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Evaluation of the Spatiotemporal Variability of the Hydro Climatic Behavior in Diyala River Basin

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By

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بسم الله الرحمن الرحيم

(قل لو كان البحر مدادا لكلمت ربي لنفد
البحر قبل أن تنفد كلمت ربي ولو جئنا بمثله
مددا)

سورة الكهف ١٠٩

SUPERVISOR CERTIFICATION

I certify that the proportion of this research entitled " Evaluation of the Spatiotemporal Variability of the Hydroclimatic Behavior in Diyala River Basin" was accomplished by "Ameer kadhim bandar" 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: / /2022

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"In the name of Allah, the most beneficent, the most merciful"

First, praise be to "Allah" who gave me the strength and health to work and enable me to finish this work.

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Thanks a lot, to the college of engineering / Babylon university

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Abstract

Climate variability linked with anthropogenic intervention can be considered as main factors affecting water cycle and hydrological system. Such factors have come to be a chief distress for water resources engineers and managers, especially in semi-arid and arid regions. This research investigates the spatiotemporal trends and extent patterns of the hydro-climate variables during the past thirty years, comprising yearly and monthly rainfall, temperature, evapotranspiration and excess rainfall, to estimate the possible effect of such alterations at a local level. The Diyala River catchment, central region of Iraq, has been considered as an example area. Accordingly, the Mann–Kendall, Pittet methods, and the double mass curve process, were used to analysis the hydro-climatic variables from 1979 to 2012 in the studied catchment. Outcomes of the study designated that excess rainfall alterations during the rainy and dry periods after 1967 had been taken substantial corresponding declining trends at 0.05 confidence level owing to dam building. It is apparent that annual runoff variations were largely caused by androgenic intervention related to the dam building to fit water use requirements for agriculture consumptions. The rainfall-runoff relationship in the basin has been altered as a result of weather inconsistency and increasingly intensified human activities. The sudden alterations in the hydro-climatic variables have been identified as well as the key causing influences for the variations in the considered Basin have been detected. The results of the study would support policymakers and water resource engineers to understand the hazard and vulnerability associated with environment alteration.

LIST OF CONTENTS

CHAPTER ONE: INTRODUCTION

CHAPTER TWO: LITERATURE REVIEW

CHAPTER THREE: MARTIAL AND METHODOLOGY

CHAPTER FOUR: RESULTS AND DISCUSSION

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

List of Table

List of Figure

List of Symbols

Symbol	definition
DRB	Diyalaa River basin
M-K	Mann Kendall
PET	Potential Evapotranspiration
p	Precipitation
BCM	Billion Cubic Meter
Ro	Runoff
PR- DCC	Precipitation-runoff double cumulative curve

CHAPTER ONE

INTRODUCTION

1.1 Background

Hydrological studies have generally focused mainly on the extent of the consequences of human actions and climate change on surface water (Jiang et al. 2011; Guo et al. 2014). Climatic change, especially temperature change, is the main factor However, human interventions are considered a factor affecting water resources in terms of time and space. The effect of these two factors is important, especially in arid and dry areas, which leads to a water crisis. These effects will vary depending on the geographical area. Its effect is noticeably evident in a large area, such as basins and sub-basins (Ma et al. 2008). The effect of these factors can be measured by following the procedures below. First, knowing the points at which the climate changes in several ways, including the Mann Kendall test and the Pettitt test (Chen and Xu 2005, Mao et al. 2015). The next step is to assess the climatic change's effects and to know the effect of other factors such as land use and water use for irrigation and industry by direct withdrawal from surface water and groundwater (Zhao et al. 2010). One of the proposed methodologies to determine the effect of these two factors is the simulation method between precipitation and surface water runoff (Li et al. 2007; Ma et al. 2008). The sensitivity of surface water data values is predicted by changing data values for precipitation and evaporation over a long period of time. To take a representative case, the Diyala River Basin was studied, which is one of the important basins that contribute to the flow rate in the Tigris River.

This region has been affected by climatic changes and drought, as well as floods that happen during the winter months as a result of excessive rains and a shortage of dams, which caused economic and social damage. In recent years, runoff in the Diyala River Basin has decreased significantly due to climatic change and human interventions (Waheed et al. 2020a).

1.2 Aim and Objectives

The main objective of the study is to comprehensively investigate the long-range climatic and hydrological data series for the largest number of stations within the Diyala River Basin, and to determine the direction of runoff and precipitation, evaporation and transpiration through the Mann-Kendall test and then analyze the main factors affecting water sources in the relevant period.

However, the study objectives will be as follows:

(1) to identify the magnitude of annual trend in the hydrologic and climatic data by a parametric test (simple linear regression);

(2) to test the temporal trend in the annual values of time series by a non-parametric test that is the Mann–Kendall method;

(3) to detect the alteration point in the annual datasets by Pettit test;

(4) to look into the long-term variability hydro-climatic data to the most extensive time interval and the largest numbers of stations in (upper part) of the DRB.

1.3 Study Outline

This study has been arranged into five Chapters as follows:

Chapter one: INTRODUCTION

Chapter one deals with the basis of the study as it introduces the main points of the study. The chapter includes the following sections: Aim & Objectives and Study Outline.

Chapter tow: LITERATURE REVIEW

this chapter introduces the overall review of the study literature survey, overview and hydro-climate data trend analysis are covered in this chapter.

Chapter three: MATERIALS AND METHODS

Chapter three reviews the details of the method and the materials. The chapter includes the following section and sub-sections: study area, data collection and analysis, tools applied, methodology (hydro-climate data trend analysis, basin average precipitation computation, and potential evapotranspiration estimation).

Chapter four: RESULTS AND DISCUSSION

Chapter four presents the details and the discussion of the results and the main findings. This chapter includes the following sections: Trend Analysis of Hydro-Climate Data, Hydro-Climatic Data Change Point Detection, Temporal variation of trend in the time-series, Basin Average Precipitation Computation.

Chapter five: CONCLUSIONS AND RECOMMENDATIONS

This chapter provides detailed: Conclusions from the results, the impact of climatic change and human interventions, and Recommendations for Research in the future.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The climatic change affects the hydrological cycle, and the hydrologic system of the basin could be primarily altered in reaction to future variations in climate variability such as air temperature and precipitation. The worldwide hydrological cycles have been substantially impacted by rising average air temperature during the last decade (Huntington 2006; Milliman et al. 2008; Mohammed and Scholz 2018). According to the IPCC, the average air temperature has grown 0.74 °C during the last century, and recorded mean temperature in dry and semi-arid regions has climbed 1.1 °C during (1980-1990) at a rate (0.22) degrees Celsius each decade, This is greater than the average for the global (Kundzewicz et al. 2009; Piao et al. 2012).

