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***Research Paper***

# Innovative trend analysis of annual rainfall in Iraq during 1980-2021

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**ABSTRACT**

Rainfall trend analysis is essential for managing water resources, agriculture, disaster management, and climate change research. The current study aims to examine annual rainfall variability and trend over 38 meteorological stations in Iraq during the period (1980-2021) using three tests: linear regression analysis (LRA), Mann-Kendall (MK), and the innovative trend analysis (ITA). The results of the three different tests showed that most stations recorded a decreasing trend except for four stations in ITA, six stations in MK, and seven stations in the LRA test, which exhibit a positive trend. However, three stations, Emaidyah, Rabiah, and Biji, showed an increasing trend for all three tests. The ITA test recorded more significant results (14 stations) than the other two tests. The larger significant result appeared in the significance level of 95 % (nine in LRA, eight in MK, and five in ITA). The outcomes of the three trend-detection approaches by assessing the statistical significance levels, 90 %, 95 %, and 99 %, revealed no significant trend in 16 stations dispersed throughout the various climatic zones of Iraq. Only Emadiayah station indicated a positive trend at the significance of 99 %. The overall results showed that the ITA test outperformed the MK and LRA tests since it produced more significant results.

***Keywords***: Rainfall: ITA; Mann-Kendall test, Climate change, Iraq

Human activities have accelerated climate change, which has led rainfall-related threats to become more common and severe over time (Mallick *et al.,* 2021; Sun *et al.,* 2018) . Hence, the high precision and exact assessment of the changes in rainfall time series has become an important study area globally addressing the reduction or elimination of rainfall-related difficulties (Wang *et al.,* 2020). There are several methods for detecting trend time series of rainfall available today, including the linear regression analysis, the Mann-Kendall (M-K) test, the Sen's T-test, the Spearman's Rho (SR) test, and the Tramo/Seats software (Zhou *et al.,* 2018; Sen, 1968; Mann, 1945; Haan, 1977). Among these approaches, the Mann-Kendall trend test is the most widely used in many locations worldwide. Serial correlation appears in time series data. And a stronger dependency on sample size, distribution, and degree, which impact the "robustness and reliability of the trend detection test" there are two weaknesses in the MK test that limit its applicability and reliability (Şen, 2014). The MMK and TFPW-MK tests are improved serial correlations but are also highly reliant on sample size and data dispersion. Şen has presented an innovative trend analysis (ITA) technique, which has been applied to identify trends in rainfall, river flow, and pan evaporation in various locations.

ITA then offers several benefits over other approaches, as demonstrated by comparisons with traditional methods, because it is independent of sample size and distribution. The ITA has gained popularity among statisticians for its many features and benefits, such as the ability to display trends graphically (Gedefaw *et al.,* 2018). Previous studies showed that ITA surpasses the MK test in detecting trends in climatic parameters (Alifujiang *et al.,* 2020; Wang *et al.,* 2020; Mallick *et al.,* 2021; Gedefaw *et al.,* 2018; Sanikhani *et al.,* 2018; Girma *et al.,* 2020) . Most of the previous research works revealed that several statistical approaches are available for trend identification, but one common technique, the MK test, has been widely employed globally. Swami (2024) examined long-term spatiotemporal variations and trends in rainfall using data from 1901 to 2020 and the influence on vegetation from 2000 to 2020 throughout Uttarakhand districts. The Pettitt test was used to detect sudden changes in time, and the Mann-Kendall (MK) test was used to examine the rainfall trend. The results suggest that most districts demonstrated a considerable negative rainfall trend in the monsoon (Swami, 2024).

However, relatively few studies have been conducted in Iraq and neighboring countries to identify patterns in rainfall time

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series. In the current study, an innovative trend analysis (ITA) was used to find the annual variation trends of rainfall data at 38 stations in three distinct climatic zones throughout Iraq during the period (1980-2021).

