Jordan Journal of Civil Engineering, Volume **20**, No. **2**, **2026**
DOI: https://doi.org/10.14525/JJCE.v20i2.07

Jordan Journal of Civil Engineering

Journal homepage: https://jjce.just.edu.jo

Assessment of Climate Change Impacts in Iraq Using Innovative and Polygonal Trend Analyses of Monthly Rainfall Data

Hasan Jamal Al-Bazaz [1)*]

[1)] *Department of Environmental Technology, College of Environmental Sciences, University of Mosul, Mosul, Iraq.*
** Corresponding Author. E-Mail: hasanalbazaz@uomosul.edu.iq*

ARTICLE INFO

Article History:
Received: 7/6/2025
Accepted: 23/10/2025

ABSTRACT

In recent years, global concern over climate change has intensified, particularly in Iraq. Forecasting hydrological data remains a significant challenge, making general trend analysis of time series critically important. This study employed two complementary methods, Innovative Trend Analysis (ITA) and Innovative Polygon Trend Analysis (IPTA), to comprehensively assess rainfall trends across Iraq using monthly rainfall data spanning 34 years (1990-2023) from 16 meteorological stations distributed throughout Iraq. ITA results revealed significant negative trends at 81.25% of the stations, with the most pronounced decreases occurring in the northern regions. Only two stations, Al-Hay and Baghdad, exhibited positive trends; Karbala did not show any apparent change in direction. The IPTA approach provided enhanced temporal resolution, uncovering distinct seasonal redistribution patterns: winter rainfall (December-February) declined at 87.5 % of the stations, whereas rainfall in late spring (May) and autumn (November) increased at 87.5 % and 68.75 % of the stations, respectively. This shift from traditional winter dominated rainfall toward transitional seasons represents a fundamental alteration in Iraq's rainfall regime. Analyses further highlighted geographic variability, with uniform negative trends in the north, complex mixed patterns in central Iraq, and predominantly negative trends in the south. The irregular polygon shapes observed in IPTA diagrams show a complex and unstable climatic environment across most study stations. These findings demonstrate the value of ITA and IPTA for detecting rainfall trends and contribute to a deeper understanding of rainfall variability and its implications for agriculture and water-resource management in Iraq.

Keywords: Climate change, Rainfall, Trend analysis, ITA, IPTA, Iraq.

INTRODUCTION

Climate change is no longer a distant concern; its effects are evident worldwide. These effects manifest in various forms and degrees, with their impacts varying between humid, semi-arid, and arid regions (Esit, 2022; IPCC, 2013; IPCC, 2023). Extreme weather events, such as floods and droughts, have severe economic and social consequences (Al-Bazaz & Mahmood Agha, 2023). often exacerbated by unsustainable human activities that have disrupted the Earth's natural balance (IPCC, 2014). Among the most significant manifestations of climate change is the decrease or increase in rainfall and temperatures (Zarch et al., 2015). Therefore, rainfall and temperature are considered the climatic elements most affected by these changes (Al-Bazaz & Mahmood Agha, 2024), given their significant impact on the global ecosystem (Ozturk et al., 2015; Qadem & Tayfur, 2024) and the hydrological cycle (Esit, 2022; Al-Bazaz & Mahmood Agha, 2023; Wang & Lirong, 2023).

Drought is mainly caused by a gradual decrease in rainfall and increased evaporation rates, reflected in some hydrological elements, such as rainfall, temperatures, soil moisture and surface run-off (Abdulla & Malkawi, 2020). The recurrence of extreme climatic events, such as floods and droughts, has raised widespread concerns about climate change (Beniston et al., 2007; Hasan, 2020). as these phenomena have severe consequences for both human life and ecosystems (Schimel, 2006; Crosbie et al., 2013; Kundzewicz et al., 2014; Lamichhane & Sanjel, 2024). To understand the potential future impacts of climate change and identify adaptation strategies, water project management, and mitigation measures, it is necessary to analyze historical climatic elements (precipitation and temperature) to understand their general trends (Cai et al., 2015; Le Minh Hai et al., 2024). Therefore, trend analysis is considered one of the most effective methods for monitoring climate change impacts (Esit, 2022).

Reports from the Intergovernmental Panel on Climate Change (IPCC, 2014) indicate that the past three decades have been the warmest at the Earth's surface since 1850, with greenhouse gas emissions peaking between 2000 and 2010. These indicators show that climate change has led to decreased food production, altered rainfall patterns, and loss of ice masses, which has directly affected water security and increased the frequency and intensity of extreme climatic phenomena. These repercussions have hindered efforts to achieve sustainable development goals and demonstrated the urgent need to take immediate measures and effective actions to adapt to these climate changes, which are fundamentally due to increased carbon dioxide emissions. Otherwise, temperatures are expected to rise significantly during the period (2021-2040). Zhang et al. (2024) showed that the increasing variability of rainfall poses a challenge to climate forecasts. This increase in variability is primarily attributed to the thermodynamics associated with atmospheric humidification. Rising temperatures lead to atmospheric humidification and, consequently, to an increase in rainfall. The researchers confirmed that rainfall variability has increased globally over the past century as a result of global warming resulting from human activities.

The report also confirmed that annual greenhouse gas emissions for 2010-2019 were the highest compared to any previous decade (IPCC, 2023). It is likely that there will be an increase in the frequency or amount of heavy rainfall in the twenty-first century in many regions of the world as global warming continues (IPCC, 2021). These climatic fluctuations require sustainable strategies for managing water resources and adapting to future climate scenarios.

In the field of climate articles, numerous scientific studies have focused on analyzing the trend of climatic elements. Şen et al. (2019) indicated that global climate changes have led to a significant increase in scientific research that relies on trend analysis of time series for climatic elements, such as precipitation and temperature (Sa'adi et al., 2017; Kushwaha et al., 2024; Güçlü et al., 2025; Adesogan & Sasanya 2025; Hassan & Khan, 2025) and humidity (Asadi & Karami, 2020; Eryürük & Eryürük, 2024). They also noted an increase in studies following classical methods in trend analysis, such as Mann-Kendall test (Mann, 1945; Kendall, 1975) recommended by the World Meteorological Organization (WMO, 2018). In recent years, modern analysis techniques have gained wide popularity, such as ITA (Sen, 2012), and IPTA (Sen et al., 2019), which are characterized by high sensitivity in detecting time series trends compared to traditional tests, like Mann-Kendall (Ahmed et al., 2023; Alifujiang et al., 2023; Esit, 2022). A study conducted by Weng et al. (2022) proved that ITA and IPTA techniques outperform MK in detecting changes in rainfall time series in China from 1959-2014.