Climate change has resulted in a rise in global mean air temperature. Significant changes in precipitation have been observed in several geographical areas around the world, resulting in severe weather events such as floods and droughts (IPCC 2007, Kang et al.2007; Shrestha et al. 2012; Dai 2013). Precipitation, temperature, and potential evapotranspiration are all factors that influence streamflow. One of its most significant parts in the hydrological cycle is a hydrological variable of this nature. As a result, changes in these variables can be utilized as a measure of hydrological response to climatic changes and variability.

Man-made activities are mostly to blame for the growing water deficit in most river basins (Vorosmarty et al. 2000). As a result, studies in the topic of hydrology at the moment have concentrated on determining the changing trend and

determining the factors that influence streamflow. (Labbat et al. 2004; Lio and Xia 2004; Fraiche 2007). The standard method of regression was used to assess. the effect of human intervention and climatic change on surface runoff. Such as the approach of Crammer, (MTT) moving Test, method of Yamamoto, Mann–Kendall's test, and the Pettitt test can utilize to detect quick changes in hydroclimatic data as well. To close the knowledge gap, this research intends to build a set of approaches and equations that take into account the uncertainties in climate change estimates to help decision-makers comprehend the impact of climatic change on surface runoff in arid climatic zones The Diyala River Basin (DRB) was chosen as a model case study to investigate the issue and achieve the primary research goal. The basin is home to a diverse set of climatic and hydrological variables. This implies that climate change consequences on water resource availability are subject to a wide range of uncertainties. The results are expected to make a significant contribution to knowledge in the realm of water resources. Based on the findings, a flexible operational strategy can be used, in which decision-makers alter operational rules based on inflow predictions and the current status of reservoirs capacity at every time interval, as a result, higher efficiency and long-term basin storage management are achieved. The climatic conditions of DRB are arid and semi-arid. The basin's annual mean precipitation is around 500 mm, with November to April accounting for nearly 90% of the water year's precipitation. The annual mean potential evapotranspiration in the highlands is 1500 mm, whereas in the lower half of the basin it is 2650 mm.

The basin is vulnerable to a series of droughts occurrences, most notably the severe drought that occurred between (1999 – 2001), as well as the two consecutive water years of 2007 and 2008. Agriculture, above all other uses, is the most water-intensive.

Within DRB, surface water, represented by streamflow, is critical for agricultural irrigation, local eco-environmental protection, and socio-economic development conservation. Changes in rainfall and mean air temperature have the greatest impact on streamflow. During the previous 30 years, the average annual precipitation in the Diyala river has been dropping, while the mean air temperature has been rising at a rate of 0.3 °C per decade, clearly exceeding the global mean temperature rising amplitude.

The outflow from the Diyala River has substantially dropped during the last few decades, according to several research. The pace of precipitation and runoff descent is exceedingly inconsistent, limiting socio-economic development in the area while also posing a significant threat to the ecology downstream of DRB (Luo and Guo 2004). The fluctuation of the DRB streamflow has been addressed in numerous researches in the subject (water resources).

2.2 Trend Analysis of Hydro-Climatic Data

In hydroclimate time series, according to the non-normal distribution features of data that is normal. The Mann–Kendall test (M-K) and the Pettitt analysis, two widely used nonparametric approaches, are typically used to find variations in hydro-climate datasets. The MK test is used to identify monotonic gradual trends; whereas, Pettitt's test is used to determine the rapid change in the level. The following is a brief explanation of these analyses.

For starters, the M-K test can be used to find trends in datasets. The M-K approach is a non-distribution-based method for determining whether the parameters under consideration are increasing or decreasing monotonically over time (Dahamsheh and Aksoi 2007; Seibart and Vis 2012). A monotonic drop (raise) trend means the parameter constantly falls (rises) across the time period under consideration.

While there is no guarantee that the trend will be linear. The M-K test can perform in place of parametrical linear regression analysis to see if the linear regression trend predicted by the model differs from zero. The time series must be devoid of autocorrelation/serial correlation in order to use the M–K test.

Second, the Pettitt test, which is also a not parametric test, is used to determine the change point in the datasets. (Zhange et al. 2001; Velazqueiz et al. 2011) use Pettitt analysis to analyze changes in hydro-climatic data. Detecting changes in the runoff time series is crucial for detecting climatic change and human interventions impacts. Spatiotemporal pattern of weather data is commonly varies due to weather alteration and human intervention (Huntington, 2006; Milliman et al., 2008; IPCC 2007; Mohammed and Scholz, 2018).

The tendency test of climatic information variability is important for meteorologists, hydrologists, and agriculturalists in terms of sustainable use of water resources (Kundzewicz et al., 2009; Brunsell et al. 2010; Piao et al., 2012). The Globe's mean temperature raised by 0.6 °C during the twentieth era as well as there is an intense move in mean air temperature from 1.4 to 5.4 °C simulated by many weather prediction models (IPCC 2001). Numerous researchers (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) informed that the variation in distribution of weather variables would affect the spatiotemporal pattern of excess rainfall, soil moisture, and subsurface dwater investments and would also modify the occurrence of extreme phenomenon such as floods and droughts. Recently, numerous scientists have conducted on spatiotemporal trend analysis and its magnitude in climatic (precipitation, air , temperature, humidity, etc.) and hydrological (stream flow) datasets by parametric (linear regression) and non-parametric (MK, Pettit) methods in many regions (Zhao et al., 2015; Alhaji et al., 2018; Pirnia et al., 2019; Gadedjisso-Tossou et al., 2020; Indarto et al.,2020; Malik and Kumar, 2020; Phuong et al., 2020; Alifujiang and Abuduwaili 2021 ; Hussain et al., 2021; Mondal et al., 2021; Lone et al., 2021; Ray and Goel, 2021; Seenu and Jayakumar, 2021). Although many recent studies have conducted trend analysis test of hydro-climatic variables in Iraq (Al-Hasani 2021; Ahmed et al. 2021; Basheer 2022; Muter et al. 2020). However, they either considered parametric or non-parametric tests without considering the changing point in the data. Accordingly, the main aim of this research is to examine the inconsistency and changing point in the hydro-climatic time-series means of the sequential Mann-Kendall and Pettit tests, respectively.

