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Spatiotemporal Characteristics of Meteorological Drought in Diyala River Catchment

A Research Submitted to the College of the Engineering University of Babylon in partial Fulfillment of the Requirements for the Degree of Higher Diploma in Civil engineering/water resources Engineering

By

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بسْمِ اللَّـهِ الرحمن الرَّحِيم

(وَقُلِ اعْمَلُوا فَسَيَرَى اللَّهُ عَمَلَكُمْ وَرَسُولُهُ وَالْمُؤْمِنُونَ

وَسَتُرَدُّونَ إِلَى عَالِمِ الْغَيْبِ وَالشَّهَادَةِ فَيُنَبِّئُكُمْ بِمَا كُنْتُمْ تَعْمَلُونَ)

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SUPERVISOR CERTIFICATION

I certify that the proportion of this research entitled "Spatiotemporal Characteristics of Meteorological Drought and Aridity in Diyala River Catchment " was accomplished by "Abeer Abed Khalil" under supervision at the University of Babylon in fulfillment of partial requirements for the degree of High Diploma in Civil Engineering.

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Date: / / 2023

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“In The Name of Allah , Most Gracious, Most Merciful”

Praise be to Allah, as befits His Majesty and the Greatness of His Power, for He has enabled me and given me the strength to complete this simple study.

Starting from the principle of **“Whoever does not thank people, does not thank Allah.”** Therefore, I extend my great thanks and gratitude from me as a student who has benefited from the knowledge of great teachers and supervisors. So without them, I would not have reached what I have reached now.

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I extend my sincere thanks to my family, who support me, encourage me, facilitate my difficulties, also their good impact on myself, and my studies.

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Abstract

It is crucial to assess the effect of climate changing and offer adequate adaptation methods by looking at the spatiotemporal distribution of climatic data and their impact on the distribution of regional aridity and meteorological dryness. In comparison to other natural disasters, drought is one that is of extremely high relevance because of its severity, duration, geographic scope, economic costs, and long-term repercussions.

The Diyala River catchment in Iraq and Iran considered as an examine area, so this research was performed on fourteen stations placed in Iraq and Iran with more than forty years of data. Reconnaissance drought index (RDI) was used for drought monitoring and the associated characteristics analysis in the given stations. During this stage, precipitation, temperature data and parameters of potential evapotranspiration were needed. The Mann-Kendall slope will be used to analyze trends. Through this research, it was found that there is a noticeable sequential increase in the intensity of drought (RDI) in the Diyala River basin.

Keywords: RDI, climate variability, and drought.

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Symbol	Meaning
DRB	Diyalaa River basin
Eq	Equation
M-K	Mann-Kendall
RDI	Reconnaissance drought index
RDIst	Standardised RDI
RDIn	Normalized RDI
RDIk	Initial RDI
PET	Potential Evapotranspiration
p	Precipitation
P_m	catchment's average annual precipitation (mm)
p_i	Station's average value (mm)
a_i	Area of station as determined by Thiessen
BCM	Billion cubic meters
SPI	Standardized Precipitation Index

CHAPTER ONE

INTRODUCTION

1.1 General Background

Climate plays a critical role in the continuation of the life cycle and the survival of humans and other creatures on the earth's surface. Living organisms need different factors in their lives to face difficulties, and the most prominent of these factors are water, air, temperature, and other conditions and factors surrounding our planet. Most of these living organisms and human beings can only live in specific environments, conditions, and climates. For example, humans cannot live in a desert climate without water sources affected by rainfall, weather temperature, and other climate factors.

Plant growth, culture, and survival all depend heavily on the climate. Due to human interventions such as life on earth, military conflicts, global warming, and the water battle, which is the key of life and existence, the climate on the globe has changed significantly over the past many millennia.

Climate change has great local and global economic effects. Some countries are using various means, including changing the geography of the land and the flow of rivers, in order to invest the energy of water for the daily life of man, irrigation, and electricity, and to preserve climate change. Therefore, in order to improve the climate and the environment in which we live, we will have to prepare a study to see the cause of climate changes and the side effects that occurred throughout the previous years and to predict the climate effects and our future patterns that will occur in the coming years in order to avoid disasters such as drought, earthquakes, and other natural climatic phenomena.

The study result will depend on the analysis of precipitation, temperature levels, (PET) potential evapotranspiration, and RDI. As a result, the purpose of this study is to evaluate the influence of long-term fluctuations and the distribution of meteorological data on the recent 41-year (1981–2021) drought and dry conditions in the region, using the Diyala watershed as an example of an arid or semi-arid basin to show the climatic characteristics in these regions.

1.2 Aim and objectives

The study's main goal is to thoroughly examine the long-range climatic and hydrological data series for the greatest number of stations within the Diyala River Basin (DBR), determine RDI using the Mann-Kendall test, and then examine the key variables affecting water sources during the relevant time period.

However, the following are the study objectives:

(1) Applying a parametric test to determine the size of the hydrologic and weather data's yearly trend (simple linear return).

(2) Using the Mann-Kendall method, which is not a parametric test, to check the temporal stream in the annual time series values.

(3) Examining the hydro-climatic data for long-term variability over a long period and the highest number of stations in the DRB.

Chapter one: INTRODUCTION

As it introduces the study's primary elements, Chapter 1 discusses the study's basis. Aim & Purpose.

Chapter two: LIERATURE REVIEW

This chapter introduces the overall analysis of the study's literature. It also provides an overview and an analysis of the hydro-climatic data trend.

Chapter three: MATERIALS AND METHODS

This chapter introduces: study area, gathering and analyzing data, tools used, Meteorological Drought (RDI), Standardised Precipitation Index, and Standardized Precipitation Evapotranspiration Index.

Chapter four: RESULTS AND DISCUSSION

Chapter four explains the results and the key conclusions in detail and in debate. The following sections are included in this chapter: Data Trend Analysis and for Hydro-Climate ,Temporal change of time-series trend and Calculation of the Basin Average Precipitation.

Chapter five: CONCLUSIONS AND RECOMMENDATIONS

This chapter explains in fully the conclusions drawn from the findings, the effects of climatic change and human actions, and recommendations.

CHAPTER TWO

LITRITURE REVIEW

2.1 Introduction

Several studies have investigated the spatiotemporal characteristics of drought in different regions of Iraq, but few have focused on the Diyala River Basin.

The first study: it's by Furat A. M. Al-Faraj and Dimitris Tigkas (Impacts of Multi-year Droughts and Upstream Human-Induced Activities on the Development of a Semi-arid Transboundary Basin)

The approach of the study is based on the analysis of drought through three drought indices (Standardized Drought Index (SPI), Reconnaissance Drought Index (RDI), and Streamflow Drought Index (SDI), coupled with the current and future conceivable artificial changes upstream, as well as taking into account the effects of climate change. As a representative case, the Diyala River basin, shared between Iraq and Iran, is selected.

The study considered data from 30 years from 1981 to 2010 (precipitation, temperature, wind speed, relative humidity, and solar radiation) from 11 meteorological stations within or near the basin, which are: Ghorveh, Saghez, Sanandaj, Ravansar, Islamabad, Marivan, Sarpolzahab, Dokan, Derbandikhan, Khanaqin, and Baghdad. It then showed two severe droughts in 1999–2001 and 2008–2009 and showed comparable marks related to the near-normal severity over the entire basin. The near-normal severity received the highest score of about 68%. The basin experienced nearly equal distribution at about 16% moderately to extremely dry and moderately to extremely wet conditions. The extremely wet conditions had the lowest marks among all other severity distribution scores.

The second study is by Omer Sabah Al-Tamimi and Shaima Abd Algalil Gamel (The Climatic Regions and Desertification Level for the Diyala River Basin in Iraq).

The stations included Sulaimaniya, Khanaqin, Tuzkhurmatu, Khakis, and Baghdad for the period 1984–2014. Depending on three climatic classifications (Kippen's, Demarton, and Raghunath), the study area classified the Diyala River Basin in Iraq into three climatic zones. The northern regions of the region fall under the semi-humid or moderate zone. The second zone is the semi-dry climate, which spreads over the middle part of the region. The third one is described as being dry and covers the southern regions. The study indicates an increase in the area of lands affected by the dry climate on account of the lands that used to lie under the effect of the semi-dry climate.

Third study : it's by Mahmoud Saleh Al-Khafaji and Rusul A H Al-Ameri(Indices-Based Evaluation of Spatiotemporal Distribution of Drought Within Derbendkhan Dam Watershed)

In this study, three drought indices (DIs) were computed for the evaluation of the spatiotemporal extent of drought within the Derbendikhan Dam Watershed (DDW) in the Diyala River Basin, Iraq.