Iraq is one of the most vulnerable countries to climate change, facing environmental, economic, and social challenges, such as rising temperatures, dwindling water resources, and desertification, that threaten agricultural productivity. The country experiences extreme heat waves, recurrent droughts, and erratic rainfall (Ali et al., 2024), with average annual temperature increases ranging from 0.28°C to 0.48°C per decade (Al-Timimi et al., 2024). While water scarcity is exacerbated by the water policies of neighboring countries and inefficient water resource management in agriculture and industry (Ali et al., 2024), economically, the agricultural sector is particularly severely hit, leading to growing food insecurity and economic instability (Al-Din & Ali, 2024). In addition, desertification and drought have led to the degradation of thousands of hectares of land, threatening the livelihoods of rural populations (Hassan et al., 2023b). Iraq is among the countries most severely affected by global climate change and was classified as one of 23 nations that experienced drought between 2020 and 2022 (Drought in Numbers, 2022).

Numerous studies have employed traditional trend analysis methods to assess increasing or decreasing trends in rainfall and temperature across Iraq (Roboaa & Al-Barazanji, 2015; Mahmood Agha & Şarlak, 2016; Salman et al., 2019; Yehia et al., 2023; Al-Merib & Obead, 2024). Most studies indicated a decline in rainfall and an increase in temperatures, although some results were not statistically significant. In contrast, Al-Lami et al. (2024) utilized only the ITA test, which provided more accurate and statistically significant results compared to the Mann-Kendall (MK) and Linear Regression Analysis (LRA) tests. Their study found no statistically significant trend at the 90%, 95%, and 99% confidence levels for annual rainfall time series across 16 meteorological stations in Iraq.

This study aims to analyze the overall trends in rainfall and temperature in Iraq using ITA and IPTA over the period 1990-2023. The analysis is based on data from 16 meteorological stations distributed across Iraq. Additionally, the study provides a comprehensive assessment of climate change impacts by applying modern trend analysis methods to the rainfall in Iraq. Also, IPTA analysis has not been used in Iraq before.

Study Area and Climate Data

Iraq occupies the western portion of Asia at the heart of the Middle East, bounded by latitudes from 29° to 37° N and longitudes from 39° to 48° E. Covering approximately 437,072 km², Iraq experiences a semi-arid climate. It borders Türkiye to the north, Saudi Arabia to the south, Iran to the east, and Syria and Jordan to the west. The topography of the country varies from mountainous terrain in the north to fertile alluvial plains in the south, with plateaus, hills, and the Jazira region between both (Nadhir Al-Ansari, 2025), as shown in Figure 1.

This geographic diversity has a significant impact on rainfall patterns, with northern areas receiving more rainfall than the south. For this study, monthly rainfall data from 16 meteorological stations across Iraq for the period 1990-2023 was analyzed. The 34-year record provides a robust basis for examining climatic variability within the study area.

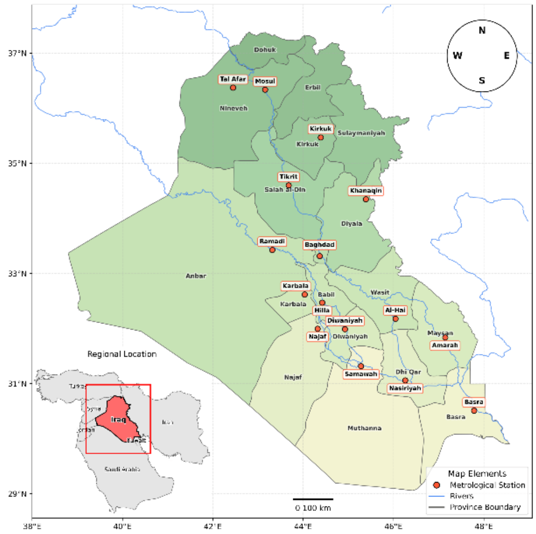

Figure 1. Study area and spatial distribution of meteorological stations in Iraq

METHODOLOGY

In this study, ITA and IPTA were applied to the monthly rainfall in order to identify rainfall trends across Iraq.

Innovative Trend Analysis (ITA)

Şen (2012) introduced the ITA technique. Its main advantage is that it does not require any *a priori* assumptions regarding standard deviation, serial correlation, or time-series length, unlike certain conventional statistical methods. Consequently, ITA is regarded as one of the most effective approaches for trend detection.

The ITA procedure begins by dividing the time series into two equal halves, each then arranged in ascending order. The values of the first half are then plotted on the horizontal axis, and those of the second half are plotted on the vertical axis, within a Cartesian coordinate system. A 45° reference line (1:1 line) is added to the plot to delineate the direction of change. Thus, the core objective of ITA is to partition the climatic data so as to distinguish and compare trends between the series first and second halves (Şen, 2012). When the plotted points cluster closely around and along the 1:1 line, this indicates an absence of a clear trend; clustering in the upper triangle (above the line) denotes an upward trend, while clustering in the lower triangle (below the line) denotes a downward trend (Figure 2).

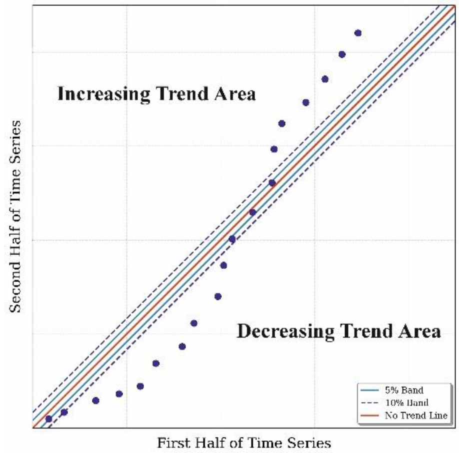

Figure 2. ITA monthly overview

The strength of ITA lies in its capacity to discriminate among different rainfall scenarios; low, moderate, and heavy, making it a versatile analytical tool for assessing climate variability (Nair et al., 2024). To help understand the trends shown in the graphs, we added ±5% and ±10% bands around the 1:1 reference line in the ITA plots (Cui, 2017; Alifujiang, 2020; Gujree, 2022; Rana, 2023). These auxiliary bands operate as graphical supports, focusing on the consistency of deviations in the data distribution. Their inclusion is intended solely to supplement the trend assessment graphically and has no statistical implications.

