold and wet during winter. The middle Euphrates region has a continental, subtropical semi-arid climate, with average temperatures greater than 32 °C in summer and less than 10 °C in winter, as well as significant daily variations. The rainfall season starts in October and ends in April.

According to FAO, (2003), the middle Euphrates region lies within the agro-ecological zone and stated that the irrigated area which extends between the Tigris and Euphrates rivers from the north of Baghdad to Basra in the south. Serious hazards for this area are poor drainage and salinity. The geographic information for the five meteorological stations that were located in different locations in the study area is given in Table 1.

Data and statistical methods

The meteorological stations in the study area are administered by the Iraqi metrological organization and seismology. The historical metrological data used in this research covers the period between 1980 and 2018. The statistical analysis methods utilized in this research

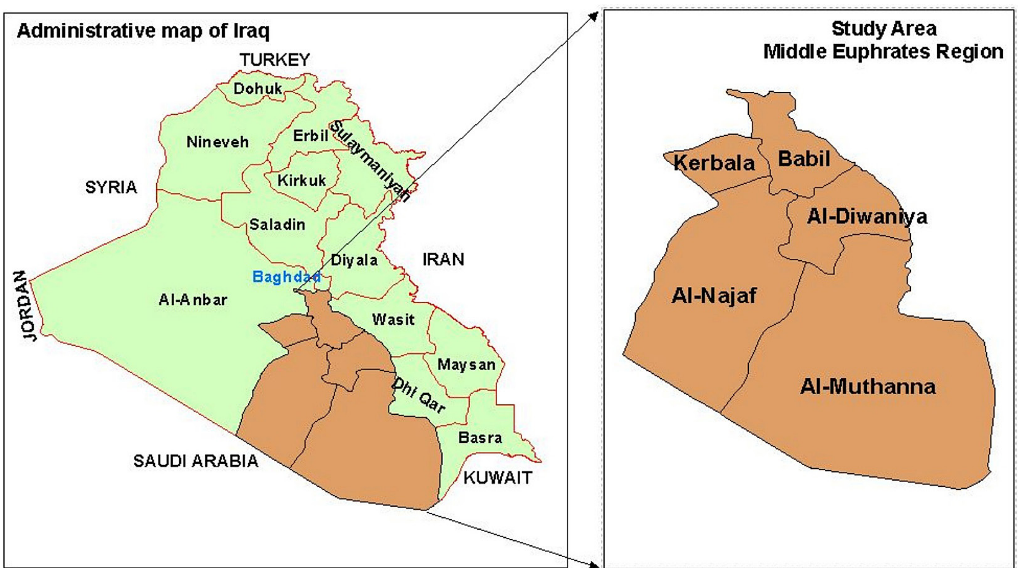

Figure 1. Location of middle Euphrates region in Iraq

Table 1. Meteorological stations in the study area

Governorate	Meteorological station	Ref. No.	Longitude (E)	Latitude (N)	Elevation (m.a.s.l)
Al-Muthana	Samawa	674	45.16	31.16	11.4
Al-Qadisiya	Diwaniya	672	44.57	31.57	20.0
Al-Najaf	Al-Najaf	670	44.19	31.57	53.0
Babylon	Hillah	657	44.27	32.27	27.0
Karbala	Karbala	656	44.03	32.34	29.0

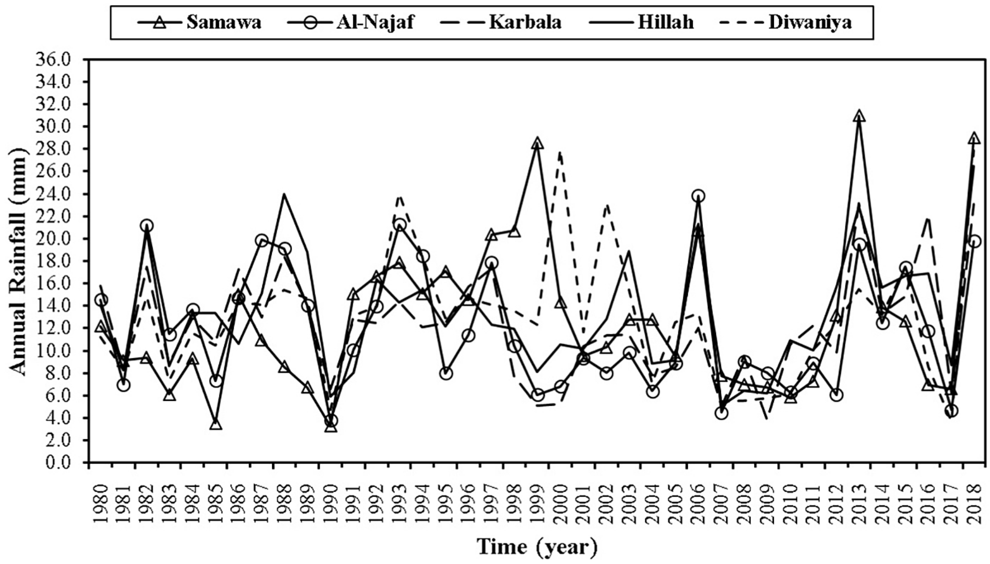

Figure 2. Flow chart for the procedure of statistical analysis

is shown in Figure 2. Water resources planning requires a long duration of good-quality datasets on relevant hydro-meteorological variables e.g., rainfall. Adequacy of the length of historical rainfall records can help researchers define long-run behaviors and the periodicity of variables. In hydrological models, an appropriate duration is essentially required for performing temporal variability, trends, and long-term homogeneous time series analysis (Habibagahi, and Pratschke, 1972).