CHAPTER THREE

MATERIALS & METHODS

3.1 Study area

The Tigris is one of Western Asia's major rivers, it originates in the Taurus mountains in Turkey, passes through Syria, and enters Iraq through the Feshkhabur village. The Tigris River Basin is divided into several sub-basins, most of it is shared by Iraq and Iran, as well as Iraq and Turkey, such as Khabour, Lesser Zab, Greater Zab, and Diyala River Basins, (Table 3.1).

Table 3.1 Several sub-basins in Tigris River. (R. 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

In this study, the Diyala River catchment will be considered as a sample basin to represent semi-arid and arid climatic condition. The Diyala River is the Tigris River's fifth tributary, which originates at the junction of the Tangro, Wand and Sirwan rivers in Lake Darbandikhan in the Sulaymaniyah Governorate in northern Iraq. (Haitham A. Hussein 2010) The river has a total length of about 574 Km and runs through Iraq and Iran, it starts in the Zagros Mountains and runs south of Baghdad, Iraq, into the Tigris River. The Diyala River Basin is located between latitudes 33°12` to 35°47` E and longitudes 44°18` to 47°58` N with a total area of approximately 32975.6259 km2, 46% of it located in Iraq and the remaining 54% is in Iran, (Fig. 3.1).

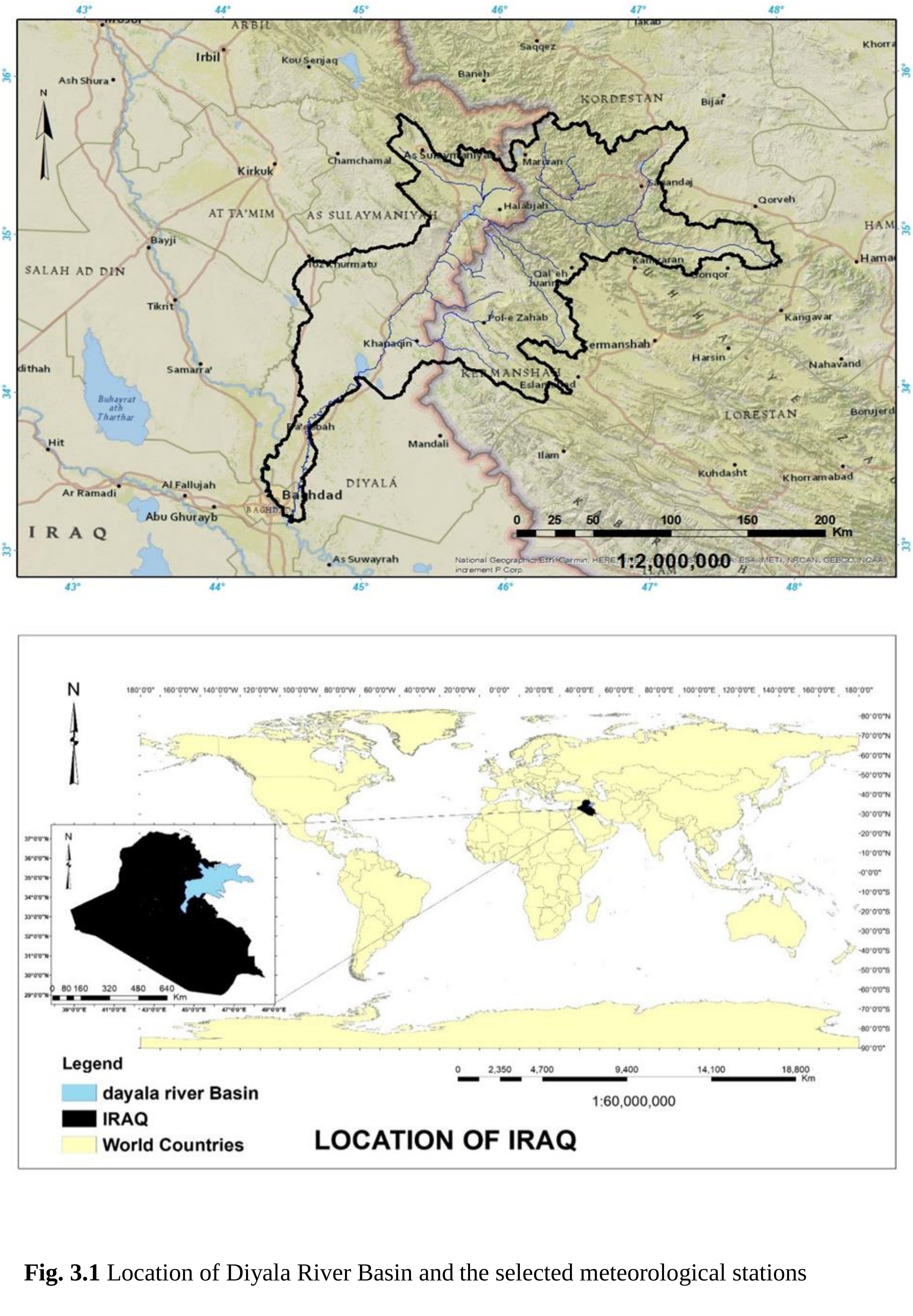

Fig. 3.1 Location of Diyala River Basin and the selected meteorological stations

There are two dams that control the flow of the river. The first is Darbandikhan, which is considered Iraq's second-largest dam. Darbandikan is an earth dam constructed in 1961 for multiple purposes, such as protection from floods, hydropower generation, and irrigation. It spans about 16,750 km2, 20% of which is in Iraq and the rest in Iran. The Darbandikhan Reservoir has a total storage capacity of 3 billion cubic meters (BCM). Diyala River is around 217 km long above this dam.

The second dam within DRB is Hemrin, which is also an earth dam. Hemrin was built in 1981 in the middle of the Diyala River, about some 120km east of Baghdad City. The main purpose of the Hemrin dam is for hydropower generating and irrigation purposes as part of the Khalus Irrigation Project. The Hemrin dam watershed covers a total area of 12,822 km2, with 68% of it located in Iraq and the rest in Iran. The Hemrin Reservoir has a total capacity of 2.4 BCM (waheed et al. 2021).

DRB is usually divided into three main parts; the upstream part is located between Darbandikhan dam and extends to the Zagros mountains, the middle one is situated between Darbandihan and Hemrin Dams, and the downstream part is located between Hemrin dam and the Tigris River, Fig. 1. The monthly flow rate at Darbandikhan, which is regarded as an important hydrometric gauging station (latitude 45.69 and longitude 35.11), was studied for the hydrological years 1931 to 2000 (Saleh, D.K. 2010).