Innovative Polygon Trend Analysis (IPTA)

Şen et al. (2019) developed the Innovative Polygon Trend Analysis (IPTA) as an extension of the Innovative Trend Analysis (ITA), providing a means to track temporal variations in climatic records at daily, monthly, and annual scales. The procedure starts by splitting a monthly rainfall series into two equal sections, the earlier and the later halves, and arranging the values from each section in a twelve-column matrix corresponding to the calendar months. Summary statistics are then calculated for every month in both halves.

The paired statistics are plotted on Cartesian axes, with first-half values on the x-axis and second-half values on the y-axis, producing twelve points that represent the months of the year. A 45° reference line (the 1:1 line) is drawn to distinguish positive from negative shifts; points positioned above this line indicate an increasing tendency, whereas points below it suggest decline. Joining the monthly points sequentially from January to December generates a polygon the outline of which depends on the underlying data, as shown in Figure 3. Highly irregular or indented polygons point to pronounced hydrological variability and complex climatic forcing in the study area (Şen et al., 2019; Şen, 2021).

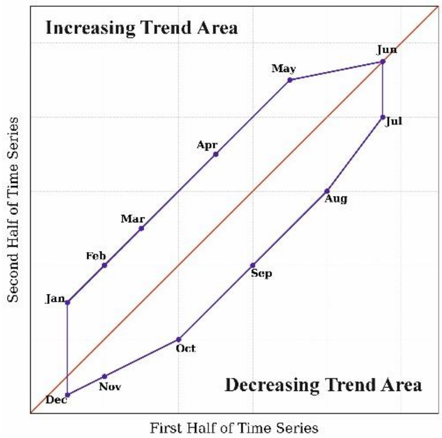

Figure 3. IPTA monthly overview

A key advantage of IPTA is that it can be applied to different lengths and accommodates a range of descriptive statistics, including means, standard deviations, and maximum and minimum values. It provides researchers with a versatile framework for assessing month-to-month rainfall behavior and for diagnosing broader signals of climate change.

RESULTS AND DISCUSSION

Rainfall is a fundamental component of the hydrological cycle, and changes in its pattern, due to current climate change, are disrupting this cycle. Monitoring the overall trend of precipitation is crucial to understanding the impact of global warming on Earth. Therefore, monitoring the general trend of rainfall is of paramount importance for understanding the effects of global warming on Earth. Accordingly, the ITA and the Innovative Polygon Trend Analysis methods were applied to monthly rainfall data for the period 1990-2023 for 16 meteorological stations distributed throughout Iraq.

Innovative Trend Analysis (ITA)

The results obtained showed significant negative trends in the majority of stations (13 out of 16), constituting 81.25% of stations, with the exception of

Baghdad and Al-Hay stations which showed a positive trend, and Karbala station which appeared without a clear trend, as shown in Figure 4. It was observed that the stations (Tal Afar, Mosul, Kirkuk, and Basra) had the highest negative trend, with the percentage of points below the ±10% confidence bands reaching (54.41%, 54.41%, 68.38%, and 66.91%), respectively.

Northern Region

A uniform negative trend was observed in the northern stations (Tal Afar, Mosul, and Kirkuk) across all stations, where the results revealed that more than 90% of data points fall below the 1:1 line, indicating a clear decrease in rainfall. The highest was at Tal Afar station (96.32%), followed by Mosul and Kirkuk stations at 95.59% and 94.12%, respectively. It was also observed that many points fall outside the ±10% confidence bands, indicating significant negative trends in rainfall patterns, as shown in Figure 5. This decrease may pose a major threat to agriculture in these regions, which are among the most prominent agricultural areas that depend primarily on rainwater, which may directly affect rain-fed crops and increase food security challenges in Iraq.

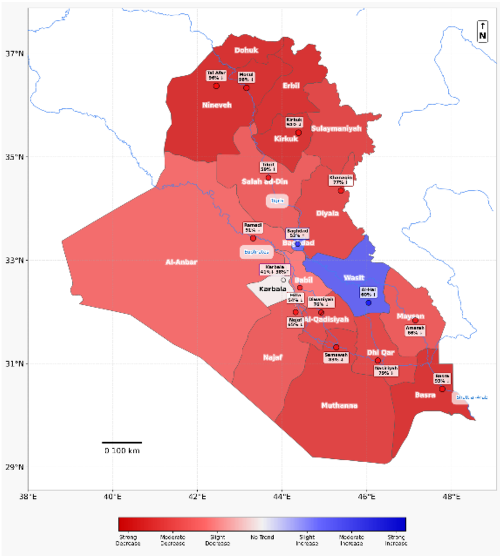

Figure 4. ITA-based rainfall analysis in Iraq (1990-2023)

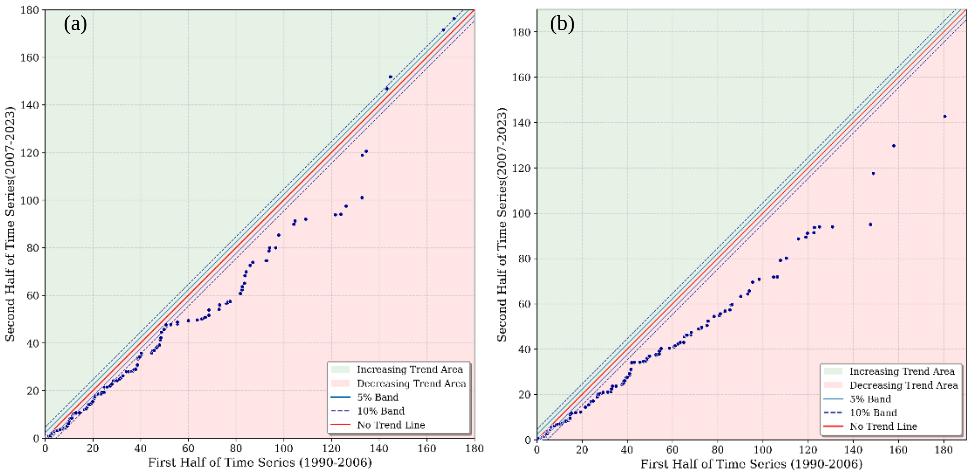

Figure 5. ITA for (a) Mosul station, (b) Kirkuk station

Central Region

The central region stations showed a clear negative trend, with the highest percentages at Ramadi and Khanaqin stations 91.18% and 77.21% below the 1:1

line, respectively, and the least pronounced at Tikrit and Hillah stations, where the percentage of points below the 1:1 line was 58.82% and 54.41%, respectively. Applying the ±5% confidence bands to these stations resulted in a significant decrease in the percentage of points outside the bands, indicating that the negative trends in these stations are less strong. As shown in Figure 6, we observe a decrease in the percentage of points below the 1:1 line from 58.82% without confidence bands to 25% with ±5% bands and to 13.24% with ±10% bands.