## MATERIAL AND METHODS

### *Area of study and data acquisition*

Iraq, which occupies 437072 km$^2$ and is situated in Southwest Asia, serves as a representative of the Study area. Iraq is situated in the northeastern region of the northern hemisphere. Iraq shares boundaries with Turkey (367 km to the north), Iran (1599 km to the east), Kuwait (255 km to the southeast), Saudi Arabia (814 km to the southeast), Jordan (179 km to the west), and Syria (599 km to the northwest) (Al-Ansari, 2021). Topographically, " Iraq is formed like a basin, with the Great Mesopotamian alluvial plain of the Tigris and Euphrates rivers. This plain is surrounded by mountain chains from the north and east, which may reach elevations of 3550 meters above sea level. From the west and southwest, the desert lands, which account for more than 40% of the total area, are connected to the Arabian Peninsula desert (Al-Salihi, 2018) . Iraq's climate is typically subtropical and semi-arid, except for the mountainous northern and northern east areas with Mediterranean climates. Most of the rain falls between December and April, with an annual average between 100 and 900 mm. Northern Iraq receives significantly more rainfall than the central and southern regions. Between November and April, about 90 % of the annual precipitation falls. The annual average rainfall is 216 mm (Al-Lami *et al.,* 2021; Al-Salihi, 2017). The average daytime temperature in the winter is about 16 °C, with nighttime lows of 2 °C and the potential of frost. However, summer months are extremely hot, with average highs of over 45 °C in July and August and lows of 25 °C at night (Ibraheem *et al.,* 2023; Lim *et al.,* 2022).

The annual rainfall data for this investigation were acquired from the Iraqi Meteorological Organization and Seismology (IMOS) for 38 meteorological stations distributed throughout Iraq and representing the three different climate zones (1988-2021). The clustered rainfall stations were classified into three regions, as shown in figure1. RClimDex was used to carry out the data quality control processes (see http://etccdipacificclimate.org/software.shtml). Any possible outliers identified were then personally inspected and fixed, including typographical errors, missing data, rejected values, and minimum values that were higher than maximum values. The percentage of missing annual data for 38 stations over 41 years was 3 %.

### *Linear regression analysis (LRA)*

The variation trend of meteorological time series can be examined using linear regression analysis on a broad time scale. As a linear function, it is written as follows:

$$y = a.t + b + \varepsilon \quad (1)$$

When a denotes the "slope of a linear function" (also known as the linear trend) and the regression coefficients a, b may be determined using the least squares approach, and  is the error term.