Based on the monthly weather data for the period (1984–2013) downloaded from the Climate Forecast System Reanalysis (CFSR) for eight stations located within

DDW, The reconnaissance drought index (RDI), standard precipitation index (SPI), and streamflow drought index (SDI) at a 12-month time scale were computed to assess droughts in the DDW. The results show that the performances of different DIs are strongly correlated with the dominant factors of drought and drought duration.

Additionally, when precipitation and evaporation are the primary controlling factors of drought events, the SPI and SDI are less accurate than the RDI. However, the SPI and SDI indices are identical in the same proportions of dry years, which are less than the ratio of dry years to an RDI, the severity of the drought from the SDI results is higher than the severity of the droughts relative to the SPI and RDI. The three indices indicate that the eastern region is drier than the western region, which is somewhat wet.

Overall, these studies highlight the importance of understanding drought characteristics to develop appropriate management strategies to mitigate its impacts on society and the environment. and suggest that drought is increasing and becoming more frequent in the Diyala River Basin.

However, there is a lack of modern new research on the spatiotemporal characteristics of drought in the Diyala River Basin, in particular, that covers more stations to become more accurate, in addition to the different methodologies used in these studies. Therefore, the present study aims to fill this gap using the Reconnaissance Drought Index (RDI) to evaluate the spatiotemporal patterns of meteorological drought in the Diyala River Basin from 1981 to 2021. The study uses data from 14 weather stations placed within the basin to provide a comprehensive picture of drought conditions in the region. The results of this study can provide valuable information for water resource management and agricultural planning in the Diyala River Basin.

2.2 Climatic Data Analysis

A popular non-parametric method for identifying differences in hydroclimatic datasets is the Mann-Kendall (M-K) test. The MK test is employed to spot progressive monotonic trends; these studies are briefly explained below.

The M-K test can be used to identify trends in data sets. To determine if the parameters under study are monotonically growing or decreasing over time, one non-distribution-based strategy is to use the M-K approach (Dahamsheh and Aksoi 2007; Seibert and Vis 2012).

The tendency may not always be linear, though the M-K test can be used instead of parametrical linear regression analysis to determine whether the model's anticipated linear regression trend deviates from zero. To use the M-K test, the time series must be free of serial and autocorrelation correlations. To manage water resources sustainably, meteorologists, hydrologists, and agriculturalists must consider the direction test of climatic information variability (Kundzewicz et al., 2009; Brunsell et al., 2010; Piao et al., 2012). The average temperature on Earth increased by 0.6 °C in the 20th century, and numerous weather prediction models forecast a sharp increase in the average air temperature of 1.4 to 5.4 °C (IPCC 2001). Numerous academics (Sankarasubramanian and Vogel, 2003; IPCC, 2007; Kang et al., 2007; Fu et al., 2007; Hao et al., 2008; Lioubimtseva and Henebry, 2009; Shrestha et al., 2012; Dai, 2013) advised that changes in the distribution of climate factors would influence the frequency of extreme phenomena like floods and droughts as well as the soil moisture, spatiotemporal style of surplus precipitation, and subsurface water employment. Numerous studies have recently investigated spatiotemporal trends and their significance in climatic (air, precipitation, humidity, temperature, etc.) and hydrological datasets using parametric (linear regression) and non-parametric (M-K) methods in a variety of locations (Zhao et al., 2015; Alhaji et al., 2018; Pirnia et al., 2019; Gadedjisso-Tossou et al., Even though numerous recent studies have tested for trends in hydro-climatic variables in Iraq (Al-Hasani 2021; Ahmed et al. 2021; Basheer 2022; Muter et al. 2020). But regardless of whether they examined non-parametric or parametric testing, they failed to account for the data's pivot point.

CHAPTER THREE

MATERIALS & METHODS

3.1 Study area

The Tigris is a main river in Western Asia that originates in Turkey's Taurus Mountains, flows via Syria, and then enters Iraq via Feshkhabur town. The Khabour, Greater Zab, Lesser Zab, and Diyala River Basins, which are its four main feeder branches, provide water for its river basin in Iraq. As a result, the river branches are shared by the countries of Turkey, Iran, and Iraq (see Table 3.1).

Table 3.1 Most of the feeder branches to Tigris River. (Mohammed et al., 2018)

Tributaries	Total basin area (Km2)	Tributary Length (Km)	Shared area %		
			Iraq	turkey	Iran
Khabour	6143	181	43	57	-
Greater Zab	26310	462	65	35	-
Lesser Zab	19780	302	76	-	24
Diyala	32975	574	46	-	54

This study will employ the Diyala River watershed, which is shared between Iraq and Iran, as a sample basin. The DRB's climatic conditions are semi-arid and arid. The Tangro, Sirwan, and Wand rivers meet to create the Diyala River, which then becomes the 5th feeder of the Tigris River in Darbandikhan Lake in Sulaymaniyah city, north of Iraq (Haitham A. Hussein, 2010).

The river runs through Iran and Iraq for a total distance of roughly 574 kilometres before entering the Tigris River south of Baghdad, where it starts in the Zagros Mountains. Between lat (33°22 to 35°78) E and long (44°19 to 47°89) N, the whole area of the Diyala River Basin (DBR) is close to 32975.6259 kilometres, with 46% of it located in Iraq and the remaining 54% in Iran (Haitham A. Hussein 2010 and wikipedia.org). (see Fig. 3.1).

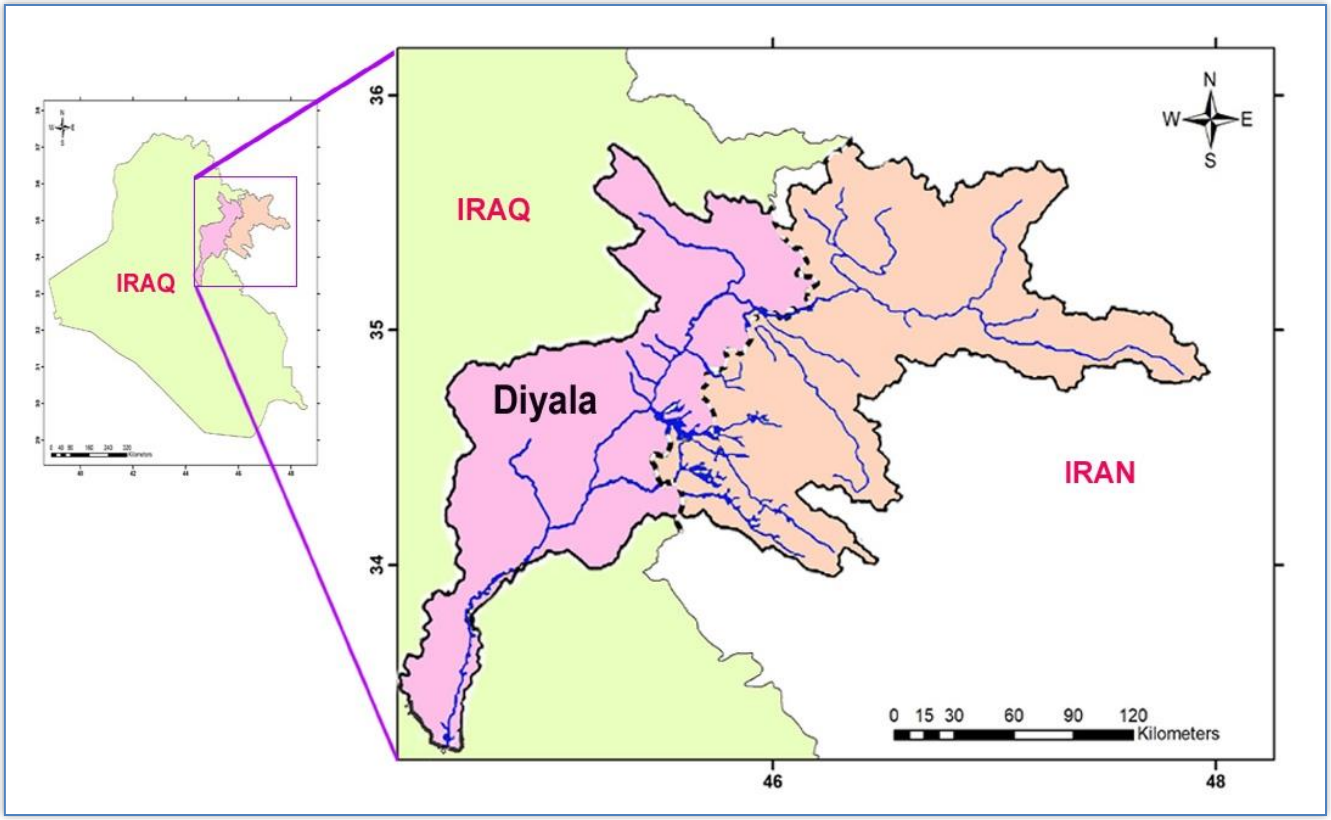


Fig. 3.1 Diyala River Basin location and selected meteorological stations.