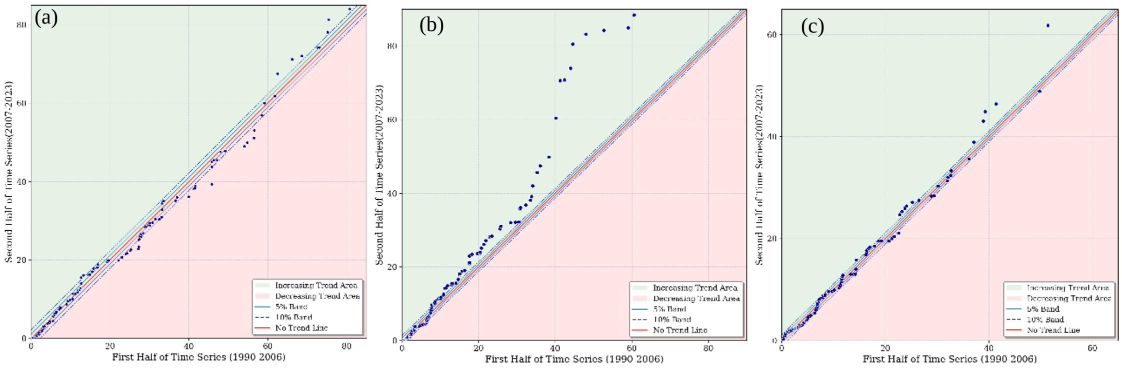

Figure 6. ITA for (a) Tikrit station, (b) Baghdad station, (c) Karbala station

At Baghdad station (Figure 6), trends generally showed an increase in rainfall, with 52.21% of points above the 1:1 line. The pattern of increase was particularly evident in low-and medium- rainfall values (53.33% and 64.44% above the 1:1 line), while high rainfall values showed a decreasing trend (51.11% below the line). This indicates that rainfall may be increasing at this station. This varied behavior across rainfall magnitudes indicates complex changes in rainfall patterns and may differentially affect water management strategies, such as flood control or water supply provision.

Figure 6 showed at Karbala station a unique pattern where the distribution was nearly equal for points above the 1:1 line 38.24% and below it 41.18%, and when applying the ±5% confidence bands, this balanced distribution became more evident (22.06% above, 22.79% below), and with ±10% bands, the vast majority of points (83.09%) fell within the bands. This indicates that the rainfall pattern in Karbala does not show a clear trend. The results of the central region reflect a significant change in rainfall series patterns, reflecting a diversity in climate patterns that may require measures to adapt to climate changes.

Southern Region

In the southern region, a clear negative trend was discovered at Basra station, which showed a consistent decreasing trend across magnitudes (low, medium, and high), with 92.65% of points below the 1:1 line. Other southern stations; namely, Samawah, Nasiriyah, Diwaniyah, Amarah, and Najaf, also showed decreasing trends at varying percentages of 83.09%, 79.41%, 76.47%, 66.18%, and 65.44%, respectively. Finally, Al-Hay station represented a notable exception within the southern region, showing a prominent increasing trend with 59.56% of points above the 1:1 line, as shown in Figure 7.

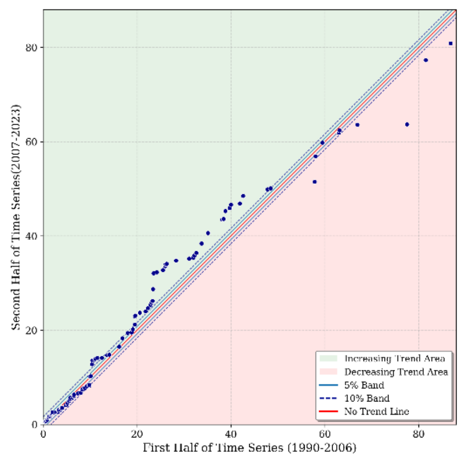

Figure 7. ITA for Al-Hay station

Innovative Polygon Trend Analysis (IPTA)

This analysis holds significant importance, as it provides a comprehensive assessment and vision of the trends observed at each station. The results of the innovative monthly trend analysis showed varied tendencies between increase and decrease across most stations, revealing a clear shift in the pattern of rainfall distribution in Iraq, as shown in Figure 8.