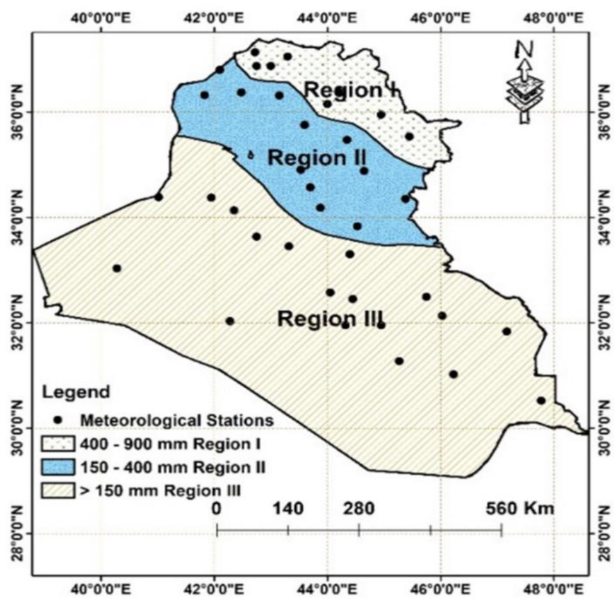


**Fig. 1:** Map of rainfall stations of Iraq grouped into three regions

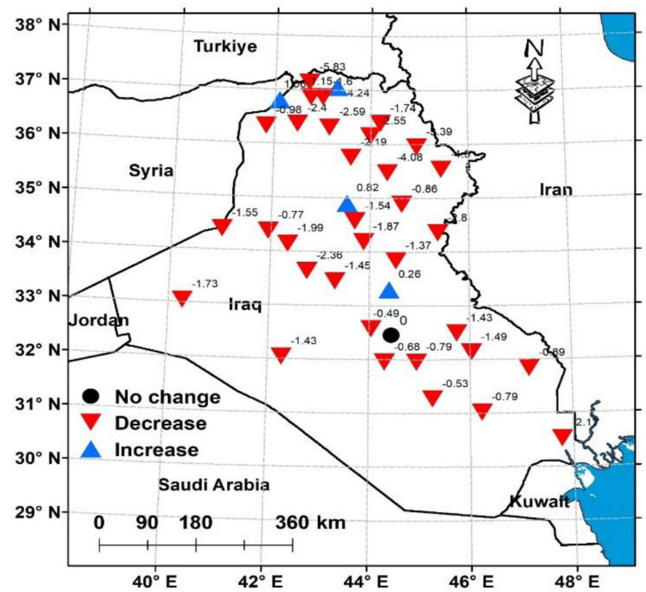


**Fig.2:** Innovative trend analysis (ITA) map for the annual rainfall time series

### *Mann-Kendall (M-K) test*

The nonparametric M-K test developed by (Mann, 1945) has been frequently utilized to evaluate the significance of monotonic trends in climate and hydrological variables time series. The MK test was applied in the current study from 1980 to 2021 to identify the historical rainfall pattern in Iraq. The MK test statistic (S) was derived using the Eq (2)

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(x_j - x_i) \tag{2}$$

where "n is the number of observations, and Yi and Yj are the ranks of ith (i = 1, 2, 3....n 1) and jth (j = I + 1, 2, 3....n) observations, respectively".

### *Innovative trend analysis (ITA)*

The ITA technique was invented by (Şen, 2012) . This approach is non-parametric. Therefore, it does not need to confirm the normal distribution of the data, and it is unaffected by the presence of serial correlation in a time series, unlike the Mann-Kendall (MK) test. The time series is separated into two comparable sections separately classified in ascending order. The first and second halves of the time series are then plotted on the X and Y axes, respectively. "If the data are collected on the 1:1 ideal line (45° line), the time series exhibits no trend. When data are placed on the upward triangular edge of the ideal line, the time series continues to increase. When data is aggregated in the downward triangular position of the 1:1 line, the time series shows a decreasing trend" (Mallick *et al.,* 2021; Şen, 2012; Şen, 2014). Any hydro-climatic or hydro-meteorological time series may be picked appropriately by looking at the high, medium, and low trends. Using the following equation, the ITA approach is described:

$$\varphi = \frac{1}{n} \sum_{1}^{n} \frac{10x_j - x_j}{\mu} \tag{3}$$

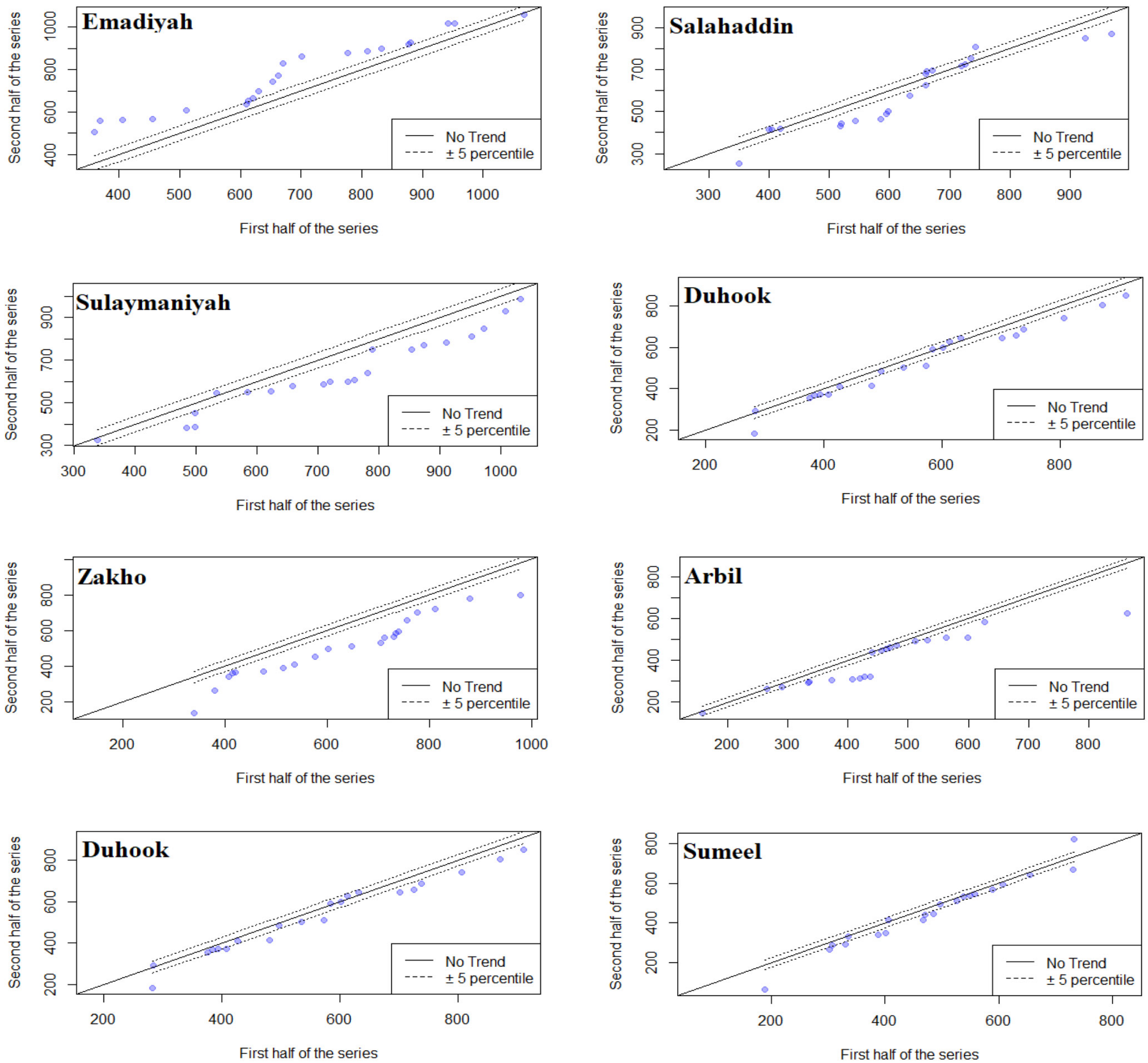


**Fig. 3:** Innovative trend analysis (ITA) of rainfall time series for northern regions of Iraq

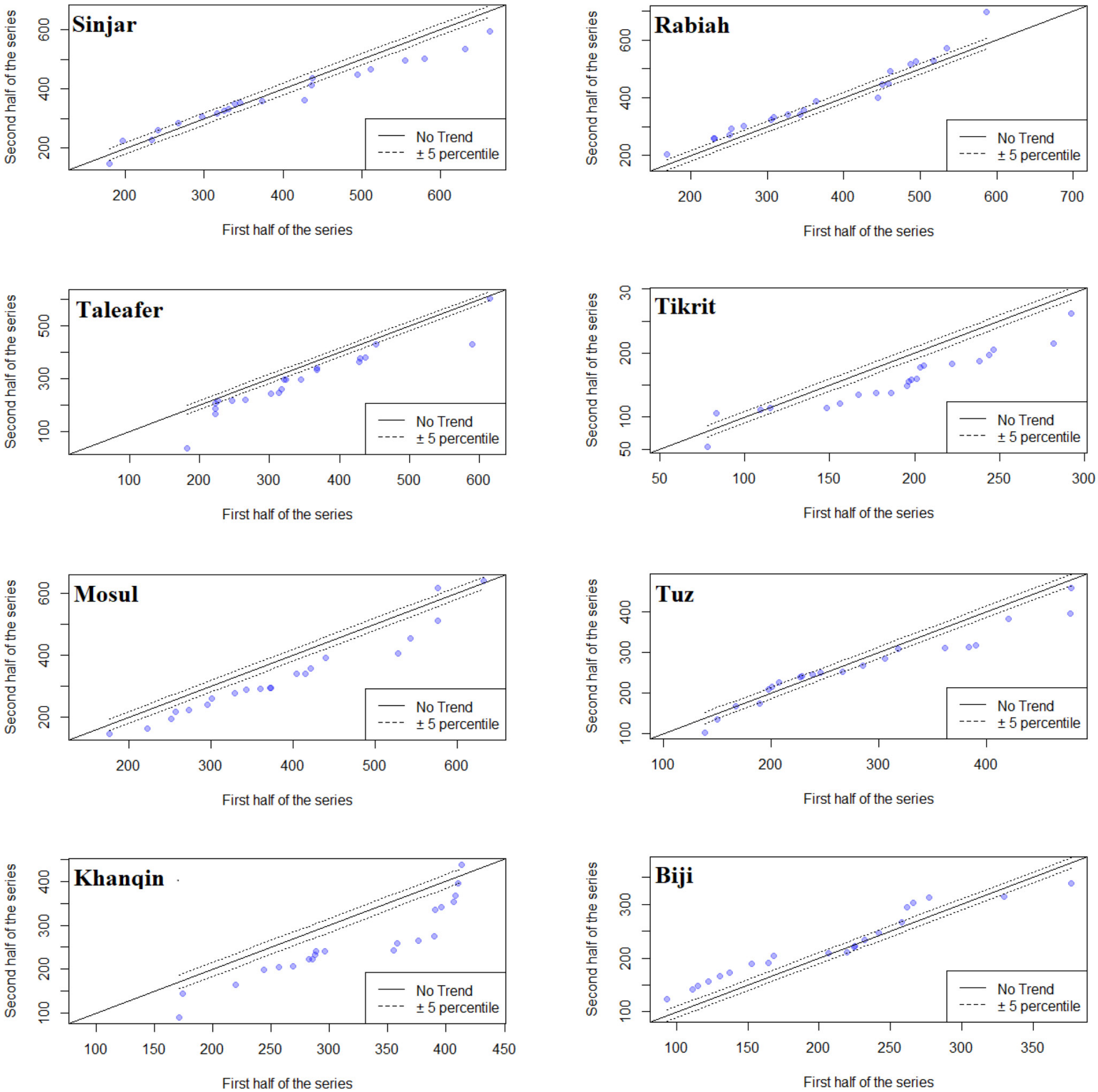


**Fig. 4:** Innovative trend analysis (ITA) of rainfall time series for middle regions of Iraq

Where  denotes the trend indicator;  represents the total number of observations; Xi denotes the first sub-series, Xj the second sub-series, and  denotes the value of Xi". The two portions of data affected by this evaluation are (i) 1980-2000 and (ii) 2001-2021 in this study. The data points are presented on the ideal 45° line, which demonstrates no trend in the time series in this study.

## RESULTS AND DISCUSSION

Fig. 2 presents the results of innovative trend analysis (ITA) statistics for the annual rainfall time series at 38 meteorological stations distributed in the three climatic zones of Iraq. The findings revealed that only four stations, Emadiyah, Rabiah, Biji and Baghdad, detected substantial positive trends of historical annual rainfall, whereas only one station, Hella, had no significant trend. Nevertheless, 34 stations revealed a significant decreasing trend at ($p < 0.05$)**.** From (1980 to 2021), the annual rainfall change's decreasing rate ranged from -0.49 mm (Kerbela) to -5.83 mm (Zakho)**.** The ITA graphic results for the three climatic zones (northern, Middle and Southern) are shown in Fig. (3 to 5), respectively. The areas of the north, namely the Emadiyah and Zakho stations, show the highest positive and negative trends, respectively.