Two dams control the flow of the river. The first is Darbandikhan Dam. Two dams are controlling the river's flow. The first one is Darbandikhan, which is the second-biggest dam in the north of Iraq. The dam is located in Darbandikan and was built in 1961 for a variety of purposes, including electric power generation, flood protection, and irrigation of agricultural crops. The watershed area covers approximately 17,850 square kilometres; 20% of it is in Iraq, and the remainder is in Iran. So the total storage capacity of the Darbandikhan tank is 3 BCM (billion cubic metres). Above this dam, the Diyala River is approximately 217 kilometres away.

Hemrin, the second dam in the Diyala River Basin, is also an earth dam. East of Baghdad city, Hemrin was constructed, and its opening was in 1981 in the midst of the Diyala River, 120 kilometres north of Baghdad. The important goal of the Hemrin dam is to generate electricity and irrigation for the Khalus Irrigation Plan. The Hemrin Dam catchment spans 12,822 km2. 68% of its area is in Iraq, but the remaining area is located in Iran. The total storage capacity of the Hemrin tank is 2.4 BCM (Hussain Muhamed et al., 2021).

The Diyala River Basin is classified into 3 areas: upstream (between the Zagros Mountains and Darbandikhan Dam),, middle (between Hemrin Dam and Darbandihan), and downstream (between the Tigris River and Hemrin Dam).

3.2 Gathering and analyzing data

The following hydrological and atmospheric data were considered in this study: Between 1981 and 2021, the Google Earth Pro programme provided monthly precipitation, minimum, and maximum atmospheric data sets from fourteen climate stations ranging in altitude from 0 to 13730 metres (Table 3.2). (R. Mohammed et al. 2018).

Latitude, longitude, and elevation for chosen stations in the DRB are shown in Table 3.2.

Table 3.2 Latitude, longitude, and elevation for chosen stations in the Diyala Basin

No.	Sub-basins	Station Names	Longitudes	Latitudes	Elevations (m)
1	Upstream	Sanandaj	47	35.33	13730
2		Ghorveh	47.8	35.17	1906
3		Ravansar	46.66	34.72	1363
4		Marivan	46.2	35.52	1287
5		Sulaymaniyah	45.38	35.56	824
6		Halabcha	45.95	35.2	620
7	Middle part	Darbandikhan	45.69	35.11	451
8		Paveh	46.35	35.04	1560
9		Eslamabad	46.43	34.13	1346
10		Tus	44.65	34.83	0
11	Downstream	Baquba	44.66	33.75	41
12		Jalawla	45.11	34.32	89
13		Kalar	45.165	34.27	231
14		Baghdad	44.41	33.31	32

The ArcGIS v10.8.2 programme was used. Also, the Mann-Kendall test was used by using XLSTAT, a Microsoft Excel add-in. The Thiessen polygon network calculation was applied to calculate the location of weather and hydrological sites and delineate the river basin. The Food and Agriculture Organisation's Penman-Monteith standard technique was also used to find the potential evapotranspiration PET (mm) (Allen et al. 1998), which was calculated by the Drin C programme. The Thiessen network method can be used to estimate the area of the polygon for each station (AI). This was made possible by the following factors:

- Using lines to connect the nearby stations.
- Making vertical bisectors from all lines
- Forming polygons around each station using the bisectors

3.3 Used Tools

1. ArcGIS 10.8.2: It was used to locate the hydrological and climatic stations, as well as to draw the river basin and perform the Thiessen network analysis.

2. DrinC 1.7: The drought indices calculator (DrinC) is a simple programme that calculates climate drought indicators like the survey drought index, standardised rainfall index, streamflow drought index, and precipitation deciles. These indexes' primary characteristics are their ease of use and low data requirements for calculation. Minimum, maximum, and mean temperatures are used in temperature-based approaches. DrinC comes with a unit for calculating potential evapotranspiration. To characterise drought, hydrological data must be collected over a time span of at least 30 water years (Tigkas et al., 2012, 2015).

3. XLSTAT: The Mann-Kendall test was performed using a Microsoft Excel add-in.

4. Google Earth Pro 7.3.4: This programme is used to obtain temperature and precipitation data for the study's location and time.

5. The website (climateingine.com): It's a website app that provides climatic information like precipitation for researchers.

3.4 Weather-Related Dryness

3.4.1 Reconnaissance Drought Index

It can be said that there are three types of RDI:: the first one is the standardised (RDI_{st}), the second one is the normalised (RDI_n), and the last one is the initial

($RDI\alpha_k$). The components of the RDI can all be used to express it. The elementary shape is typically employed as a barren index, while the standard form is used to assess the severity of drought. The collected values for potential evapotranspiration and precipitation form the foundation of the aridity index (Vangelis et al. 2013).

The wet period is represented by a positive RDIst value, while on the other hand, the negative one indicates a dry time in comparison to the typical environment of the relevant study region. When the RDI's magnitude decreases, the severity of the drought increases. There are four levels of drought severity:

1. Extreme when (RDI_{st}) is less than (-2.0) .
2. Severe when (RDI_{st}) is less than (-2.0) and greater than (-1.5).
3. Moderate when (RDI_{st}) is less than (-1.5) and greater than (-1.0).
4. Mild when (RDI_{st}) is less than (-1.0) and greater than (-0.5).

3.4.2 Standard Precipitation Index (SPI)

Drought can be recognised and tracked by the SPI. A sequence of collected precipitation for a series of yearly time scales is used to evaluate SPI for a certain region. The rainfall series is fitted to a probability distribution, which is then converted to a normal magnitude distribution. So the mean SPI for the targeted area and the selected duration is therefore zero. Finally, the positive SPI values show greater than middle precipitation, while negative numbers show less than median precipitation. Time records of climatological precipitation are closely matched by the gamma distribution (Vangelis et al. 2013).

CHAPTER FOUR
ANALYSIS OF THE RESULTS

4.1 Data Trend Analysis for the Hydro-Climate

Anthropogenic and environmental change have an impact on long-term hydrological system models (Roba and Al-Berazanji 2013; Al-Ansari 2013; Al-Ansari et al. 2014). By examining these patterns, it might be possible to identify areas where individuals can have a positive impact. The Mann-Kendall test is used to study long-term trends in mean annual temperature, rainfall, and potential evapotranspiration. Diyala River Basin (DRB) for One Decade, a Case Study of Aridity and Semi-Aridity, and the statistical features of the weather factors making up the M-K test of interannual variability for various climatic conditions Precipitation averaged 271 mm in 2015, rising to 702 mm in 2018, after falling to that level the year before. It was 677 mm in 1982 and 271 mm in 2015. In 2021, the precipitation was 250 mm, the smallest amount ever recorded. It has been noticed that the lowest recorded evaporation value from 1993, which was 1863.9 mm, is shown in Figure 4.1.

The distribution of the DRB's brief averages for precipitation, temperature, and evapotranspiration is shown in Figures 4.2, 4.3, and 4.4. The average annual rainfall in the upstream sub-basin ranges from (387–713) mm to (276–609) mm in the middle part and 148–330 mm in the downstream sub-basin. And the average air temperature in the lower basin and the middle part stations in Bakoba and Paveh is 23 °C, and the higher basin station in Sulaymaniyah is 18 °C. It should be noted that the upstream in the sub-basin receives more precipitation than the middle and downstream. And the air temperatures are lower in the upper sub-basin compared to the middle and lower basins.