Many researchers studied and discussed the adequacy of record length; they reported that the length of records strongly affects the results of frequency analysis. The variation of the recorded metrological time series can determine the minimum required length for satisfactory estimates. According to Subramanya, (2017), 30 – yr logged data is required, and less than, 10 – yr data is insignificant in frequency analysis. In the present research, a 38 – yr length of rainfall records was considered sufficient to carry out this analysis.

For the acquired raw rainfall datasets, the rainfall season in the study area started at the beginning of October and extended along the end of May. Number of recorded and missing data per each ground station logged is given in Table 2.

In this research, a replace-by-the-mean imputation method has been used in this research to estimate the missing data in rainfall time series (Walker et al., 2016).

Based on the fact that a time series is stationary if the mean, variance and auto-covariance are constant, so that, for stochastic variables X_t where the series X_1, X_2, ..., X_t is a stochastic time series (is defined as a first-order autoregressive process AR (1)):

$$X_t = \varphi X_{t-1} + \epsilon_t \tag{1}$$

where: ϵ_t – is the white noise component.

For $|\varphi| = 1$, the time series is not stationary and is known as a unit root. Otherwise, if $|\varphi| < 1$, the time series is stationary, while if $|\varphi| > 1$, the time series increases with time and is known explosive. The stationary test was carried out by a unit root or Dickey-Fuller test. In this test, the statistics are defined based on the linear regression model and calculated *t-test* statistics:

Table 2. Datasets of rainfall time series in the study area

Meteorological station	No. of recorded raw data	No. of missing data	% of missing data
Samawa	284	28	8.97
Diwaniya	303	9	2.88
Al-Najaf	304	8	2.56
Hillah	287	25	8.01
Karbala	309	3	0.96

For a first-order autoregressive process model AR (1):

$$\tau' = \frac{(\acute{\varphi} - 1)}{\sqrt{s_1^2 c_1}} \tag{2}$$

For a first-order autoregressive process model AR (1) with constant μ:

$$\acute{\tau}_\mu = \frac{(\acute{\varphi}_\mu - 1)}{\sqrt{s_2^2 c_2}} \tag{3}$$

For a first-order autoregressive process model AR (1) with constant μ and a linear trend function of time (*t*):

$$\acute{\tau}_\mu = \frac{(\acute{\varphi}_\tau - 1)}{\sqrt{s_3^2 c_3}} \tag{4}$$

where: s_k^2 – the mean square error, c_k – the variance. The test hypotheses include the null hypothesis and two possible alternative hypotheses: H_0 is the null hypotheses: φ = 1, the stochastic time series is not stationary, $H_a(1)$ is the first alternative hypotheses: $|\varphi|<1$, the stochastic time series is stationary, $H_a(2)$ is the second alternative hypotheses: $|\varphi| > 1$, the stochastic time series is explosive.

The test of homogeneity is required for long time series that are allowed to identify a variation over a time. In this research; von Neumann ratio test was used, which precise at all times but does not permit perceiving the breakpoint of the change in time scale. The von Neumann ratio allows the detection of the rainfall randomness ratio of the mean squared first differences to the rainfall series variance (Karamouz et al., 2003).

The von Neumann statistic (ϱ) estimated as follows (Habibagahi, and Pratschke, 1972):

$$\varrho = \frac{\sum_{t=1}^{N-1} (X_{t+1} - X_t)^2 \big/ (N-1)}{\sum_{t=1}^{N} (X_t - \bar{X}_t)^2 \big/ N} \tag{5}$$

where: X_t – a series of N observations (t = *1, 2, 3,….., N*).

The expected average of ϱ is equal to 2 when the time series is homogeneous, but, when the time series contains a gap, then the average of this ratio inclines to be lower than expected.