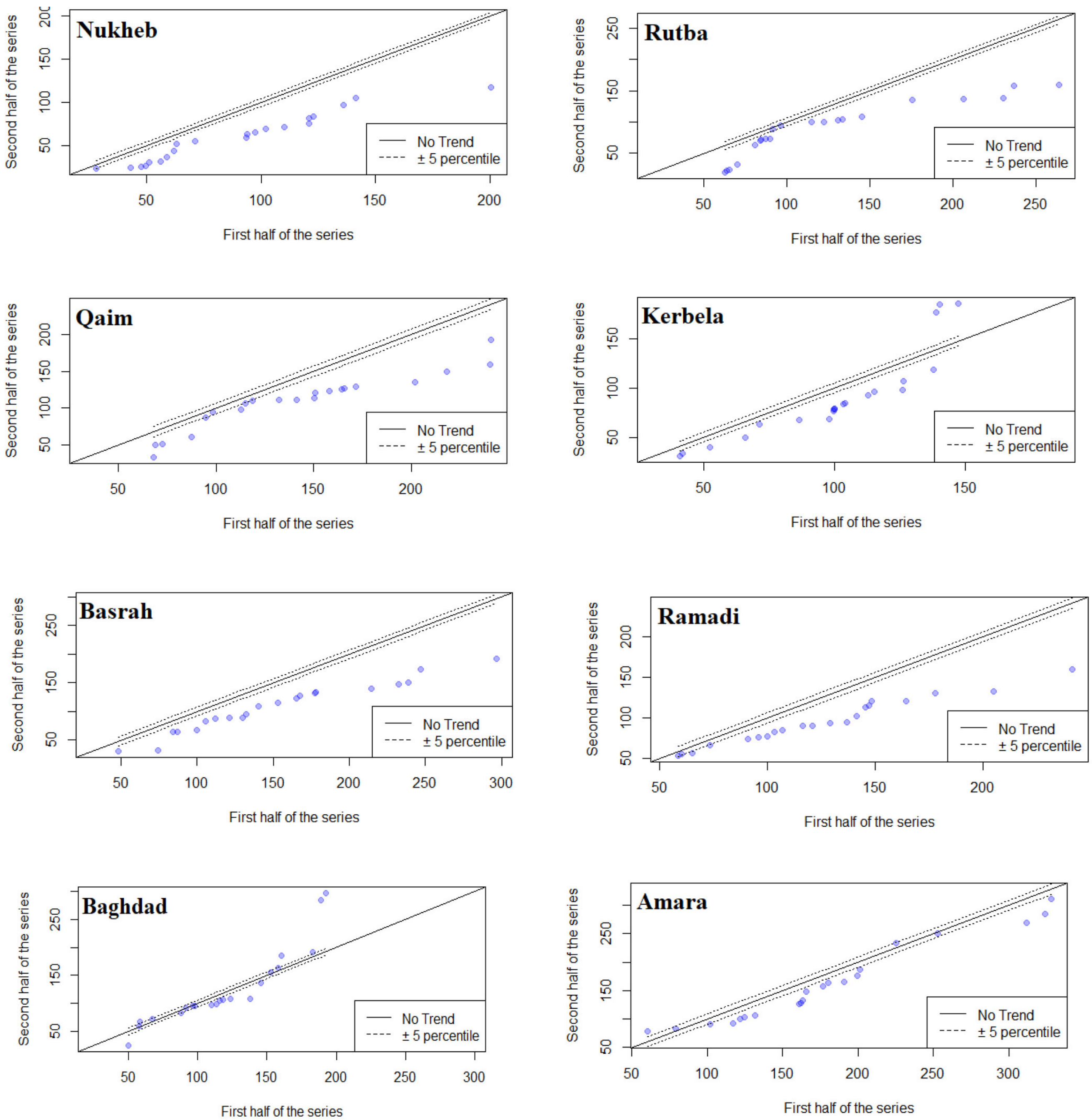


**Fig. 5:** Innovative trend analysis (ITA) of rainfall time series for southern regions of Iraq

A less negative trend appears in most stations in the southern region except Basra station (-2.17) (Fig. 5).

The MK test was carried out to examine the yearly rainfall trend for 38 meteorological stations using the imputation data (Fig. 6). Out of the 38 stations, the MK test found that six stations, Emadiyah, Rabiah, Biji, Hella, Samaw and Amara, exhibited increasing or positive trends that were significant at the level of ($p < 0.05$). However, the other stations show a negative trend, with values ranging between -0.1 (Tuz) and -2.48 (Zakho). The findings also show that the high decline in trend was characterized in the northern and middle regions s of Iraq.