3.2 Data collection and analysis

The following hydro and atmospheric data were taken into account in this study. Monthly precipitation, minimum and maximum atmospheric data sets from fourteen climate stations ranging in altitude from 0 to 13,730 meters (Table 3.2) (R. Mohammed et al. 2018) were available by (Google Earth Pro) program between 1979-2012.

Table 3.2 Longitude, Latitude and Elevation for the selected stations in Diyala River Basin

Sub-basin	Station Name	Longitude	Latitude	Elevation
Upstream	Sanandaj	47	35.33	13730
	Kermanshah	47.117	34.267	13220
	Ghorveh	47.8	35.17	1906
	Ravansar	46.66	34.72	1363
	Marivan	46.2	35.52	1287
	Sulaymaniyah	45.38	35.56	824
	Halabcha	45.95	35.2	620
Middle part	Darbandikhan	45.69	35.11	451
	Eslamabad	46.43	34.13	1346
	Khanaqin	45.35	34.35	202
	Tus	44.65	34.83	0
Downstream	Balad	44.36	33.95	49
	Baquba	44.66	33.75	41
	Baghdad	44.41	33.31	32

The monthly runoff (1931–2000) of the Darbandikhan hydrological station in the Diyala River was considered (USGS 2010).

Thiessen network calculations are used to predict the position of climatic and hydrological stations, and delineation the basin of the river, ArcGIS 10.8 was utilized and XLSTAT, a Microsoft Excel add-in, was used to run the Pettitt and Mann-Kendall tests. The Penman-Monteith standard technique of the Food and Agriculture Organization was used to calculate potential evapotranspiration PET (mm) (Allen et al. 1998), which was calculated by ETo (mm) and (Drin C) program.

The area of the polygon for each station (ai) can be estimated by Thiessen network method. This has been accomplished as a result of the following factors:

A - joining the near stations with each other with lines;

B - creating vertical bisectors of all lines;

C - Using the bisectors to form polygons around each station.

3.3 Tools Applied

1- ArcGIS 10.8:

ArcGIS 10.8 was used to locate the hydrological and climatic stations, river basin drawing, and Thiessen network analysis

2- DrinC 1.7:

The drought indices calculator (DrinC) is an easy-to-use software that has been to calculate indicators of climate drought, including the survey drought index, standardized rainfall index, streamflow drought index, and precipitation deciles. The fundamental characteristics of these indexes are their simplicity of application and low data requirements for calculation. With temperature-based approaches minimum, maximum, and mean temperature, DrinC provides a unit for estimating potential evapotranspiration. Hydrological data must be prepared over time series of no less than 30 water years to characterize drought (Tigkas et al. 2012, 2015).

3-XLSTAT: a Microsoft Excel add-in was used to run the Pettitt and Mann-Kendall tests.

4-Google earth pro 7.3.4:

This program is used to obtain temperature and precipitation data for the place and time specified in the study

3.4 Hydro-Climatic data Trend Analysis

As a first stage, statistical change tests were relied on, as most of the hydroclimate information series used in this study do not follow a standard distribution at (α= 0.05), according to the results of these tests. In order to quantify fluctuations in streamflow, precipitation, potential evaporation, and a time series of air temperature in the DRB, two widely unlabeled procedures (Pettitt's test & Mann Kendall's analysis) were used. The former was used to

detect monotonous or steady trends, while the latter was used to detect sudden mid-level changes.

The Pettitt test is used to determine the change at a particular point in the time series of the flow rate. It was also used, which is one of the methods of homogeneity test in the process of data quality control, and most importantly, to verify the validity of homogeneity in the data, thus reducing the concerns of unreliability. Pettitt points out that time series are not homogeneous as the data changes at a certain point during this series.

The Mann-Kendall test is used to find trends in climatic time series and whether they are increasing or decreasing by assuming null hypothesized (H0) when there's no trend and alternative hypothesized (Ha) when there's a trend, It is calculated by the following equation:(Kokeb et al. 2021)

$S=\sum_{i=1}^{n-1}\sum_{j=i+1}^{n} sign(x_j - x_i)$……..……………………………………(1)

where n denotes the number of data points.

xi and xj denote the value of data.

If $(x_j - x_i) < 0$ → sign $(x_j - x_i)$= - 1

If $(x_j - x_i) = 0$ → sign $(x_j - x_i)$= 0

If $(x_j - x_i) > 0$ → sign $(x_j - x_i)$= 1

When n ≥10

The distribution on the Mann Kendall test is standard with a mean E(S) = 0, and Var(S) is determined by,

Var (s) $=\frac{n(n-1)(2n+5)-\sum_{k=1}^{m} t_k(k)(k-1)(2k+5)}{18}$…..………………...………(2)

Where

n= number of the points of the data,

m= number of connected groups

tk= number of extent k ties.

To produce a standardized Mann-Kendall test statistic ZMK:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, & \text{if } S > 0 \\ \frac{S+1}{\sqrt{Var(S)}}, & \text{if } S < 0 \end{cases} \quad \text{...} (3)$$

The upward trend is shown by a positive Z-value, whereas the downward trend is indicated by a negative Z-value. If Z_{mk} is more than the ordinary normal variate $Z_{\alpha/2}$, the trend is significant, with percent being the significance level. The trend is important when $Z_{mk}|$=1.96 for a 5% significance level, and $Z_{mk}|$=2.575 for a 1% significance level (Gocic and Trajkovic 2013).

Sen's slope calculator.

is a tool that allows you to calculate the slope of Sen's slope calculator (Sen 1968) is the non-parametric approach for computing the linear rate of change (slope) and the intercept to estimate the amplitude of a trend. The equation Xi = x1, x2, ... xn is used to derive the slope for the given series of time, with N data in pairs:

$$\beta_i = \frac{x_j - x_k}{j-k}, k \le j and\ i = 1, 2, \ldots, N \quad \text{.......................................}(4)$$

Sen's slope calculator is derived from the average of N-values of β_i.

If: N odd $\rightarrow \beta = \frac{\beta.N+1}{2}$

If: N even $\rightarrow \beta = \frac{\frac{\beta.N}{2} + \frac{\beta.N+2}{2}}{2}$

3.5 Potential Evapotranspiration Estimation

There are three primary categories of potential evapotranspiration estimation methodologies. The first category includes physical approaches known as methods of hydrologic or water balance, which are limited to laboratory use. Analytical methods based on climatic parameters are included in the second group. Equations focusing on two fundamental climate components mass transportation and energy's balance are used to express possible evapotranspiration processes.