The detection of a function or quantity trends in time series of hydrologic variables is essential to spot the pattern. It is necessary to perform statistic tests in order to understand the uncertainty in the historical records of the studied events, and therefore to extract basic pattern of behavior. The Mann–Kendall trend test is a non-parametric test that used to predict if the time series has an upward or downward trend. This test does not require the datasets to be linearly or normally distributed. For the time series $x_1, x_2 \dots x_n$, the Mann-Kendall statistic (ς) is expressed as (Gao et al., 2020):

$$\varsigma = \sum_{t=1}^{N-1} \sum_{j=t+1}^{N} \begin{cases} -1 \; if(x_j - x_t) < 0 \\ \;\;0 \; if(x_j - x_t) = 0 \\ +1 \; if(x_j - x_t) > 0 \end{cases} \tag{6}$$

where: x_t and x_j – the rainfall values in time series *t* and *j* (where $j > t$), respectively. The variance of Mann-Kendall statistic is defined as:

$$\sigma^2(\varsigma) = \frac{1}{18}\left[\begin{matrix} N(N-1)(2N+5) - \\ -\sum_k f_k(f_k - 1)(2f_k + 5) \end{matrix}\right] \tag{7}$$

where: k changed over the set of tied ranks and f_k is the frequency that the number rank k extended. The detection of a significant trend standardized by Z statistics which can be expressed as:

$$Z = \begin{cases} \frac{\varsigma - 1}{\sqrt{\sigma^2(\varsigma)}} \; \varsigma > 0 \\ 0 \; \varsigma = 0 \\ \frac{\varsigma + 1}{\sqrt{\sigma^2(\varsigma)}} \; \varsigma < 0 \end{cases} \tag{8}$$

The detection of a trend can be determined according to the Z values, that is, the positive value of Z referred to upward trend while the negative

Z referred to downward trends. For a significance level of ($\alpha = 0.05$), the following hypothesis were assumed: A null hypothesis, H_0, of no detected trend in the time series, whereas the alternative hypothesis, H_1, is that an increasing or decreasing trend is detected. For a significance level of ($\alpha = 0.05$), the hypotheses tested according to achieve one of the following conditions: If $|Z| > Z_{(1-\alpha/2)}$, then null hypothesis (H_0) is rejected, otherwise, the H_0 is accepted.

The magnitude of the slope of the trend line can be predicted by using a robust, nonparametric estimator known as "Sen's Slope". For the set of driver variable x_t with N in which is the number of time series data pairs, the slope is expressed according to Sen's as (Gao et al., 2020):

$$R(t) = m \times t + B \tag{9}$$

where: m is the slope magnitude of the trend line $R(t)$, and B is the trend line intercept. The slopes m_i are calculated as:

$$m_i = \frac{x_t - x_T}{t - T}; t > T \tag{10}$$

where: x_t, x_T are data pair values at previous t and next T times. The Sen's slope is computed as:

$$m_{Median} = \begin{cases} m_{\left[n+\frac{1}{2}\right]} \ if\ n\ is\ odd \\ \frac{1}{2}\left[m_{(n/2)} + m_{(n+2/2)}\right] \ if\ n\ is\ even \end{cases} \tag{11}$$

where: the sign of Sen's slope indicates the trend of data, whilst, the Sen's slope value refers to the trend steepness.

In this research, analysis of autocorrelation and cross-correlation is used to provide evidence for testing the dataset as well as the relationship between neighboring stations. Autocorrelation is the degree of persistence over respective lags of a variable. It is used to measure the degree of correlation between the values of the driver variable (in this research, the rainfall) across different observations in the dataset; that is a characteristic measure of data in the time series context. The autocorrelation function at lag-k is defined as (Karamouz et al., 2003):

$$\rho_k = \frac{\sigma_k^2}{\sigma^2} \tag{12}$$

where: ρ_k is the lag-k autocorrelation function, σ_k^2 is the covariance at lag-k and σ^2 is the variance of a time series $x_1, x_2, \ldots x_N$. In which;

$$\sigma_k^2 = \frac{\sum_{t=1}^{N-k}(x_t - \bar{x})(x_{t+k} - \bar{x})}{N} \tag{13}$$

Thus;

$$\rho_k = \frac{\sum_{t=1}^{N-k}(x_t - \bar{x})(x_{t+k} - \bar{x})}{\sum_{t=1}^{N}(x_t - \bar{x})^2} \tag{14}$$

For the auto-correlation functions (ACFs) at lag-k of a stationary time dataset, the confidence intervals are:

$$CI = \pm Z_{critical}\, SE(k) \tag{15}$$

$$SE(k) = \sqrt{\frac{1 + 2\sum_{i=1}^{k-1} ACF(i)}{N}} \tag{16}$$

where: *CI's* are the confidence intervals at a significance level α (for the present study is 5%), and SE(k) is the standard error of ACF.