The linear regression analysis results appeared similar to the behavior of MK tests and reported that in addition to the six stations (Emadiyah, Rabiah, Biji, Hella, Samawa, and Amara) also Baghdad station, showed an increasing trend at the significance level of 95 %, and the remaining stations showed a negative trend with a range of values between -0.22 (Diwaniya) and -.2.87 (Zakho). This test's findings are also compatible with the results of the MK test (see Fig. 6).

**Table 1:** Performance comparisons of trend detecting techniques across all stations

| S.No. | Station | α | Z | ITA | S.No. | Station | α | Z | ITA |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Emadiyah | No | No | Yes(+++) | 20 | Biji | No | No | No |
| 2 | Salahaddin | No | No | Yes(-) | 21 | Hadithah | Yes(- -) | Yes(- -) | Yes(- -) |
| 3 | Sulaymaniyah | No | No | Yes(- - -) | 22 | Tikrit | No | No | No |
| 4 | Sinjar | No | No | No | 23 | Samaraa | Yes(- -) | No | No |
| 5 | Duhook | No | No | No | 24 | Heet | Yes(- - -) | Yes(- -) | Yes(- -) |
| 6 | Zakho | Yes(- -) | Yes(- -) | Yes(- - -) | 25 | Najaf | No | No | No |
| 7 | Arbil | No | No | Yes(- -) | 26 | Ramadi | Yes(- -) | No | No |
| 8 | Rabiah | No | No | No | 27 | Kahalis | Yes(- -) | Yes(- -) | No |
| 9 | Taleafer | No | No | Yes(- -) | 28 | Baghdad | No | No | No |
| 10 | Kirkuk | Yes(- -) | Yes(-) | Yes(- - -) | 29 | Kerbela | No | No | No |
| 11 | Nukheb | Yes(- - -) | Yes(- -) | No | 30 | Hella | No | No | No |
| 12 | Dukcan | No (-) | No | Yes(- - -) | 31 | Makmoor | No | No | Yes(- -) |
| 13 | Sumeel | No | No | No | 32 | Kut | Yes(- -) | Yes(- -) | No |
| 14 | Mosul | No | No | Yes(- - -) | 33 | Diwaniya | No | No | No |
| 15 | Rutba | Yes (-) | No | No | 34 | Hai | No | No | No |
| 16 | Tuz | No | No | No | 35 | Samawa | No | Yes (-) | No |
| 17 | Khanqin | Yes(- -) | Yes(- -) | Yes(- - -) | 36 | Amara | No | No | No |
| 18 | Qaim | Yes(- -) | Yes(- -) | No | 37 | Nasiriya | No | No | No |
| 19 | Anah | No | No | No | 38 | Basrah | Yes(- -) | Yes (-) | Yes(- -) |