This group's approaches include the Penman-Monteith and Priestley -Taylor methodologies. The last group includes econometric techniques. The common idea is that temperature is a good measure of the air temperature's evaporation effect. Because of their low information requirements, these methods have proven quite popular. Thornthwaite, Blaney-Criddle, and the Hargreaves equations are the most generally used ways for this category's representation.

It's crucial to pay attention to the part of the best PET calculation for an elevation. and specific climate This is necessary because the use of diverse methodologies might lead to errors in water resource available calculations.

method of Hargreaves.

The method of Hargreaves is a method for calculating evaporation through transpiration. It is easy and dependable, needs little data, is straightforward to calculate, but has little effect on arid climatic station results. And this approach is temperature-dependent. Because only the min. and max. temperature data are required. This approach has been investigated by several academics, including Hargreaves and Sammani (1982, 1985).

Solar radiation (RA) is commonly calculated from a series of equations or inferred from published tables for a certain latitude and day (Xu and Singh 2001: Vangelis et al. 2013). Implementation.

$$PET=0.023\times R_a\times {T_m}^{\frac{1}{2}}\times (T_m+17.800)\ldots\ldots(5)$$

PET= potential evaporation in millimeters, Ra denotes total extraterrestrial solar radiation in millimeters, and Tm denotes the mean monthly temperature in degrees Celsius (R. Mohammed et al. 2018).

3.6 Basin Average precipitation Computation

Computation of annual average precipitation in the DRB, ArcGIS 10.8 is used to complete the instructions below. The process for setting up is as follows: As a function of the land cover picture, shapefile of so-called watershed polygons can be created. The production of two shapefiles follows this stage. Each point representation corresponds to a long-term precipitation value.

As well as the potential evapotranspiration (PET) for the long term, average precipitation for the long term and area. Each gauging station's potential evapotranspiration and precipitation readings are multiplied by each polygon's area ai (km2).

The values of mean potential evapotranspiration PET m) mm) & mean rainfall Pm (mm) are calculated by multiplying the values of precipitation and evapotranspiration at each station by its area and dividing the result by total area of the basin.

$$\mathbf{X_m} = \frac{\sum_{i=1}^{n} a_i \times x_i}{\sum_{i=1}^{n} a_i} \quad \text{...(6)}$$

Where;

X_m= average precipitation of the catchment P (mm) or PET (mm) for long term.

a_i= area of station calculated by Thiessen (km2)

x_i= the average value of the station (mm)

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Trend Analysis of Hydro-Climate Data

Changing environmental and anthropogenic interventions influence long-term patterns in hydrological systems (Roba and Al-Berazanji 2013; Al-Ansari 2013; Al-Ansari et al. 2014). Investigating such patterns may aid in the identification of points where humans can intervene. The Mann-Kendall test is used to identify trends for a long time in mean annual temperature, rainfall, potential evaporation, and flow of current. The statistical features of the main weather factors constituting the M-K test of interannual variability for various climatic conditions, and the unique arid and semi-arid case study, Diyala River Basin (DRB) For one decade, which is an example of regions of aridity and semi-aridity, exhibited an increasing trend in mean temperature with a max. value +0.36 °C, the year 2010 had the high mean air temperature (19.3 °C) while 1992 had the lowest (15.62 °C), whereas precipitation showed a negative trend with a maximum loss of 86.35mm per decade. The average precipitation is approximately 451mm. The year 1984 had the highest precipitation (679 mm), while 1999 had the lowest at 210 mm. Potential transpiration increased at a rate of 34.2 mm per decade. The predicted potential evaporation of the basin increased from 1417.5mm in 1983 to 1627.7 mm in 2010, with an average value of around 1542 mm. The results reveal that, as indicated in the case study, the environment is becoming warmer and drier as a consequence of the change in the climate. The amount of rain that fell on the ground each year was reduced. The annual average main temperature rose, while the depth of the annual runoff has decreased.

These results are broadly in line with those of earlier research (Fadhil.2010; Al-Ansary.2013; Roba and AL-Berazanji.2013; Al-Ansary et al 2014)