It is useful to examine the correlation as a major index between one time series and another with a time lag. This can be carried out using cross-correlation analysis, which is performed by measuring performed by measuring correlation between sets of time series related to one another with a time lag. The cross-autocorrelation function at lag-k is defined as (Boyd, 2001):

$$CCF(k) = \frac{\gamma_{x,y}}{\sqrt{\sigma_x^2 \sigma_y^2}} \tag{17}$$

where: $CCF(k)$ is the lag-k cross-correlation measure, $\gamma_{x,y}$ – the covariance, and σ_x^2 and σ_y^2 – the variance of a time series $x_1, x_2, \ldots x_N$, and $y_1, y_2, \ldots y_N$, respectively.

$$\gamma_{x,y} = \frac{\sum_{t=1}^{N}(x_i^t - \bar{x}_i)(y_i^t - \bar{y}_j)}{N} \tag{18}$$

$$\sigma_x^2 = \frac{1}{N}\sum_{t=1}^{N}(x_i^t - \bar{x}_i)^2 \tag{19}$$

$$\sigma_y^2 = \frac{1}{N}\sum_{t=1}^{N}(y_j^t - \bar{y}_j)^2 \tag{20}$$

RESULTS AND DISCUSSION

Rainfall, potential evaporation, and mean temperature are the major involved parameters in the analysis of any hydrological model. In this research, the averages of monthly values of the recorded rainfall season over the period (1980–2018) were collected. The periods of these stations were slightly different from one to another; two of them have a high percentage of missing data (Samawa and Hillah). Table 3 gives the general statistics about the data extracted from the five stations.

The averages of annual rainfall (for rain season) over 38 years for each of the five stations are shown in Figure 3.

From Figure 3, seasonal patterns are revealed, and temporal varieties, as well as spatial variability, were highlighted; such situations are prevalent for datasets in the Winter season. The rainfall historical records set the fact that the rainy season often begins in October and reaches its highest value at the end of January of each year. On the other hand, decreases from the beginning of May to the end of September of each year.

The result of stationary for rainfall time series is performed by the Dickey-Fuller test. The Lag (1) difference of annual averages time series

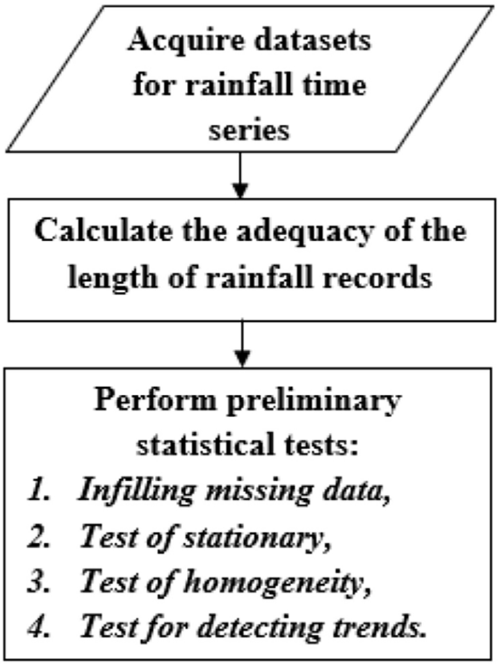

Figure 3. Time series for rainfall session over period in the study area

(during a rainy season) for each ground station is shown in Figure 4.

The result in Figure 4 appears to be a random pattern, revealing a stationary time series. Table 4 shows the results of a unit root or Dickey-Fuller test to check whether the time series is stationary or non-stationary.

Results of Table 3 approved the stationary nature of the rainfall time series in all meteorological stations within the study area. The homogeneity of the time series can be checked by involving the von Neumann test, for which the null hypothesis is that a time series is homogenous between two given times of a single shift. Table 5 shows the results of the homogeneity tests of the rainfall time series in the stations of the study area.

From the results of Table 5 it is revealed, that the computed p-value is less than the tabulated value at the significance level of (0.05), the null hypothesis H0 was rejected, and accept the alternative hypothesis Ha that confirms the non-homogeneity of rainfall time series for Samawa station. While, all other stations in the study area produced computed p-values that were greater than 0.05, thus; the null hypothesis H0 is accepted.

The results of the Mann-Kendall test outlined the behavioral trend in the time series datasets. Table 6 presents the Mann-Kendall trend statistic of the two-tailed test of significant values at the 5% level for all stations in the study area.

The results of Table 6 indicated that all stations in the study had no trend (negative slopes). The trend shape, magnitude, and statistics by mean of Sen’s slope for rainfall time series were presented in Table 7 and Figure 5, respectively.

As shown in Table 7, the Sen’s slope values approach zero, the smaller the trends. Also, the negative signs of the slope for trends of rainfall time series were observed for the stations, Al-Najaf, Karbala, and Diwaniya, which shows a decrease in trends. For Samawa and Hillah stations, a little increasing trend was detected that

Table 3. Summary for general statistics of the rainfall datasets

Meteorological station	Observations	Observations with missing data	Minimum (mm)	Maximum (mm)	Mean (mm)	Std. deviation (mm)
Samawa	39	0	3.28	30.99	12.777	6.678
Al-Najaf	39	0	3.79	23.84	11.96	5.497
Karbala	39	0	3.84	23.19	12.163	4.83
Hillah	39	0	5.13	26.47	13.339	5.224
Diwaniya	39	0	3.71	27.90	13.0	5.738