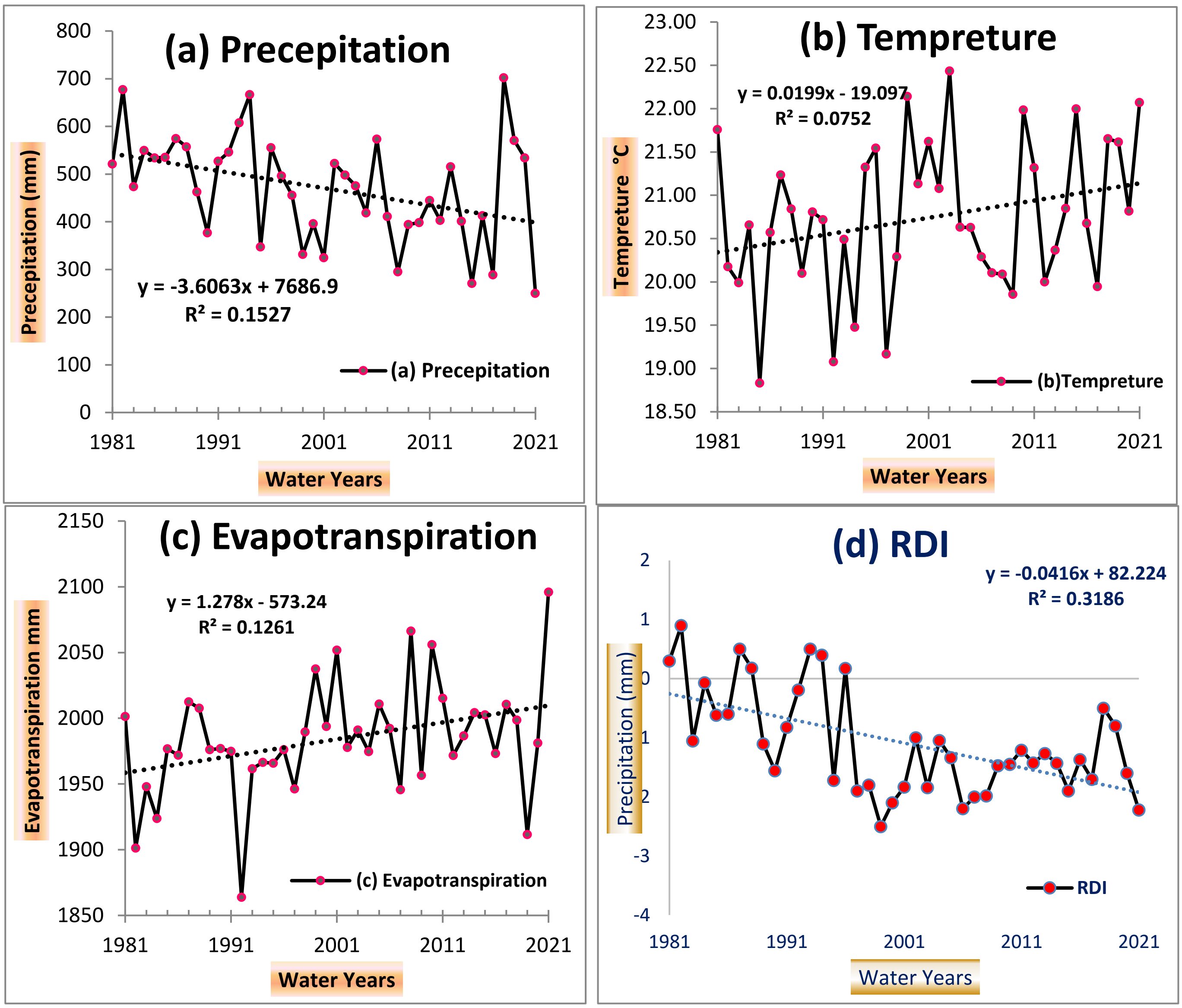


Fig. 4.1 The long-term values of (a) Precipitation; (b) Mean air temperature; (c) Potential evapotranspiration; and (d) Reconnaissance drought Index (RDI) over Diyala Basin in the period from 1981 to 2021

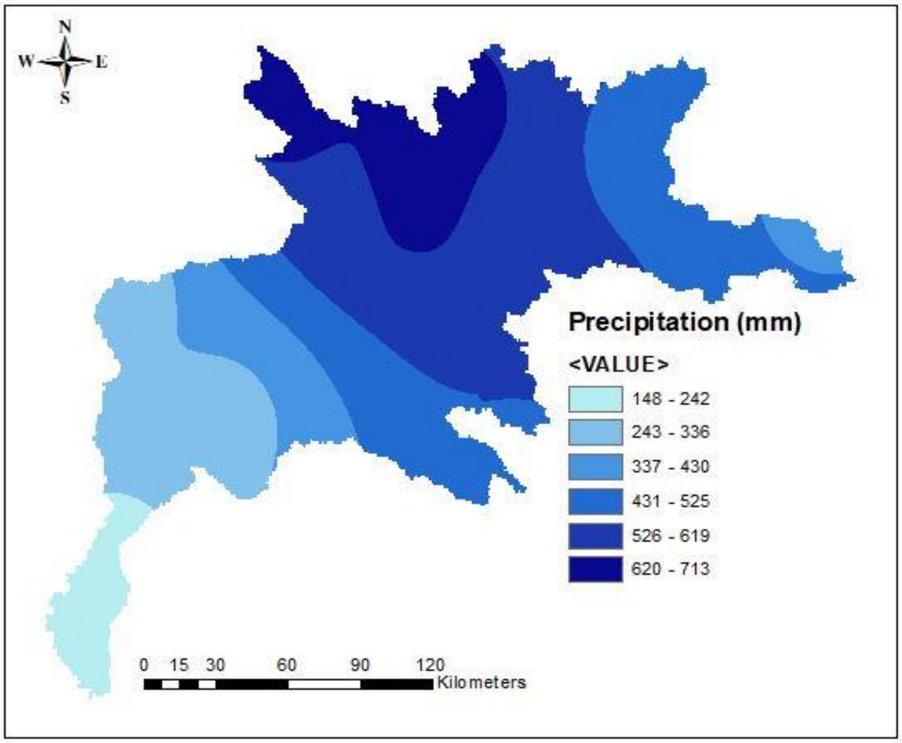


Fig. 4.2 The annual spatial distribution of the precipitation during the period 1981-2021 over the Diyala Basin

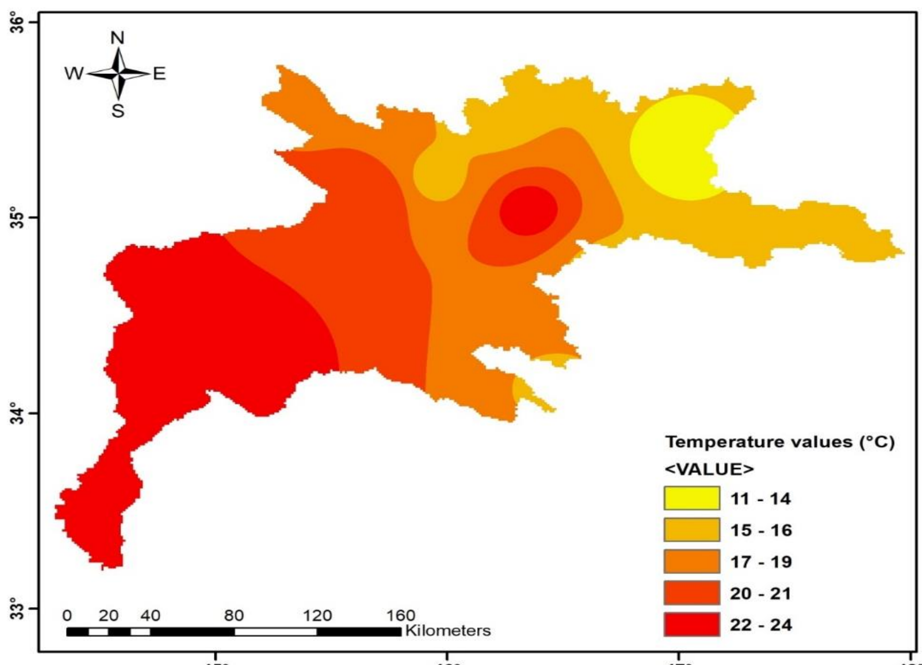


Fig. 4.3 The annual spatial distribution of the mean air temperature during the period 1981-2021 over Diyala Basin