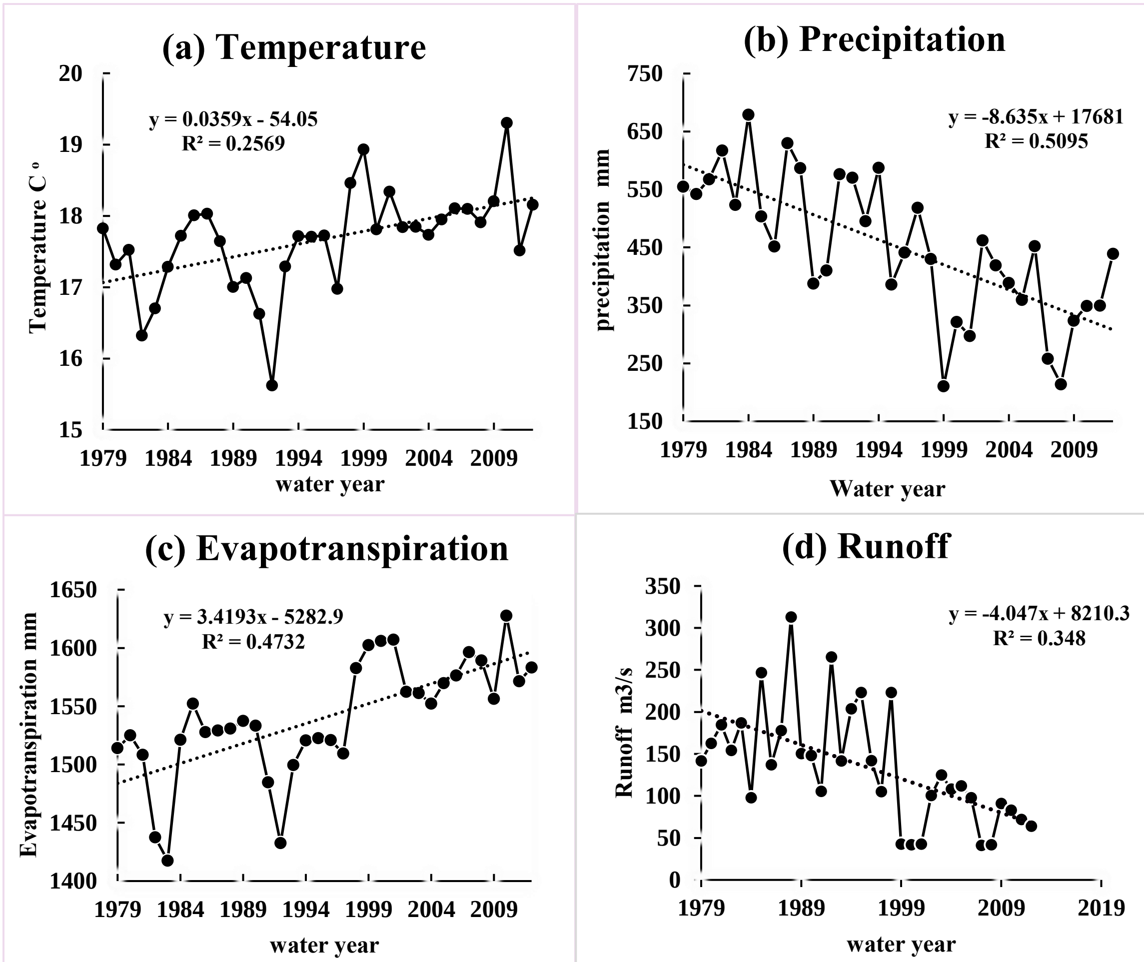

Fig. 4.1 a- long term air temperature for DRB b- long term precipitation for DRB
c- long term evapotranspiration for DRB d- long term runoff for DRB

The rate of runoff is defined as the proportion of flow to the rainfall over a given time period, it was chosen to describe the hydro-climatic situation in the DRB (Fig.4.1). For the study duration, the equivalent rate of runoff was (-113.9) m3/s. The rate of decline was found to be (-34.5) m3/s per decade. The decrease in the rate of runoff (Fig. 4.1d) suggests that, as previously projected, the flow yield has weakened during the last three decades (Al-Ansari 2013; Al-Ansari et al 2014).

The average annual precipitation in the lower basin station of Baghdad is 107 mm, the middle part station of khanaqin is 220 mm and the higher basin station of Sulaymaniyah is 662 mm. This means that the upper part of the sub-basin is distinguished by greater altitudes (in comparison to the middle and lower basin), as well as higher precipitation amounts. The apparent trend of increasing average air temperature over the four-decade led to significant precipitation decreases and potential evapotranspiration increases of the entire BRB, as shown below in Fig. 4.2, 4.3 and 4.4

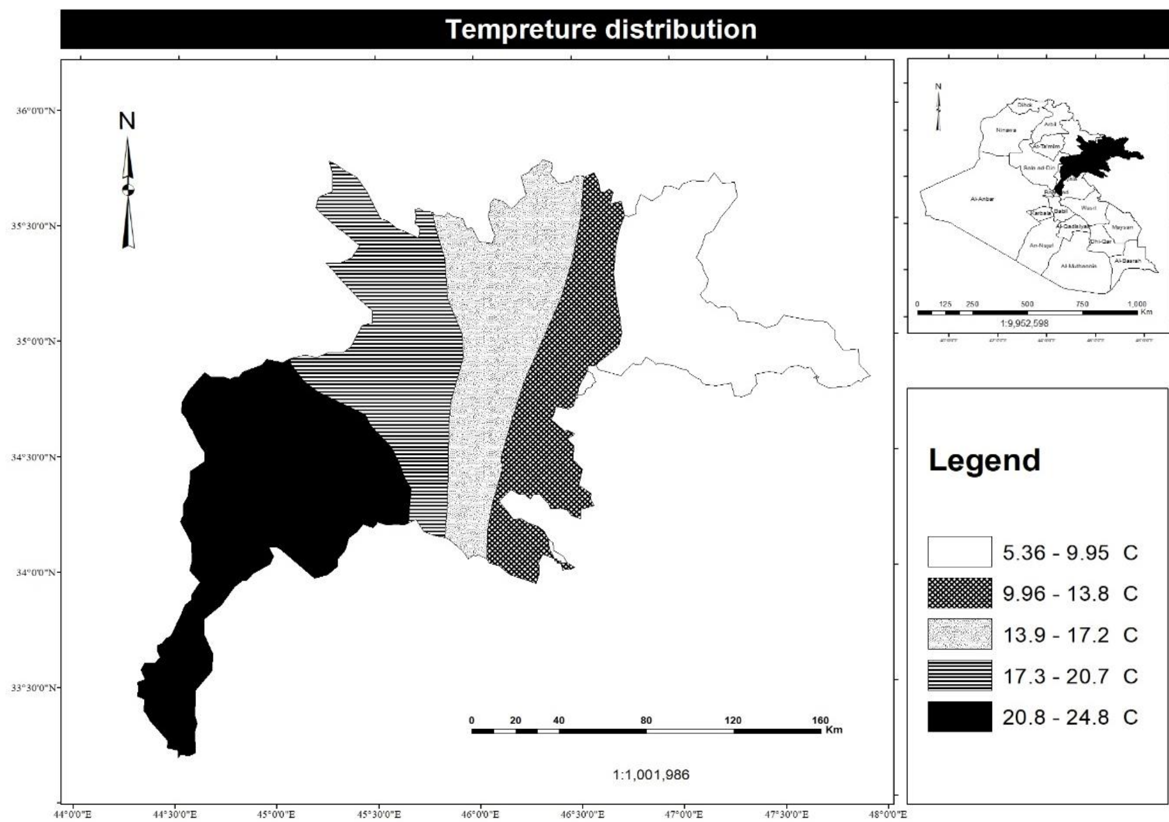

Fig. 4.2 temperature distribution for study period in DRB

Table 4.1 the ratios of monthly average precipitation for a long time to total average annual precipitation for a long time in the examined hydrologic year.