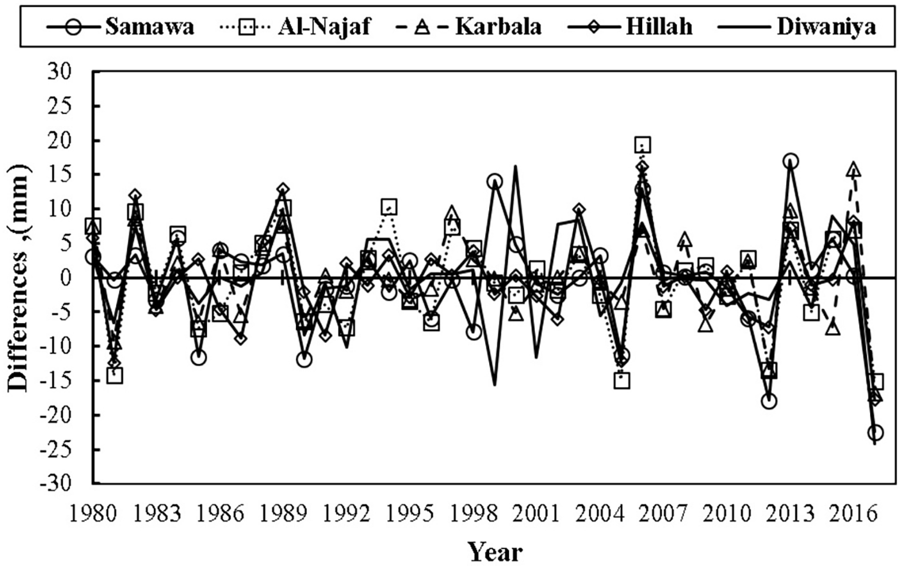

Figure 4. Lag (1) differences for each station in the study area

Table 4. Results of Dickey-Fuller test

Station	Stationary test statistics base on significance level α = 0.05			
	$\acute{\tau}$ calculated	$\acute{\tau}$ critical	P-value (one-tailed)	Interpretation*
Samawa	-2.846	-0.619	0.179	Stationary
Al-Najaf	-3.182	-0.619	0.095	Stationary
Karbala	-2.286	-0.619	0.415	Stationary
Hillah	-2.567	-0.619	0.281	Stationary
Diwaniya	-2.623	-0.619	0.258	Stationary

Note: *based on comparison between computed p-value and the significance level, one should accept or reject one of the following hypotheses: Null hypothesis (H_0): There is a unit root for the series, the series is stationary, Alternative hypothesis (H_a): There is no unit root for the series.

Table 5. Results of von Neumann test

Station	Homogeneity test statistics base on significance level α=0.05		
	P-value (two-tailed)	ϱ	Interpretation*
Samawa	0.016	1.302	There is a change in the data
Al-Najaf	0.388	1.908	Homogeneous
Karbala	0.310	1.841	Homogeneous
Hillah	0.275	1.804	Homogeneous
Diwaniya	0.151	1.670	Homogeneous

Note: *based on comparison between computed p-value and the significance level (α = 0.05), one should accept or reject one of the following hypotheses: Null hypothesis (H_0): no change of the time series, Alternative hypothesis (Ha): There is a date at which there is a change in the data.

was shown as a reverse trend to that prevailing in the study area.

Figure 6 shows the auto-correlation functions (ACFs) of the time series for the stations in the study area. The results show that for all stations except Samawa, a slight fluctuation with abrupt damping as the lag time increases, and a reduction of correlation after a few lags. These findings are consistent with the results of trend analysis, which attributed to the expected pattern of rainfall at most stations in the study area that does not indicate the robust trend evident.

Table 6. Results of Mann–Kendall test for rainfall time series of meteorological stations in the study area

Station	Mann-Kendall (ς)	Variance σ^2 (ς)	P-value (two-tailed)	Interpretation*
Samawa	37.00	6831.667	0.663	No trend
Al-Najaf	-114.00	6832.667	0.172	No trend
Karbala	-59.00	6833.667	0.486	No trend
Hillah	20.00	6832.667	0.818	No trend
Diwaniya	-35.00	6833.667	0.683	No trend

Note: * H_0 (null hypothesis) – there is no trend in the time series, H_a (alternative hypothesis) – there is a trend in the time series.