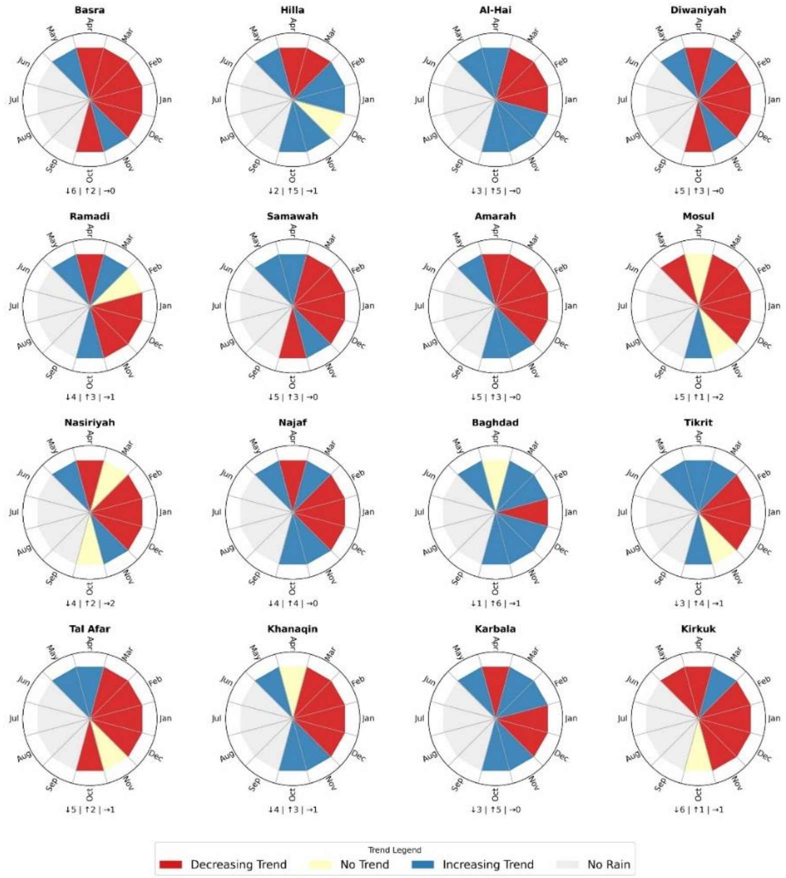

Figure 8. Monthly rainfall trend patterns for meteorological stations

Stations in the northern and southern regions showed a clear pattern of decrease, especially during winter months (December, January and February), while stations in the central region demonstrated more varied and fluctuating patterns. Winter rainfall (December-February) decreases in 87.5% of stations, while increasing by the same percentage in late spring (May), whereas autumn rainfall amounts (November) increase in 68.75% of stations. This indicates a notable decrease in traditional winter rainfall, counterbalanced by an increase in rainfall during transitional periods (autumn and spring). Furthermore, IPTA diagrams display irregular polygons for all stations, suggesting that the prevailing climatic conditions are unstable and of a complex nature.

Northern Region

The polygon shown in Figure 9 demonstrates a clear deviation of monthly rainfall averages toward the decreasing trend, particularly for months with high rainfall, with some limited shifts toward the increasing trend in some spring or autumn months for the three stations in the northern region. A decreasing trend was recorded in January, February, and December at all northern region stations, with variations in the remaining months. March showed a decreasing trend at Mosul and Tal Afar stations while recording an increasing trend at Kirkuk. May showed a decreasing trend at Mosul and Kirkuk *versus* an increasing trend at Tal Afar, and October recorded a decreasing trend at Tal Afar *versus* an increasing trend at Mosul and no clear trend at Kirkuk. As for April and November, their trends varied, with April showing no clear trend at Mosul, an increasing trend at Tal Afar, and a decreasing trend at Kirkuk, while November showed no clear trend at Mosul and Tal Afar and a decreasing trend at Kirkuk.

This pattern indicates a general decrease in rainfall rates in the northern region during the main winter season with variation in seasonal transition periods.

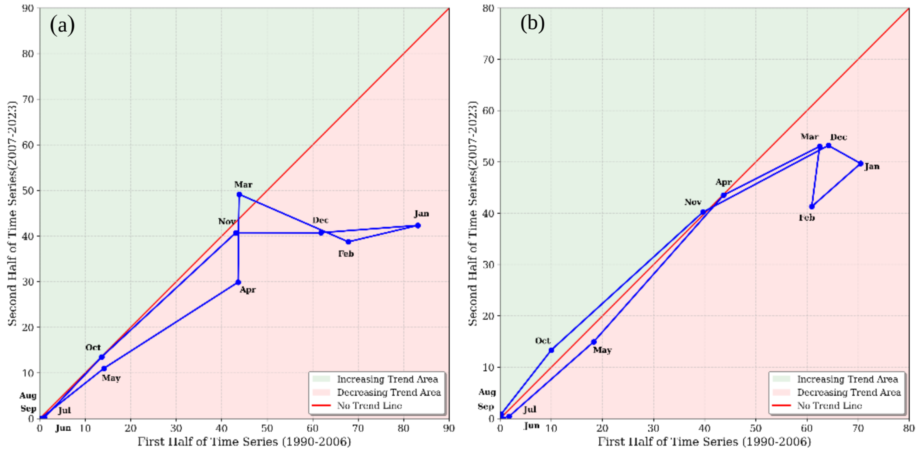

Figure 9. IPTA for (a) Kirkuk station, (b) Mosul station

Central Region

The analyses of the central region stations in Figure 10 reveal significant changes in rainfall rates between the two halves of the study period, with clear variation in change trends. The results show a decreasing trend in Khanaqin, Ramadi, Karbala, and Tikrit stations during winter months, while an ascending trend was recorded at Baghdad and Hillah stations. All central region stations showed an increasing trend in May and October, while the remaining months varied. A decreasing trend was recorded in January at five stations (Baghdad, Khanaqin, Ramadi, Tikrit and Karbala) *versus* an increasing trend at Hillah station only. February showed a decreasing trend at Khanaqin and Tikrit stations and no clear trend at Ramadi, while recording an increasing trend at Baghdad, Hillah, and Karbala stations. March showed a decreasing trend at Khanaqin and Hillah stations and an increasing trend at four other stations (Baghdad, Karbala, Tikrit and Ramadi). April recorded a decreasing trend at Ramadi and Karbala, an increasing trend at Tikrit, and no clear trend at Baghdad and Khanaqin. November also varied, showing a decreasing trend at Ramadi, an increasing trend at four stations (Baghdad, Hillah, Karbala and Khanaqin), and no clear trend at Tikrit. December showed a decreasing trend at four stations (Khanaqin, Ramadi, Tikrit and Karbala), an increasing trend at Baghdad, and no clear trend at Hillah. This variation indicates differences in rainfall rates between years, increasing the complexity of future climate predictions.