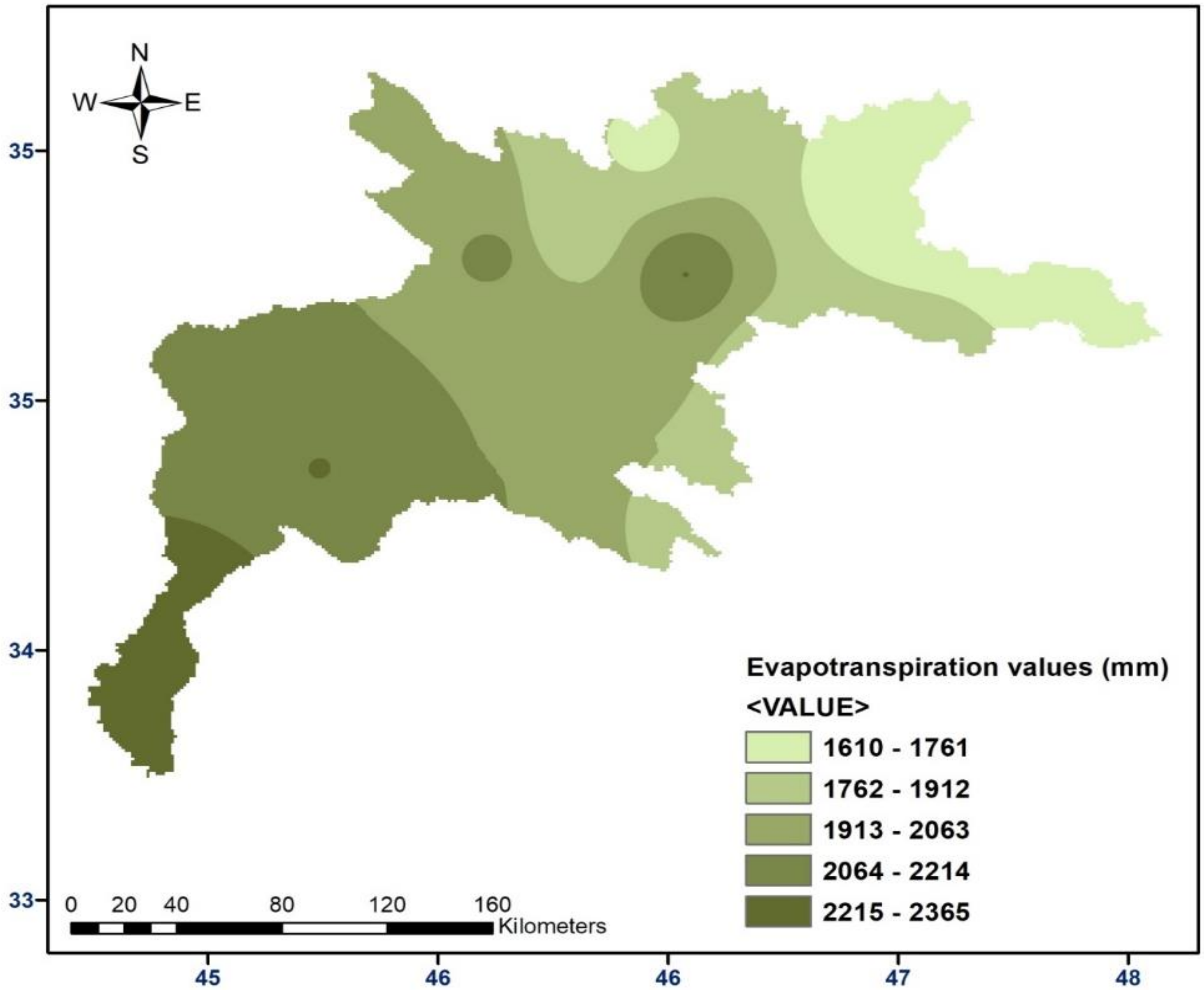


Fig. 4.4 The Annual spatial distribution of the potential evapotranspiration during the period 1981-2021 over Diyala Basin

4.2 Temporal change of time-series trend

The stations in the basin were classified based on terrain characteristics, climate harmony, and location. The Mann-Kendall test was used to estimate a temporal trend analysis on all the stations considered.

The Mann-Kendall test should be interpreted as follows:

H_0 :No trend.

H_a : trend

If the -value is more than 0.05, the null hypothesis H_0 should be rejected and the alternative hypothesis Ha allowed.

4.2.1 Upstream Stations

The stations where the Tigris River's tributaries are placed were shown, and the Mann-Kendall (M-K) results for RDI for each station are displayed in Table 4.1. The following figures will be the M-K tests for our study upstream stations:

Table 4.1 Results of Mann-Kendall (M-K) test for upstream stations

Station Name	M-K (RDI)	
	ρ-Value	α
Sanandaj	0.480	0.05
Ghorveh	0.0772	0.05
Ravansar	0.021	0.05
Marivan	0.024	0.05
Sulaymaniyah	0.001	0.05
Halabcha	0.002	0.05

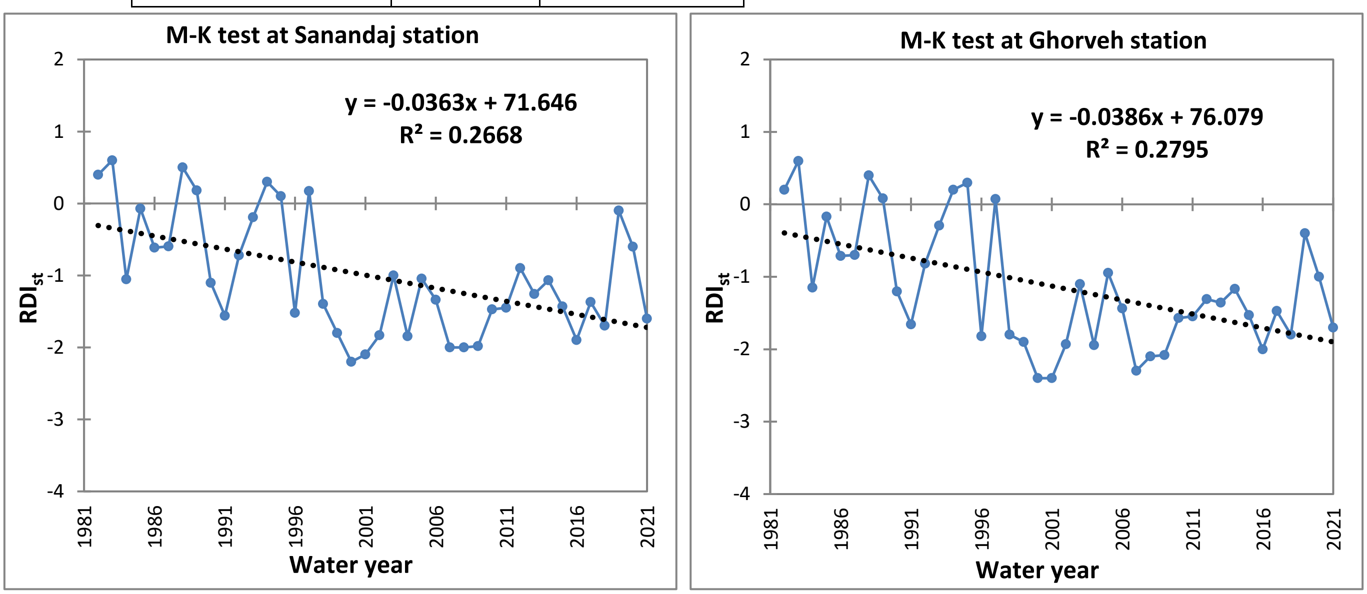


Fig.4.5 Mann-Kendall (M-K) test for Reconnaissance Drought Index (RDI) at Sanandaj and Ghorveh stations.

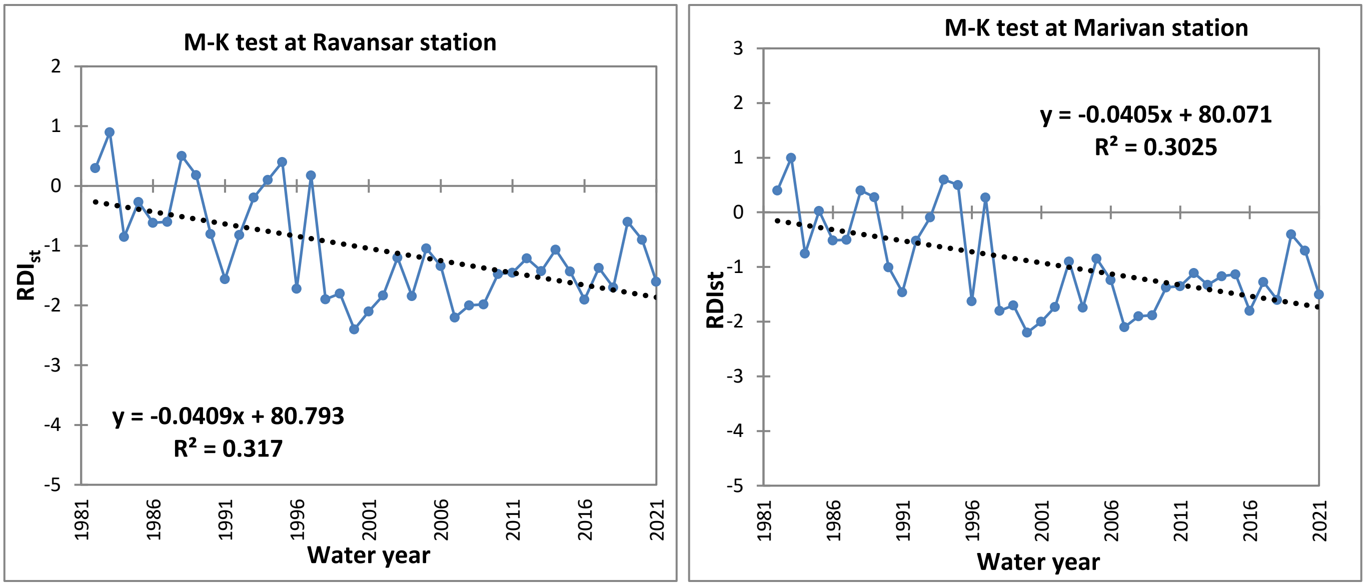


Fig.4.6 Mann-Kendall (M-K) test for Reconnaissance Drought Index (RDI) at Ravansar and Marivan stations.