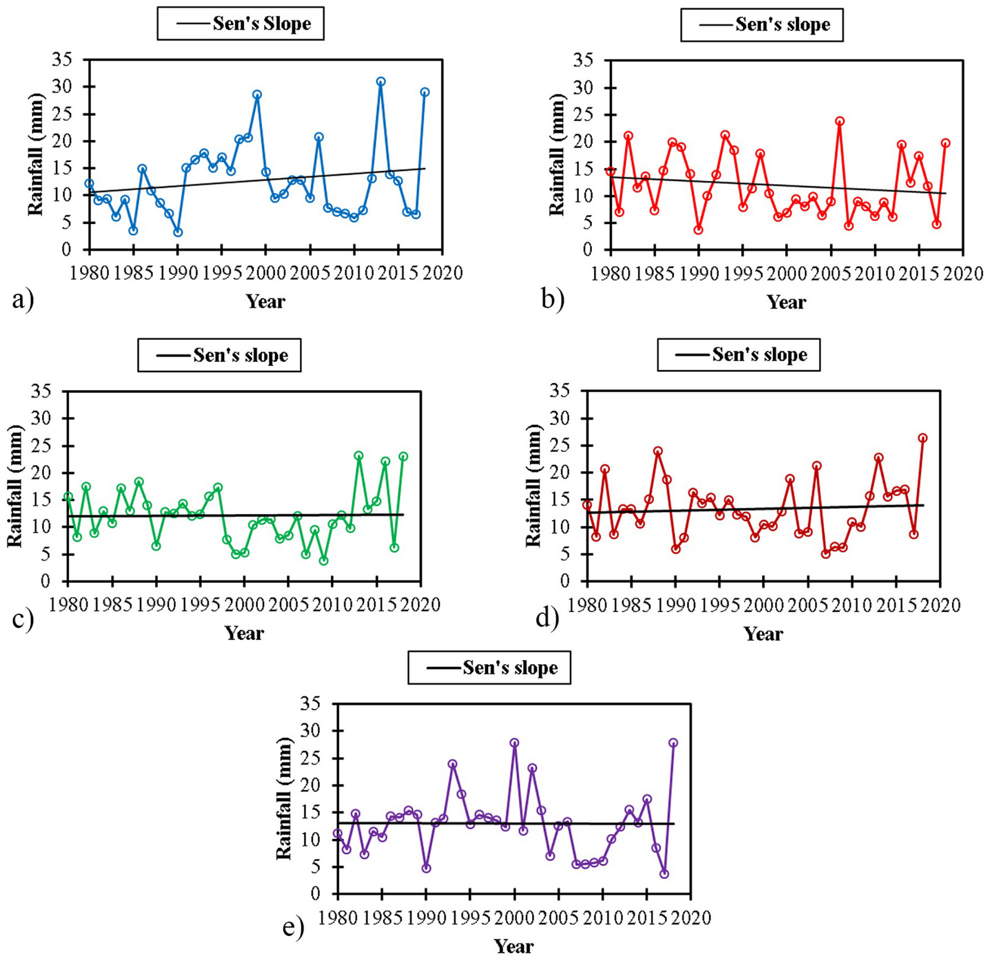

Figure 5. The Sen's slope for rainfall time series at station in the study area, (a) Samawa station, (b) Al-Najaf station, (c) Karbala station, (d) Hillah station, (e) Diwniya ststaion

Table 7. The Sen's slopes for rainfall time series at confidence interval of (95%)

Sen's slope statistics	Slope value	Confidence interval	
Station		Lower	Upper
Samawa	0.025	-3.38	4.0275
Al-Najaf	-0.1	-4.5038	4.4833
Karbala	-0.05	-3.1283	3.0625
Hillah	0.017	-3.3362	3.7616
Diwaniya	-0.035	-3.561	3.5516