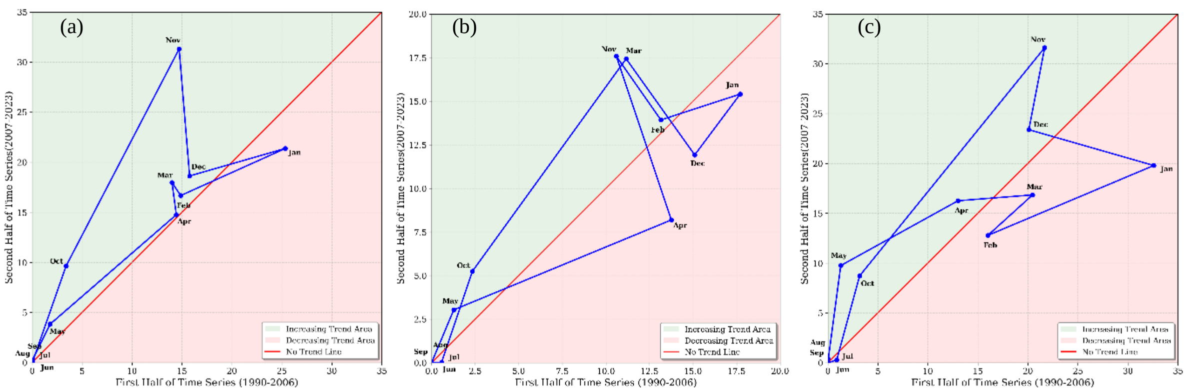

Figure 10. IPTA for (a) Baghdad station, (b) Karbala station, (c) Al-Hay station

Southern Region

The southern region includes Al-Hay, Nasiriyah, Najaf, Basra, Diwaniyah, Samawah, and Amarah stations. The results showed common features with important differences between stations. A decreasing trend was recorded in January at all southern region stations, as well as in February except for the Najaf station, which showed an increasing trend. March varied between a decreasing trend at Basra, Amarah, Al-Hay, and Samawah stations; an increasing trend at Najaf and Diwaniyah stations; and no clear trend at Nasiriyah. April showed a decreasing trend at five stations (Basra, Nasiriyah, Najaf, Diwaniyah and Amarah) *versus* an increasing trend at Al-Hay and Samawah stations. May showed an increasing trend at all southern region stations, indicating an increase in late spring rainfall. October varied between a decreasing trend at Basra and Diwaniyah stations, an increasing trend at Al-Hay and Najaf stations, and no clear trend at Nasiriyah. In November, all southern region stations; namely, showed an increasing trend, indicating an increase in autumn rainfall. In December, six stations; namely Basra, Nasiriyah, Najaf, Diwaniyah, Samawah, and Amarah showed a decreasing trend, while only Al-Hay station showed an increase (Figure 10). This diverse pattern confirms a shift in rainfall distribution, with a general decrease in winter months and an increase in autumn and late spring months, indicating a change in the region's traditional climate system.

CONCLUSIONS

The present study merged Innovative Trend Analysis (ITA) and Innovative Polygon Trend Analysis (IPTA) to investigate how rainfall has changed across Iraq during the 34-year interval from 1990 to 2023, drawing upon monthly records collected at 16 meteorological stations.

Results from ITA point to a broad drying tendency: approximately 81.25% of the stations exhibit downward trends in rainfall. This tendency is most acute in the north, where Tal Afar, Mosul, and Kirkuk stations each showed more than 90% of their paired data below the 1:1 reference line. The highest was at Tal Afar station (96.32%), followed by Mosul and Kirkuk stations at 95.59% and 94.12%, respectively. a signal that threatens rain-fed agriculture in that region. In central Iraq, Baghdad station registers a moderate increase in rainfall, with 52.21% of points above the 1:1 line, whereas other stations in the same belt record declines of differing magnitudes. The southern region displays predominantly negative behavior: six of the seven stations indicate decreasing rainfall, with Basra station recording the sharpest deficit (about 92.65% of points below the reference line). Al-Hay station stands out as the lone southern site with an upward tendency with 59.56%.

IPTA delivered critical additional insights by revealing pronounced seasonal re-distribution that ITA alone could not detect. Specifically, 87.5% of stations experienced declining winter rainfall (December-February), accompanied by increases during transitional periods, late spring (May, 87.5% of stations), and autumn (November, 68.75% of stations). The irregular polygon shapes in IPTA plots further underscore the increasingly unstable and complex nature of the country’s climatic conditions.

The complementary use of ITA and IPTA proved invaluable. While ITA efficiently identified overall directional trends and their statistical significance, IPTA excelled at capturing subtle monthly transitions and seasonal re-distribution patterns. This methodological synergy made it possible to detect critical changes in precipitation regimes that might be overlooked when using either method alone.

These results call for the development of strategies for water resources management that enhance storage capacity to accommodate increased rainfall during transitional seasons, strengthen flood control infrastructure to address rising variability, and promote the simultaneous adaptation of agricultural practices through revised cropping calendars, the adoption of drought-resistant crop varieties, and the improvement of irrigation schedules in line with changing rainfall patterns.

Finally, the evidence presented here highlights significant shifts in Iraq’s rainfall regime, both in terms of overall declines and noticeable seasonal re-distributions, posing immense challenges for a country already suffering from water scarcity. The demonstrated synergy of ITA and IPTA offers a powerful analytical foundation for policy decisions and adaptive strategies aimed at strengthening Iraq’s climate resilience across its vulnerable ecological and agricultural landscapes.

REFERENCES

Abdulla, F.A., & Malkawi, D.A.H. (2020). Potential impacts of climate change on the drought conditions in Jordan. *Jordan Journal of Civil Engineering*, *14*(1), 108-118.

Adesogan, S.O., & Sasanya, B.F. (2025). Climate smart water conservation strategy for sustainable development in Nigeria: A systematic review. In R.U. Onyeneke, C.C. Emenekwe, & C.U. Nwajiuba (Eds.), *Energy transition, climate action and sustainable agriculture*. Springer. https://doi.org/10.1007/978-3-031-83165-2_9

Ahmed, M. O., Ogedengbe, K., & Lawal, N. S. (2023). Innovative trend analysis of hydro-meteorological variables in Ibadan, Nigeria. *Journal of Fundamental and Applied Sciences*. https://doi.org/10.4314/jfas.v14i1.15

Al-Ansari, N. (2025). Water resources in Iraq: Perspectives and prognosis. *Journal of Water Resources and Geosciences*, *4*(1).