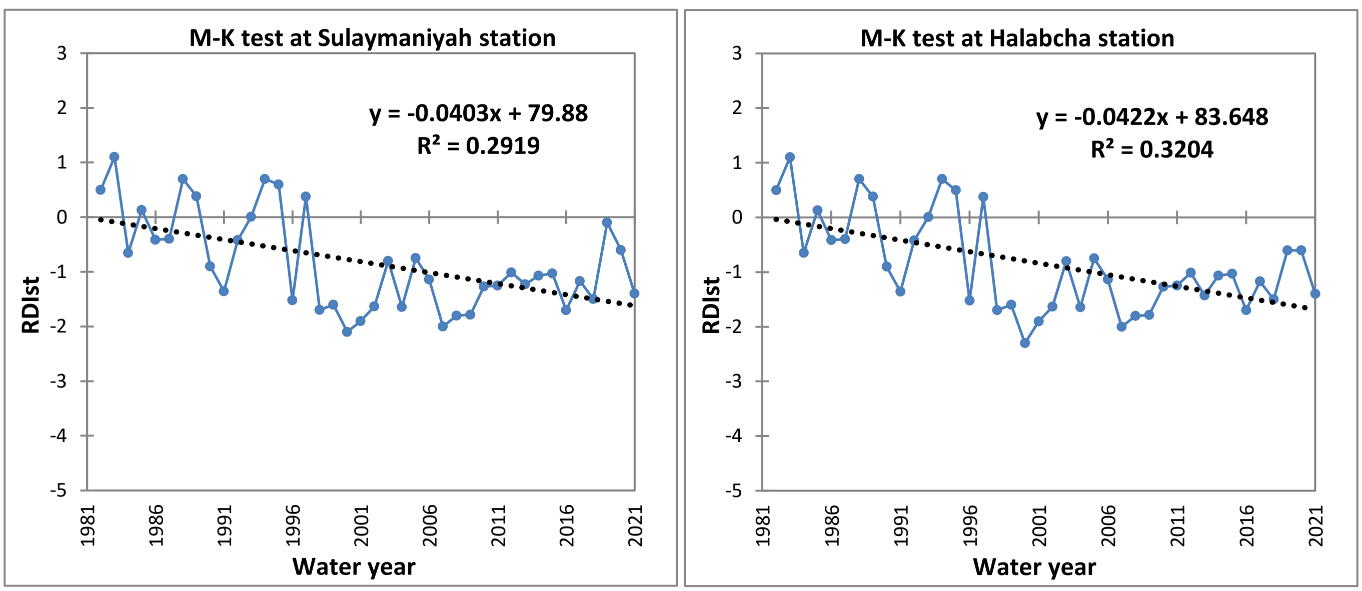


Fig.4.7 Mann-Kendall (M-K) test for Reconnaissance Drought Index (RDI) at Sulaymaniyah and Halabcha stations

4.2.2 Middle part station

The findings of the Mann-Kendall for RDI in each station are displayed in Table. It covers the stations where the tributaries of the Tigris River are not under the jurisdiction of the Darbandikhan Dam. Figures 4.8 and 4.9 will be the M-K tests for our study middle stations:

Table 4.2 Results of the Mann-Kendall (M-K) test for middle part stations.

Station Name	M-K (RDI)	
	ρ-Value	α
Darbandikhan	0.0001	0.05
Islamabad	0.0001	0.05
Paveh	0.004	0.05
Tus	0.0002	0.05

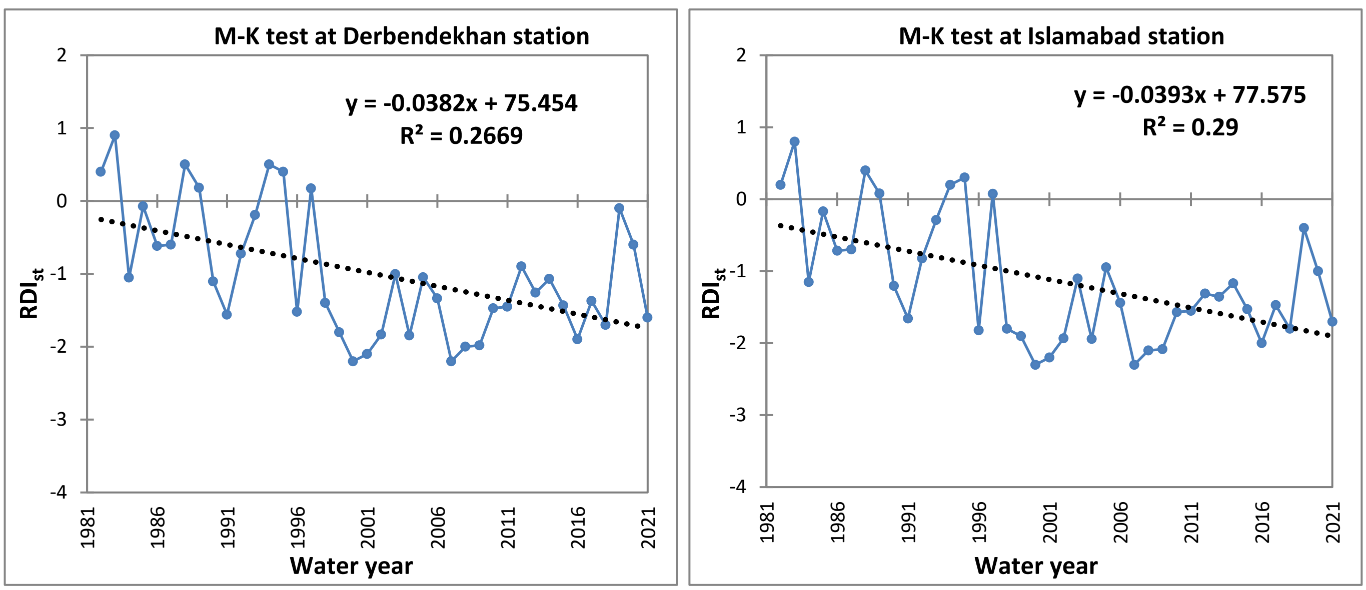
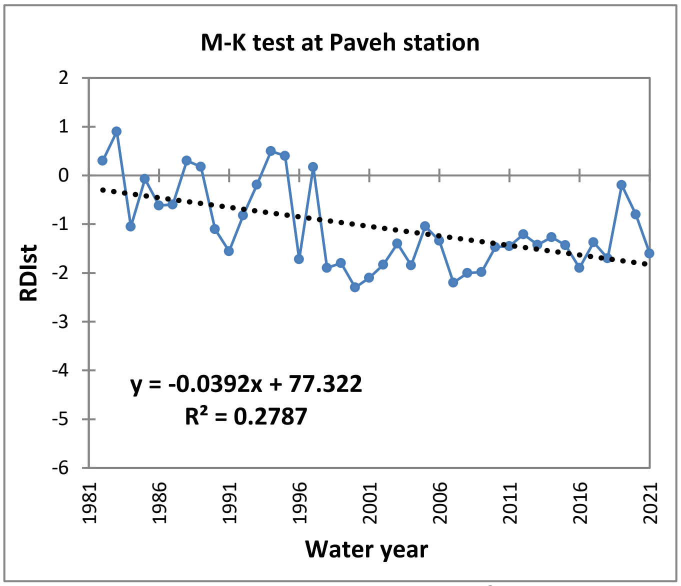


Fig.4.8 Mann-Kendall (M-K) test for Reconnaissance Drought Index (RDI)at Darbandikhan, Islamabad stations.



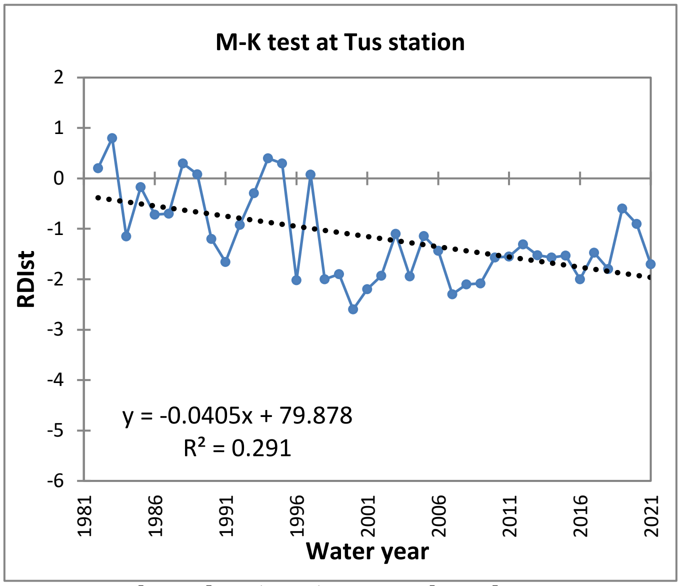


Fig.4.9 Mann-Kendall (M-K) test for Reconnaissance Drought Index (RDI) at Paveh and Tus stations.