station	$\frac{\text{average precipitation at any month}}{\text{total average precipitation}} \times 100\%$					
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Sulaymaniyah	3.84	11.04	16.3	18.9	18.86	17.73
Marivan	4.12	10.94	15.06	16.15	18.76	17.56
Sanandaj	4.45	10.88	14.11	15.74	17.61	17.96
Ghorveh	5.52	10.62	12.62	13.79	15.03	18.19
Halabcha	4.04	10.69	16.62	17.92	19.43	17.48
Ravansar	5.33	11.97	14.27	15.57	16.64	17.02
Kermanshah	3.94	11.07	14.38	15.48	15.88	18.44
Eslamabad	5.44	12.4	14.42	16.15	16.08	17.6
Darbandikhan	4.05	10.62	16.65	19.28	19.3	17.46
Tus	4.91	13.66	17.42	18.68	17.38	16.19
Khanaqin	3.45	14.13	16.88	20.41	16.78	16.53
Balad	4.54	13.86	18.02	18.69	16.91	16.05
Baquba	4.34	14.93	17.75	19.13	16.03	15.33
Baghdad	4.25	13.52	16.9	19.9	14.67	15.44
station	$\frac{\text{average precipitation at any month}}{\text{total average precipitation}} \times 100\%$					
	Apr.	May	Jun.	Jul.	Aug.	Sep.
Sulaymaniyah	9.66	3.47	0.08	0	0	0.12
Marivan	12.47	4.51	0.25	0.04	0	0.14
Sanandaj	12.66	5.93	0.49	0.06	0.02	0.09
Ghorveh	14.52	8.38	0.72	0.21	0.11	0.29
Halabcha	10.4	3.15	0.17	0.01	0	0.09
Ravansar	12.95	5.81	0.28	0.02	0	0.14
Kermanshah	15.23	5.18	0.28	0.02	0	0.1
Eslamabad	11.96	5.54	0.26	0.02	0	0.13
Darbandikhan	9.15	3.28	0.09	0	0	0.12
Tus	8.17	3.31	0.19	0	0	0.09
Khanaqin	7.89	3.76	0.12	0	0	0.05
Balad	7.75	3.96	0.17	0	0	0.05
Baquba	7.94	4.42	0.12	0	0	0.01
Baghdad	9.31	5.91	0.08	0	0	0.02

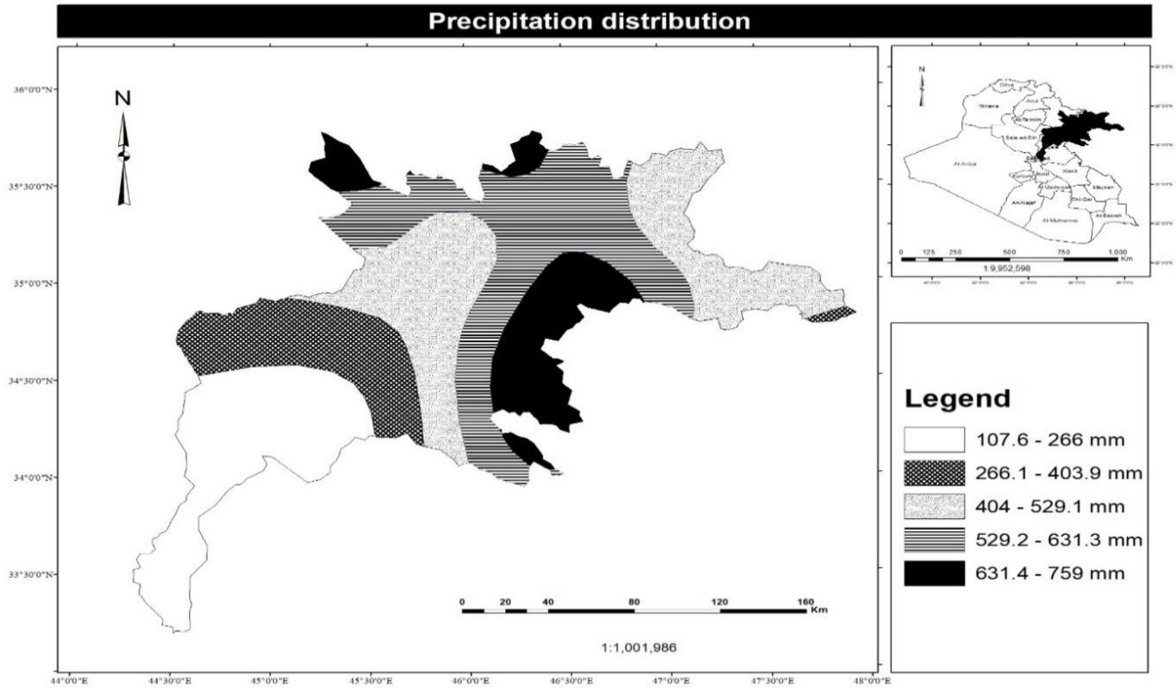

Fig. 4.3 precipitation distribution for study period in DRB.

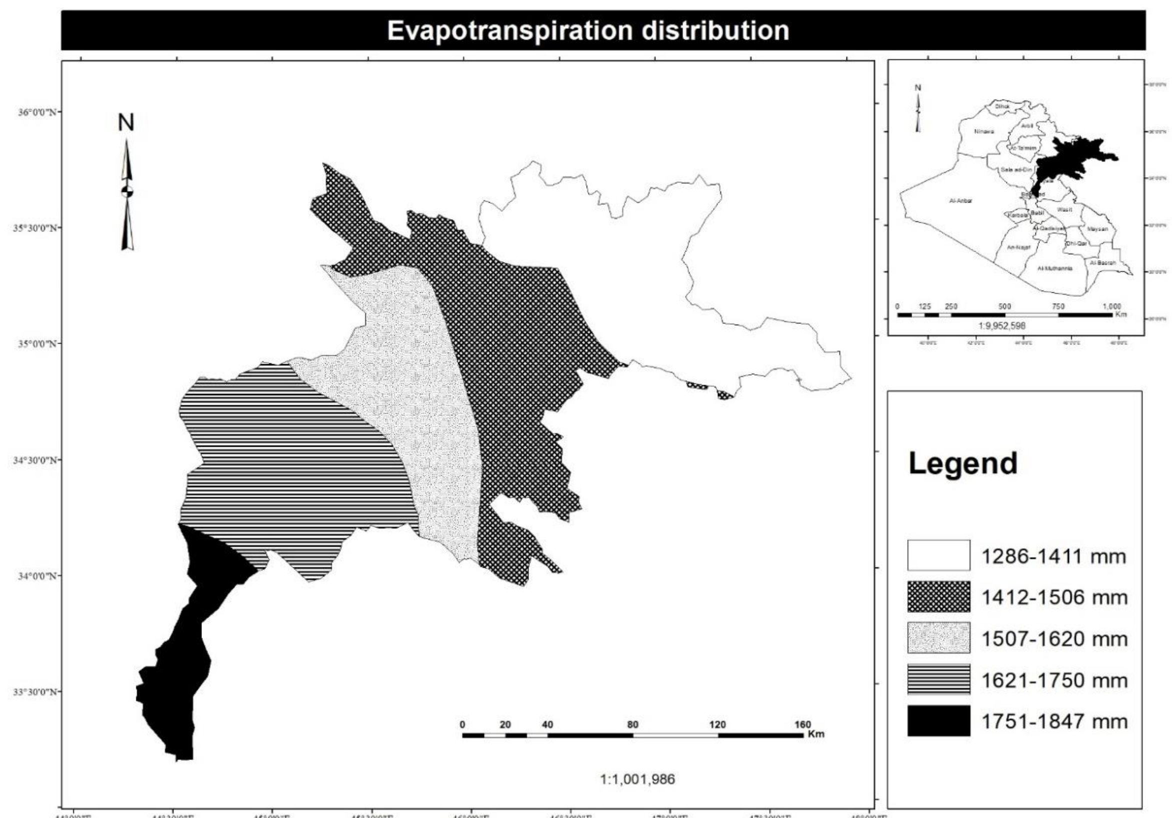

Fig. 4.4 evapotranspiration distribution for study period in DRB.