Al-Bazaz, H. J., & Mahmood Agha, O. M. A. (2024). Climate change and the behaviour of meteorological drought and its impact on wheat yield. *Engineering and Applied Science Research*, *51*(2), 248-258. https://doi.org/10.14456/easr.2024.24

Al-Bazaz, H.J., & Mahmood Agha, O.M.A. (2023). Study of the homogeneity of climatic data for rain, temperature and humidity for Nineveh Governorate. *AL-Rafdain Engineering Journal*, *28*(2), 173-185. https://doi.org/10.33899/rengj.2023.137763.1225

Al-Din, A. S., & Ali, S. N. (2024). Environmental and climate changes and their effects on the agricultural sector in Iraq. *Journal of Economics and Administrative Sciences*, *30*(143), 275-286. https://doi.org/10.33095/b04fna75

Ali, S.H., Qubaa, A.R., & Al-Khayat, A.B.M. (2024). Climate change and its potential impacts on Iraqi environment: Overview. *IOP Conference Series: Earth and Environmental Science*, *1300*, 012010. https://doi.org/10.1088/1755-1315/1300/1/012010

Alifujiang, Y., Abuduwaili, J., & Abliz, A. (2023). Precipitation trend identification with a modified innovative trend analysis technique over Lake Issyk-Kul, Kyrgyzstan. *Journal of Water and Climate Change*, *14*(6), 1798-1815. https://doi.org/10.2166/wcc.2023.413

Alifujiang, Y., Abuduwaili, J., Maihemuti, B., Emin, B., & Groll, M. (2020). Innovative trend analysis of precipitation in the Lake Issyk-Kul Basin, Kyrgyzstan. *Atmosphere*, *11*(4). https://doi.org/10.3390/atmos 11040332

Al-Lami, A. M., Al-Timimi, Y. K., & Al-Salihi, A. M. (2024). Innovative trend analysis of annual rainfall in Iraq during 1980-2021. *Journal of Agrometeorology*, *26*(2), 196-203. https://doi.org/10.54386/jam.v26i2.2561

Al-Merib, F.H., & Obead, I.H. (2024). Trends characterization for rainfall time series in Middle Euphrates Region, Iraq. *Ecological Engineering & Environmental Technology*, *25*(10), 347-358. https://doi.org/10.12912/27197050/191954

Al-Timimi, Y.K., AL-Lami, A.M., Basheer, F.S., & Awad, A. Y. (2024). Impacts of climate change on thermal bioclimatic indices over Iraq. *Iraqi Journal of Agricultural Sciences*, *55*(2), 744-756. https://doi.org/10.36103/j93nst49

Asadi, M., & Karami, M. (2022). Modeling of relative humidity trends in Iran. *Modeling Earth Systems and Environment*, *8*, 1035-1045. https://doi.org/10.1007/s40808-021-01093-9

Beniston, M., Stephenson, D. B., Christensen, O. B., Ferro, C. A. T., Frei, C., Goyette, S., Halsnaes, K., Holt, T., Jylhä, K., Koffi, B., Palutikof, J., Schöll, R., Semmler, T., & Woth, K. (2007). Future extreme events in European climate: An exploration of regional climate model projections. *Climatic Change*, *81*(1), 71-95. https://doi.org/10.1007/s10584-006-9226-z

Cai, X., Zhang, X., Noël, P. H., & Shafiee-Jood, M. (2015). Impacts of climate change on agricultural water management: A review. *WIREs Water*, *2*, 439-455. https://doi.org/10.1002/wat2.1089

Cui, L., Wang, L., Lai, Z., Tian, Q., Liu, W., & Li, J. (2017). Innovative trend analysis of annual and seasonal air temperature and rainfall in the Yangtze River Basin, China during 1960-2015. *Journal of Atmospheric and Solar-Terrestrial Physics*, *164*, 48-59. https://doi.org/10.1016/j.jastp.2017.08.001

Eryürük, K., & Eryürük, Ş. (2024). Assessing trends in monthly precipitation and relative humidity: An analysis for climate change reference in Konya. *Necmettin Erbakan University Journal of Science and Engineering*, *6*(1), 105-114. https://doi.org/10.47112/neufmbd.2024.35

Esit, M. (2023). Investigation of innovative trend approaches (ITA with significance test and IPTA) comparing to the classical trend method of monthly and annual hydrometeorological variables: A case study of Ankara region, Turkey. *Journal of Water and Climate Change*, *14*(1), 305-329. https://doi.org/10.2166/wcc.2022.356

Güçlü, Y.S., Acar, R., & Saplıoğlu, K. (2025). Seasonally adjusted periodic time series for Mann-Kendall trend test. *Physics and Chemistry of the Earth, Parts A/B/C*, *138*, Article 103848. https://doi.org/10.1016/j.pce.2024.103848

Gujree, I., Ahmad, I., Zhang, F., & Arshad, A. (2022). Innovative trend analysis of high-altitude climatology of Kashmir Valley, North-West Himalayas. *Atmosphere*, *13*(5). https://doi.org/10.3390/atmos13050764

Hasan, I.F. (2020). Flood frequency analysis of annual maximum streamflows at selected rivers in Iraq. *Jordan Journal of Civil Engineering*, *14*(4), 573-588.

Hassan, S.A., & Khan, M.S. (2025). Nonlinear analysis of hydroclimatic variability in Pakistan using ITA and IPTA methods. *Pure and Applied Geophysics*, *182*(8), 3255-3283. https://doi.org/10.1007/s00024-025-03741-y

Hassan, W.H., Nile, B.K., Kadhim, Z.K., Mahdi, K., Riksen, M., & Thiab, R.F. (2023). Trends, forecasting and adaptation strategies of climate change in the middle and west regions of Iraq. *SN Applied Sciences*, *5*, Article 312. https://doi.org/10.1007/s42452-023-05544-h

Intergovernmental Panel on Climate Change. (2013). *Climate change 2013: The physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. https://www.ipcc.ch/site/assets/uploads/2018/03/WG1AR5_SummaryVolume_FINAL.pdf

Intergovernmental Panel on Climate Change. (2014). *Climate change 2014: Synthesis report*. https://www.ipcc.ch/site/assets/uploads/2018/02/SYR_AR5_FINAL_full.pdf

Intergovernmental Panel on Climate Change. (2021). *Climate change 2021: The physical science basis*. Cambridge University Press. https://doi.org/10.1017/9781009157896

Intergovernmental Panel on Climate Change. (2023). *Climate change 2023: Synthesis report*. https://doi.org/10.59327/IPCC/AR6-9789291691647.00

Kendall, M. G. (1975). *Rank correlation methods* (4th edn.). Charles Griffin.