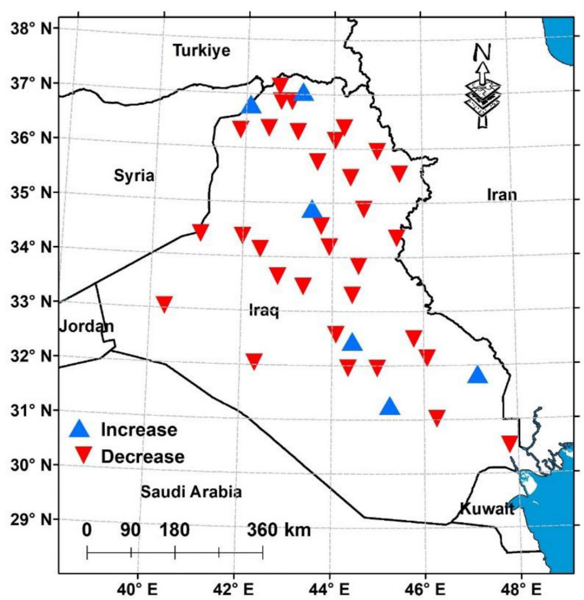


**Fig. 6:** Slope values for M-K test (z) for all stations of Iraq

We examined the results of three trend-detecting approaches by examining the significance level of the obtained statistics. Table 1 reveals that the MK test, autocorrelation test, and ITA test showed no significant trend for 16 stations distributed across the three climate zones of Iraq, and most of these stations lie in the middle and southern climate zones. In contrast, the remaining stations showed a significant trend at 90 %, 95 %, and 99 %. Nevertheless, one station (Rutba), three stations (Kirkuk, Samawa and Basrah) and one station (Salhaaddin) were identified as having significant trends at a significance level of > 90 % for LRA, MK and ITA tests, respectively. At the same time, nine stations Zako, Kirkuk, Khanqin, Qaim, Hdithah, Samara, Ramadi, Kut and Basrah, eight stations, Zakho, Kirkuk, Rutba, Khanqin, Hdithah, Heet, Khalis, and Kut and five stations, Arbil, Taleafer, Haditha, Heet, Makmoor, and Basrah were identified as having a significant trend at a significance level of > 95 %. For the LRA, MK, and ITA tests, respectively. In addition, two stations, Nukheb and Heet, no station and six stations: Emadiyah, Sulymaniyah, Zakho, Kirkuk, Mosul and Khanqin) had a significant trend at a significance level of > 99 %. For LRA, MK and ITA tests, respectively. The results also showed that no station detected a positive trend for AC and MK tests, while ITA indicated a positive trend for only one station (Emadiyah). Subsequently, when we looked at three trend identification methods based on significance level, we found that ITA outperformed the MK and LRA tests based on the performance (significant level) of the trend detection approaches. Generally, from 1988 to 2021, all tests showed that the annual rainfall trend was decreasing, which was predominant in most meteorological stations. The ITA test outperformed the other two trend detection methods (MK and LRA) since it produced more significant results.

Several studies conducted in Iraq and its neighboring countries found a decreasing trend in rainfall, which was in agreement with the results of the current study (Mallick *et al.,* 2021; Serencam, 2019; Alkan, 2024). The negative trend in most of the middle and southern climate zones has an impact on the agricultural sector in these regions; Bakr *et al.,* (2024) examined the impact of climate change on the vegetation cover for two regions in the middle and southern climate zones of Iraq (Wasit and Ninevah) using NDVI Image during the period (2000- 2022). The results indicated a significant decrease in vegetation cover in both regions (Bakr *et al.,* 2024). Many studies have evaluated the impact of the decreasing precipitation levels during the last decades on the hydrological situation in different regions of Iraq, especially in the marshes area of southern Iraq, and the results revealed that more than 90% of this area are sensitive to desertification (Al-Yasiry *et al.,* 2023).

## CONCLUSION

One of the most crucial topics in climate change studies is trend analysis. This study used LRA, M-K test, and ITA to explore variation patterns of rainfall at 38 stations across Iraq between 1980 and 2021. Most stations in the three different climate zones over Iraq show a significant negative trend ($p < .05$). Only four stations in ITA, six stations in MK and seven stations in LRA test exhibit increasing trends and three stations (Emaidyah, Rabiah and Biji) showing a positive trend for all different three tests. The results of the three trend-detecting methods, by examining the significance level of the obtained statistics, showed that there is no significant trend in 16 stations distributed over all different climate zones in Iraq. Since it generated more significant findings, The ITA test performed better than the MK and LRA tests, two additional trend-detecting techniques. Overall, the ITA approach demonstrates significant benefits. First of all, the ITA approach is easy to comprehend and compute. Moreover, ITA displays a broad range of applications without considering the distribution assumption for serial correlation, seasonal cycle, or size. The study's findings will help assist policymakers and government officials in Iraq to establish plans and execute steps for ecologically friendly and sustainable climatic management, hydrological management, and agricultural management.

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***Conflict of interest*:** The authors declare no conflict of interest

***Data availability*:** Annual rainfall data for this study were obtained from the Iraqi Meteorological Organization and Seismology (IMOS) for 38 meteorological stations distributed across Iraq, representing the three climatic zones from 1988 to 2021.

***Author contribution*:** **Alaa M. AL-Lami**: Draft writing and Data analysis; **Yaseen K. Al-Timimi:** Planning the experiments and reviewed the manuscript; **Ali M. Al-Salihi:** Data collected data and maps preparation.

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