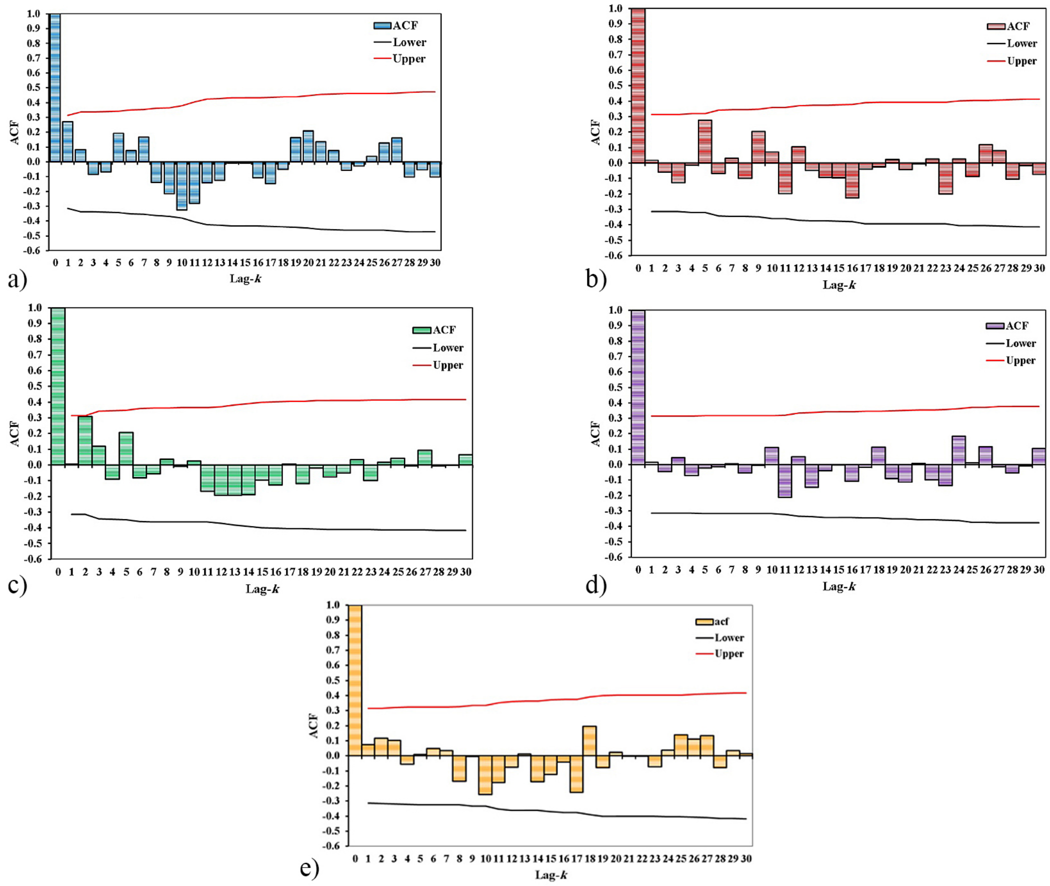

Figure 6. Auto correlation function at different lags for the rainfall time series for the station in the study area, (a) Samawa station, (b) Al-Najaf station, (c) Karbala station, (d) Hillah station, (e) Diwniya ststaion

Table 8. Cross-correlation functions against lags to show the mutual effect between the meteorological stations

Stations*	Cross-correlation function CCF(k)									
Lag-k	a/b	a/c	a/d	a/e	b/c	b/d	b/e	c/d	c/e	d/e
0	0.4271	0.3608	0.4185	0.5346	0.7109	0.7433	0.5021	0.7693	0.4078	0.5606
1	-0.0016**	-0.1664	-0.0098	0.2927	-0.0949	-0.0153	-0.1820	0.0418	-0.1970	-0.1644
2	0.0320	-0.0665	-0.0852	0.2033	0.0718	-0.0563	-0.0856	0.3007	0.1644	-0.0063
3	-0.2435	-0.0984	-0.1124	0.0894	-0.0032	-0.1395	-0.0909	0.0488	0.0085	-0.1154
4	-0.4642	-0.2636	-0.2431	-0.1855	0.0284	-0.1762	-0.0489	-0.1754	-0.0144	-0.0035
5	-0.1437	-0.0663	-0.0218	0.2444	0.1629	0.1789	0.3645	0.1830	0.4871	0.2515
6	-0.2108	-0.3617	-0.1216	0.0604	-0.2565	0.0180	0.2590	-0.0613	0.1441	0.1979

Note: * For abbreviation purposes, the stations were denoted as follows: a = Samawa station, b = Al-Najaf station, c = Karbala station, d = Hilla station, and e = Diwaniya station. ** Negative sign of the correlation function is interpreted that when one variable increases, the other decreases, and vice versa.

The cross-correlation matrix specified for different lags and mutual influence of studied metrological stations in the study area is presented in Tables 8. From the results of Table 8, the reference cross-correlation functions for Karbala /Hilla stations produced a stronger positive correlation than for other stations. In comparison, the prediction for other stations produced either lower or negative values. It is beneficial to visualize the cross-correlation functions predicted for the temporally annual rainfalls that correspond to an optimum number of lags as shown in Figure 7.

The results in Figure 7 as for the correlation between the time series of rainfall, and the spatial distribution of the stations in the study area,