4.2.3 Downstream stations.

It includes stations located after Hamrin Dam, the results of the Mann-Kendall test to RDI in each station a Downstream stations.

Table 4.3 Results of Mann-Kendall (M-K) test for downstream stations.

Station Name	M-K (RDI)	
	ρ-Value	α
Baquba	0.002	0.05
Jalawla	0.004	0.05
Kalar	0.0002	0.05
Baghdad	0.037	0.05

The following figures will be the M-K tests for our study downstream stations.

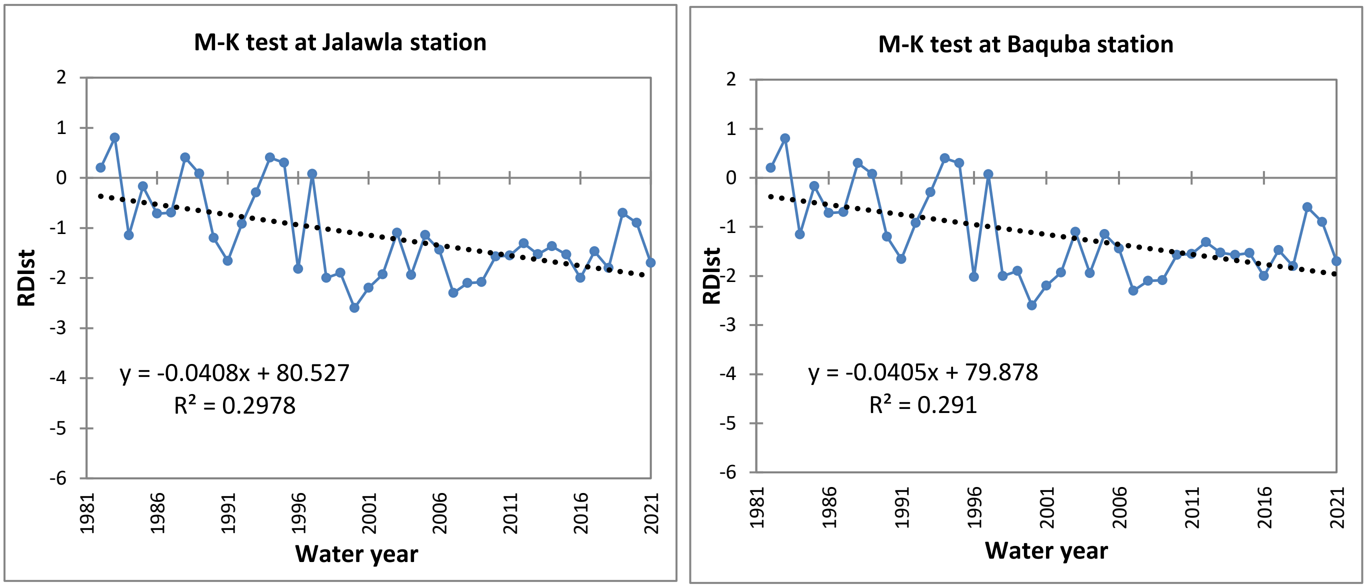


Fig.4.10 Mann-Kendall (K-K) test for Reconnaissance Drought Index (RDI) at Baquba and Jalawla stations.

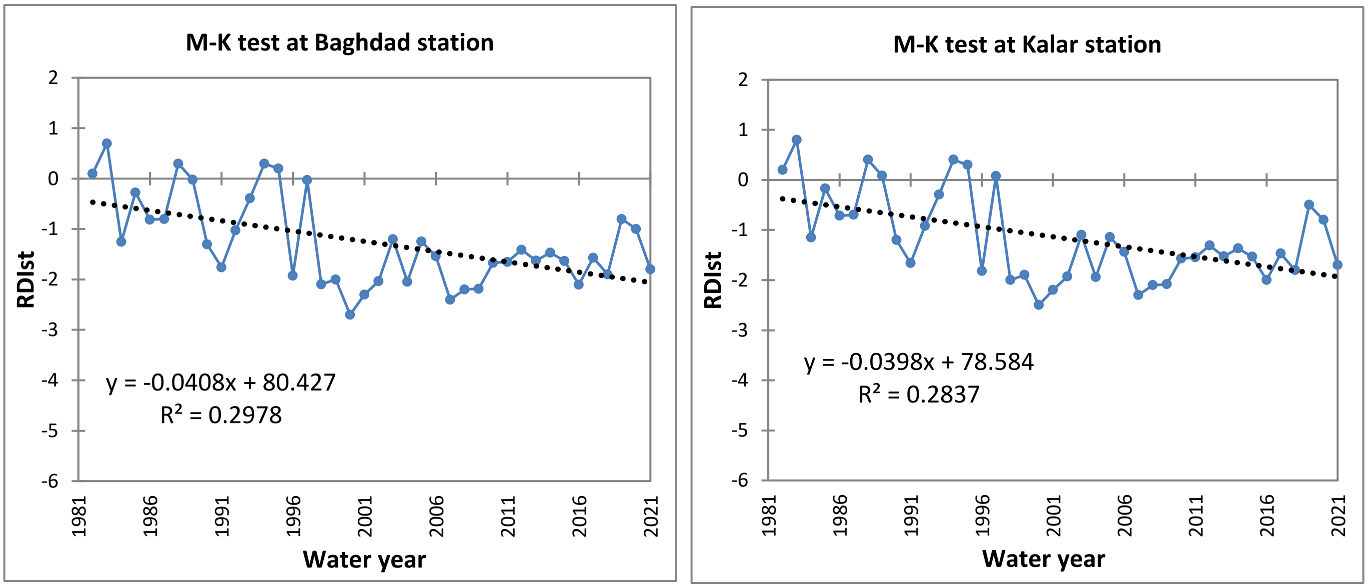


Fig.4.11 Mann-Kendall (M-K) test for Reconnaissance Drought Index (RDI) at Baghdad and Kalar stations.

4.3 Calculation of the Basin Average Precipitation

To provide a precise assessment of the geographic range of precipitation and evapotranspiration across the DRB, Thiessen's network has already been built. This method assigns a weight to each point depending on the basin area closest to it. A Thiessen network (ai, km^2) was used to determine the area of each station polygon, as shown in Table (4.4) The precipitation values for each sample station were multiplied by the dimensions of each polygon (ai, km^2). As depicted in Fig. 4.12, weather stations are dispersed both inside and outside the basin polygons. A different meteorological station is given to each of the fourteen sub-areas in the diagram, which depicts the division of the entire basin into sub-areas.

The average values of average potential evapotranspiration PET_m (mm) and average precipitation P_m (mm) were then calculated by adding up all of the values from the previous step and dividing the entire amount by the basin's area using the equation (Eq).

$$P_m = \frac{\sum_{i=1}^{n} a_i \times p_i}{\sum_{i=1}^{n} a_i}$$

where P_m is the catchment's average annual precipitation in millimeters (mm) or millimeter equivalents (mm).

a_i =Area of station as determined by Thiessen (km^2)

p_i = the station's average value of precipitation (mm)

Observe Table 4.4 The long-term average precipitation Pm (mm) to the entire basin region is :