Kundzewicz, Z.W., & Matczak, P. (2015). Hydrological extremes and security. In *Hydrological sciences and water security: Past, present and future* (IAHS Publ. No. 366, pp. 44-50). International Association of Hydrological Sciences. https://doi.org/10.5194/piahs-366-44-2015

Kushwaha, P., Pandey, V.K., Kumar, P., Sardana, D., & Yadav, A. (2024). Projection of mean and extreme precipitation and air temperature over India: A CMIP6 analysis. *Journal of Water and Climate Change*, *15*(6), 2562-2581. https://doi.org/10.2166/wcc.2024.523

Lamichhane, S., & Sanjel, S. (2024). Assessing flood risk at the catchment scale by integrating hazard and vulnerability with climate change context. *Jordan Journal of Civil Engineering*, *18*(3), 503. https://doi.org/10.14525/JJCE.v18i3.12

Le Minh Hai, L., Phan Thi Ha, P.T., Dang Nguyen Dong Phuong, D.N., Nguyen Thi Hong, N.T., Nguyen Duy Liem, N.D., & Ho Minh Dung, H.M. (2024). Evaluating trends of temperature index in Gia Lai Province based on IITA and IPTA approaches under climate change. *IOP Conference Series: Earth and Environmental Science*, *1345*, 012016. https://doi.org/10.1088/1755-1315/1345/1/012016

Mahmood Agha, O.M.A., & Şarlak, N. (2016). Spatial and temporal patterns of climate variables in Iraq. *Arabian Journal of Geosciences*, *9*, Article 302. https://doi.org/10.1007/s12517-016-2324-y

Mann, H.B. (1945). Nonparametric tests against trend. *Econometrica*, *13*(3), 245-259.

Naira, A.N.G.R., Sankaran, A., Suresha, A.P., Thomas, C., Ajith, A.K., & Vasanthan, A. A. (2024). Detection of climate non-stationarity of Indian rainfall using innovative trend family of techniques. *KSCE Journal of Civil Engineering*, *28*, 2515-2536. https://doi.org/10.1007/s12205-024-1338-3

Ozturk, T., Ceber, Z.P., Türkeş M., & Kurnaz, M.L. (2015). Projections of climate change in the Mediterranean Basin by using downscaled global climate model outputs. *International Journal of Climatology*, *35*(14). https://doi.org/10.1002/JOC.4285

Qadem, Z., & Tayfur, G. (2024). In-depth exploration of temperature trends in Morocco: Combining traditional methods of Mann Kendall with innovative ITA and IPTA approaches. *Pure and Applied Geophysics*, *181*, 2717-2739. https://doi.org/10.1007/s00024-024-03535-8

Rana, M.S., & Mahanta, C. (2023). Flash-flood susceptibility modelling in a data-scarce region using a novel hybrid approach and trend analysis of precipitation. *Hydrological Sciences Journal*, *68*(16), 2336-2356.

https://doi.org/10.1080/02626667.2023.2259887

Roboaa, E. M., & Al-Barazanji, Z. (2015). Mann-Kendall trend analysis of surface air temperatures and rainfall in Iraq. *Quarterly Journal of the Hungarian Meteorological Service*, *119*(4), 493-514.

Sa'adi, Z., Shahid, S., Ismail, T., Chung, E.S., & Wang, X.J. (2019). Trends analysis of rainfall and rainfall extremes in Sarawak, Malaysia using modified Mann-Kendall test. *Meteorology and Atmospheric Physics*, *131*, 263-277. https://doi.org/10.1007/s00703-017-0564-3

Salman, S.A., Shahid, S., Ismail, T., Ahmed, K., Chung, E.S., & Wang, X. J. (2019). Characteristics of annual and seasonal trends of rainfall and temperature in Iraq. *Asia-Pacific Journal of Atmospheric Sciences*, *55*, 429-438. https://doi.org/10.1007/s13143-018-0073-4

Schimel, J., Balser, T.C., & Wallenstein, M. (2007). Microbial stress-response physiology and its implications for ecosystem function. *Ecology*, *88*(6), 1386-1394. https://doi.org/10.1890/06-0219

Şen, Z. (2012). Innovative trend analysis methodology. *Journal of Hydrologic Engineering*, *17*(9), 1042-1046. https://doi.org/10.1061/(ASCE)HE.1943-5584.0000556

Şen, Z. (2021). Conceptual monthly trend polygon methodology and climate change assessments. *Hydrological Sciences Journal*, *66*(3), 503-512. https://doi.org/10.1080/02626667.2021.188109

Şen, Z., Şişman, E., & Dabanli, I. (2019). Innovative polygon trend analysis (IPTA) and applications. *Journal of Hydrology*, *575*, 202-210. https://doi.org/10.1016/j.jhydrol.2019.05.028

United Nations Convention to Combat Desertification. (2022). *Drought in numbers* (Part 1). https://www.unccd.int

van Dijk, A.I.J.M., Beck, H.E., Crosbie, R.S., de Jeu, R.A.M., Liu, Y.Y., Podger, G.M., Timbal, B., & Viney, N.R. (2013). The millennium drought in southeast Australia (2001-2009): Natural and human causes and implications for water resources, ecosystems, economy, and society. *Water Resources Research*, *49*(2), 1040-1057. https://doi.org/10.1002/wrcr.20123

Wang, X., & Lirong, L. (2015). The impacts of climate change on the hydrological cycle and water resource management. *Water*, *15*(13). https://doi.org/10.3390/w15132342

Weng, X., Long, X., & Ye, Y. (2022). *Comparative analysis of rainfall trends in the Jinghe River Basin during 1959-2014*. Research Square. https://doi.org/10.21203/rs.3.rs-1268301/v1

World Meteorological Organization. (2018). *Guide to climatological practices* (WMO-No. 100). World Meteorological Organization.

Yehia, M.A., Al-Taai, O.T., & Ibrahim, M. K. (2023). Spatiotemporal distribution of mean temperature and total precipitation over Iraq for the period (1980-2017). *IOP Conference Series: Earth and Environmental Science*, *1158*, 032004. https://doi.org/10.1088/1755-1315/1158/3/0320044

Zarch, M.A.A., Sivakumar, B., & Sharma, A. (2015). Droughts in a warming climate: A global assessment of standardized precipitation index (SPI) and reconnaissance drought index (RDI). *Journal of Hydrology*, *526*, 183-195. https://doi.org/10.1016/j.jhydrol.2014.09.071

Zhang, W., Zhou, T., & Wu, P. (2024). Anthropogenic amplification of precipitation variability over the past century. *Science*, *385*(6707), 427-432. https://doi.org/10.1126/science.adp0212