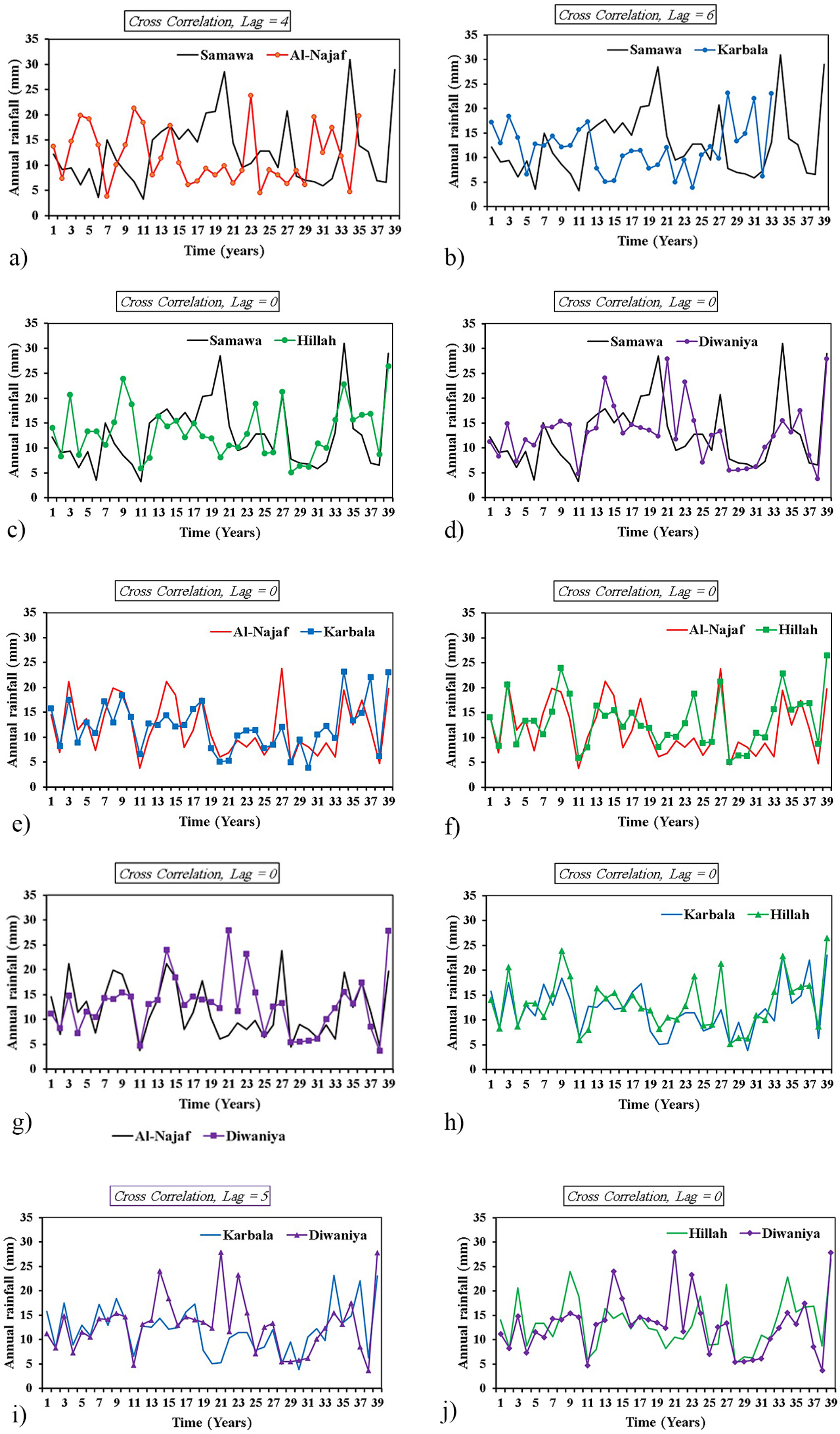

Figure 7. Mutual correlation for time series between metological station in the study area, (a) correlation of time series for Samawa/Al-Najaf, (b) correlation of time for Samawa/Karbala, (c) correlation of time series for Samawa/Hilla, (d) correlation of time series for Samawa/Diwaniya, (e) correlation of time series for Al-Najaf/Karbala, (f) correlation of time series for Al-Najaf/Hilla, (g) correlation of time series for Al-Najaf/Diwaniya, (h) correlation of tme series for Karbala/Hilla, (i) correlation of time series for Karbala/Diwaniya, (j) correlation of time series for Hilla/Diwaniya

showed a minor effect on the cross-correlation functions. On the other hand, converged behavior during 38 years produced a high positive cross-correlation function of optimum value (0.7693) at lag (0) for Karbala/Hilla stations. While the cross-correlation functions over the same period have diverged across all other stations and for different lags.

CONCLUSIONS

The coverage of 38 – yr was found adequate period to perform such type of trend analysis carried out in this research. The maximum percentage of missing data was about 9.0%, which was acceptable. All stations were found stationary time series according to results of Dickey-Fuller test. The homogeneity in accordance with von Neumann test, shows that all rainfall time series in the metrological station were homogeneous except that for Samawa station, which may be attributed to non-climatic factors. These two tests could thereby support a reliability of the analysis.

The classic Mann-Kendall test for auto-correlated rainfall time series during the winter season detected no trend for time series in the metrological stations. Sen's slope estimator detected slight steepness (negative and positive) implicitly in some cases, thus, both negative and positive Sen's slopes have resulted in the low natural variance of the rainfall data that probably depends on the spatial distribution of the station and is affected significantly by the characteristics of the time series.

The autocorrelation analysis at different lags was analyzed. The results show the significance of the first-lag correlation at the confidence level ($\alpha = 0.05$) for all stations, from the results of other different lags, the effect of the negative ACFs reflects the descending probability of trend detection per each time series.

The cross-correlation functions reveal that the mutual responses between metrological stations for the optimum lag ($k = 0$) was in the following order: Karbala/Hillah, Al-Najaf/Hillah, and Al-Najaf/Karbala as fair-correlated stations, while Hilla/Diwaniya, and Samawa/Diwaniya as poorly correlated stations. This indicates that the cross-correlations functions in the trend study could product-leading inferences between the mutual correlations of stations as confirmed by the research findings.

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