$$P_m = \frac{15516998.6}{32977} = 470.5 \text{ mm}$$

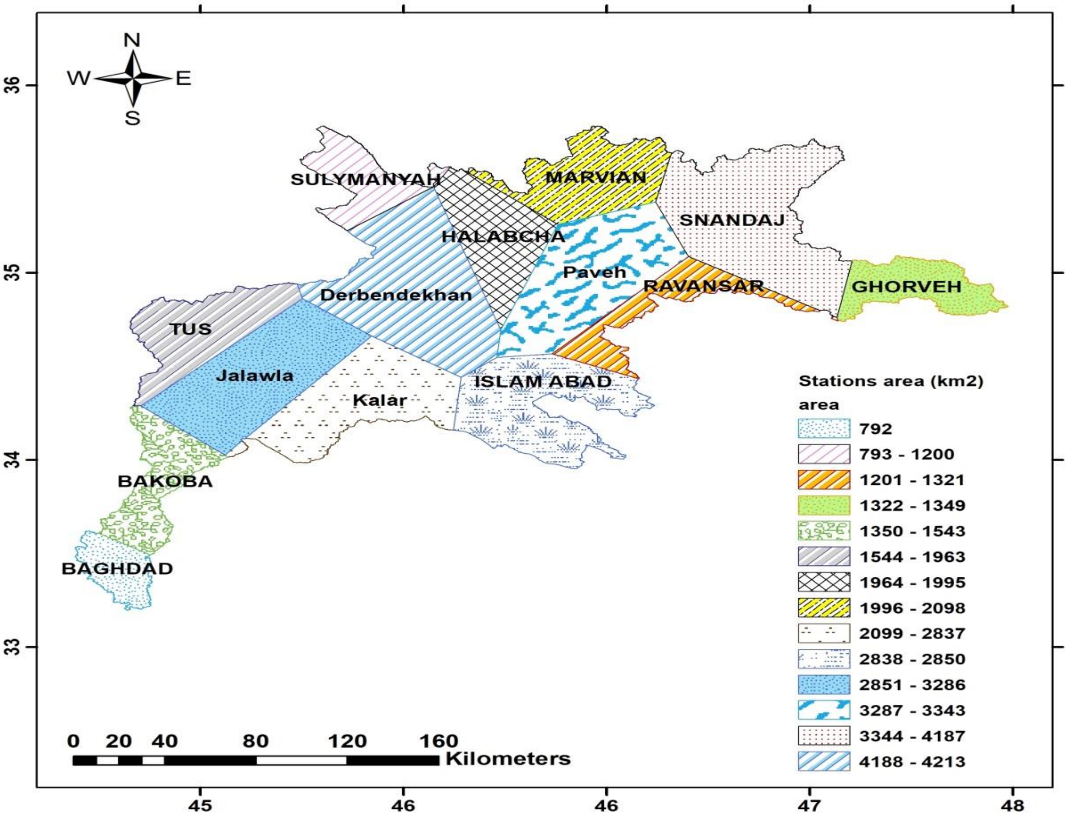


Fig.4.12 Polygon of Thiessen for Diyala River Basin

Table 4.4 Thiessen's calculations for precipitation and potential evapotranspiration

No.	Stations	Area (a_i) (km^2)	(P_i) (mm)	$P_i \times a_i$	(PET_i) (mm)	$PET_i \times a_i$
1	Baghdad	792	147.5	116820	2364.8	1872921.6
2	Ghorveh	1349	387	522063	1632.7	2202512.3
3	Jalawla	3286	288.4	947682.4	2228.52	7322916.72
4	Kalar	2837	330.2	936777.4	2139.58	6069988.46
5	Marvian	2098	648.8	1361182.4	1714.2	3596391.6
6	Paveh	3343	608.5	2034215.5	2214.94	7404544.42
7	Ravansar	1321	538.6	711490.6	1798.4	2375686.4
8	Snandaj	4187	474.2	1985475.4	1609.7	6739813.9
9	Sulymanyah	1200	699.2	839040	1919.1	2302920

10	Tus	1963	275.9	541591.7	2197.1	4312907.3
11	Islam Abad	2850	509.5	1452075	1848.9	5269365
12	Baqubah	1543	170.9	263698.7	2317.9	3576519.7
13	Halabchah	1995	713	1422435	1780.4	3551898
14	Darbandikhan	4213	565.5	2382451.5	2095.1	8826656.3
		Σ 32977		Σ 15516998.6		Σ 65425074.68

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The reconnaissance drought index (RDI) was used to analyse observed monthly rainfall data from 1981 to 2021; to evaluate meteorological droughts in the Diyala River Basin, Iraq. The Mann-Kendal test was used to examine the temporal distribution.

- When data on precipitation, mean air temperature and calculated potential evapotranspiration are available, established linear regression equations can help estimate the RDIst drought index.
- The drought hazards have increased in the Diyala Basin over the past few decades in comparison to earlier decades. It, therefore, specified the need for additional irrigation during these periods of water shortage.
- The Mann-Kendall and linear regression analyses revealed a statistically significant increasing trend of RDI between 1981 and 2021 (i.e., rising severity of drought episode) at = 0.01, significant level, which denoted an increase in precipitation scarcity over Diyala Basin.

5.2 RECOMMENDATIONS

Implementation of the following recommendations will require a collaborative effort among stakeholders, decision-makers, and the public to achieve sustainable water resource management and support the socioeconomic development of the region :

- Water resource management authorities in the Diyala River catchment should develop and implement effective drought mitigation strategies to reduce the impacts of drought on the region's economy and population.
- Promote the use of modern technologies such as remote sensing, GIS, and data analytics to monitor the changes in meteorological parameters in the catchment. This would help to provide timely and accurate information on drought conditions in the catchment, which is critical for decision-making and water resource management.
- Further research should be conducted to investigate the impact of climate change on drought conditions in the Diyala River catchment and to develop strategies to mitigate these impacts.

References:

Sonia I. Seneviratne and Neville Nicholls - Changes in Climate Extremes and their Impacts on the Natural Physical Environment :

https://www.ipcc.ch/site/assets/uploads/2018/03/SREX-Chap3_FINAL-1.pdf

Hussein, Haitham A. (2010). Dependable discharges of the upper and middle diyala basins. Journal of Engineering.

Butt, Amna, Shabbir, Rabia, Ahmad, Sheikh Saeed, & Aziz, Neelam. (2015). Land use change mapping and analysis using Remote Sensing and GIS: A case study of Simly watershed, Islamabad, Pakistan. The Egyptian Journal of Remote Sensing and Space Science.

Mohammed R, Scholz M - Climate Variability Impact on the Spatiotemporal Characteristics of Drought and Aridityin Arid and Semi-Arid Regions :

https://www.researchgate.net/publication/337743259_Climate_Variability_Impact_on_the_Spatiotemporal_Characteristics_of_Drought_and_Aridityin_Arid_and_Semi-Arid_Regions

Dimitris Tigkas, Harris Vangelis & George Tsakiris- Drought characterisation based on an agriculture-oriented standardised precipitation index :

https://ui.adsabs.harvard.edu/abs/2019ThApC.135.1435T/abstract

Yilinuer Alifujiang ,Jilili Abuduwaili andYongxiao Ge. Trend Analysis of Annual and Seasonal River Runoff by Using Innovative Trend Analysis with Significant Test :

https://www.mdpi.com/2073-4441/13/1/95

Al-Ansari NA (2013) , Management of water resources in Iraq: perspectives and prognoses.

http://www.diva-portal.org/smash/get/diva2:1013105/FULLTEXT01.pdf

Darlington Ikegwuoha and Megersa Olumana Dinka, Drought prediction in the Lepelle River basin, South Africa under general circulation model simulations :

https://www.researchgate.net/publication/354762846_Drought_prediction_in_the_Lepelle_River_basin_South_Africa_under_general_circulation_model_simulations

Hussain Muhamed , Mustafa N. Hamoodi , Abd Alrazzak T. Ziboon (2021) Managing the Excess Floodwaters in the Lake Hemrin Using Remote Sensing and GIS Techniques.

DrinC, Drought Indices Calculator :

https://drought-software.com/download/

Google Earth Pro v7.3.4 :

https://www.google.com/intl/ar/earth/versions/

XLSTAT add for excel : https://www.xlstat.com/en/

ArcGIS 10.8.2 : https://support.esri.com/en/Products

The website (power.larc.nasa.gov).

The website (climateingine.com).

The website (en.wikipedia.org).

The website (https://spei.csic.es/home.html).

The website (https://dreamcivil.com/thiessen-polygon-method/)

الخلاصة

من الأهمية بمكان تقييم تأثير تغير المناخ وتقديم طرق تكيف مناسبة من خلال دراسة التوزيع الزماني المكاني للبيانات المناخية وتأثيرها على توزيع الجفاف الإقليمي وجفاف الأرصاد الجوية. بالمقارنة مع الكوارث الطبيعية الأخرى ، يعتبر الجفاف من الكوارث ذات الأهمية العالية للغاية بسبب شدته ومدته ونطاقه الجغرافي وتكاليفه الاقتصادية وتداعياته على المدى الطويل.

تم اختيار حوض نهر ديالى الذي يقع جزء منه في العراق والجزء الاخر في إيران كمنطقة دراسة. تم إجراء هذا البحث على اربعة عشر محطة موجودة في العراق وإيران لمدة زمنية مقدارها أربعين عامًا من البيانات. تم استخدام مؤشر الجفاف الاستطلاعي (RDI) لرصد الجفاف وتحليل الخصائص المرتبطة به في المحطات المعينة. خلال هذه المرحلة ، كانت هناك حاجة لجمع بيانات الانواء الجوية ومنها الأمطار وبيانات درجة الحرارة ومن ثم حساب التبخر- النتح المحتمل. تم استخدام فحص الانحدار Mann-Kendall لتحليل الاتجاهات. من خلال هذا البحث ، تبين أن هناك زيادة ملحوظة متسلسلة في شدة الجفاف (RDI) في حوض نهر ديالى.

جمهورية العراق
وزارة التعليم العالي والبحث علمي
جامعة بابل
كلية الهندسة
قسم الهندسة المدنية

الخصائص الزمانية المكانية للجفاف الجوي في حوض نهر ديالى

بحث مقدم لكلية الهندسة في جامعة بابل كجزء من متطلبات الحصول على درجة الدبلوم العالي في الهندسة المدنية /الموارد المائية

بواسطة

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1444هـ 2023 م