Figures 4.2, 4.3 and 4.4 show the distribution of average temperature, precipitation, and evapotranspiration for a long time in the DRB. The average air temperature in the upstream sub-basin ranges from 5-10°C and 17-20°C in the middle part and 21-25 in the downstream sub-basin. And long-range precipitation throughout the basin varied in spatial distribution from 107 mm in Baghdad to 220 mm in Khanaqin and 662 in Sulaymaniyah, it's worth noting that the upstream of sub-basin receives more precipitation than the middle and downstream. In addition, Tables 4.1 and 4.2 show the ratios of monthly average rainfall and evapotranspiration for a long time to average annual rainfall and evapotranspiration for a long time in the examined hydrologic year, which began in October. According to statistical research, precipitation accumulated during the rainy months, From October through May, accounts for around 99.5 percent of the total annual precipitation. And the other months supply around 0.5 percent of total precipitation during the months of aridity of June to September. The amount of yearly precipitation depth and runoff depth fell, but the average annual temperature rose. These studies are substantially in line with earlier research (Fadhil 2011; Roba and Al-Berazanji 2013).

The DRB hydroclimatic conditions were represented by the runoff coefficient, which is represented as a proportion of runoff flux compared to the precipitation over a given time period. The reduction in the runoff modulus implies that, as previously calculated, the flux field has weakened in the preceding four decades (Kahya and Kalayci 2004 Al-Ansari 2013; Al-Ansari et al. 2014).

Table 4.2 the ratios of monthly average potential evapotranspiration for a long time to total average potential evapotranspiration for a long time in the examined hydrologic year.

station	$\frac{\textbf{average potential evapotranspiration at any month}}{\textbf{total average potential evapotranspiration}} \times \mathbf{100}\%$					
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Sulaymaniyah	6.75	3.46	2.22	2.10	2.75	5.22
Marivan	6.98	3.34	2.05	1.83	2.32	4.59
Sanandaj	6.76	3.19	1.96	1.70	2.11	4.47
Ghorveh	6.67	3.20	1.95	1.67	2.08	4.42
Halabcha	6.85	3.54	2.28	2.15	2.81	5.29
Ravansar	6.92	3.30	2.04	1.82	2.35	4.79
Kermanshah	6.98	3.47	2.17	1.92	2.45	4.96
Eslamabad	7.01	3.51	2.27	2.05	2.71	5.16
Darbandikhan	6.77	3.56	2.35	2.23	2.96	5.45
Tus	6.78	3.58	2.41	2.45	3.23	5.84
Khanaqin	6.84	3.73	2.59	2.64	3.42	6.03
Balad	6.94	3.74	2.57	2.65	3.45	6.14
Baquba	6.98	3.76	2.59	2.67	3.48	6.18
Baghdad	7.03	3.86	2.69	2.75	3.59	6.29

station	$\frac{\text{average potential evapotranspiration at any month}}{\text{total average potential evapotranspiration}} \times 100\%$					
	Apr.	May	Jun.	Jul.	Aug.	Sep.
Sulaymaniyah	8.26	12.1	15.04	16.68	14.9	10.52
Marivan	7.76	11.65	15.13	17.44	15.8	11.11
Sanandaj	7.87	11.87	15.55	17.63	15.82	11.06
Ghorveh	7.88	11.83	15.64	17.71	15.92	11.03
Halabcha	8.27	12.02	14.92	16.53	14.80	10.54
Ravansar	7.89	11.67	15.07	17.42	15.72	11.01
Kermanshah	7.95	11.66	15.13	17.06	15.35	10.91
Eslamabad	8.17	11.82	14.79	16.69	15.03	10.79
Darbandikhan	8.42	12.14	14.82	16.31	14.59	10.41
Tus	8.79	12.27	14.50	15.67	14.12	10.36
Khanaqin	8.89	12.23	14.27	15.30	13.82	10.26
Balad	9.03	12.28	14.06	15.06	13.75	10.34
Baquba	9.11	12.33	13.97	14.89	13.67	10.37
Baghdad	9.17	12.32	13.79	14.63	13.55	10.35

4.2 Hydro-Climate Data Change Point Detection

For the 35-year hydrological period, the annual Runoff at DRB averaged 129 m3/sec during (1979 to 2012). For the 2000 water year, the minimum was 42 m3/sec. For the 1988 water year, the maximum was 313 m3/sec. The average flow rate in the DRB decreased -38m3/s per decade during the study period. Using the Pettitt technique, (Figs. 4.5 a and b) demonstrate the point of change in precipitation and the runoff time series. In the investigated time series, the water year 1996 is regarded as a turning point. The results were made to agree with those of several other researchers working in this field. (Sen et al. 2012). runoff and precipitation were reasonably regular before 1996, but the parameters of runoff and precipitation changed after 1996. the Pettitt test together, the year 1996 can be considered as a turning point in terms of runoff and precipitation, demonstrating the consequences of both the change of the climate and human involvement. As a result, the period from 1979 to 1996 was used as the time frame of reference, during which the effects of interference caused by humans on runoff were less noticeable.

Pettitt test for (precipitation):

K	258
t	1994
P-value	< 0.0001
α	0.05

Interpretation of the test:

H0: The data is homogeneous.

Ha: There is a point in time when the data changes.

null hypothesized H0 should be rejected, and accept the alternative hypothesized Ha because of ρ-value is less than α= 0.05.

Pettitt test for (flow):

Test interpretation:

K	272.
t	1996
ρ-value	< 0.0001
α	0.05

Interpretation of the test:

H0: The data is homogeneous.

Ha: There is a point in time when the data changes.

null hypothesized H0 should be rejected, and accept the alternative hypothesized Ha because of ρ-value is less than α= 0.05.

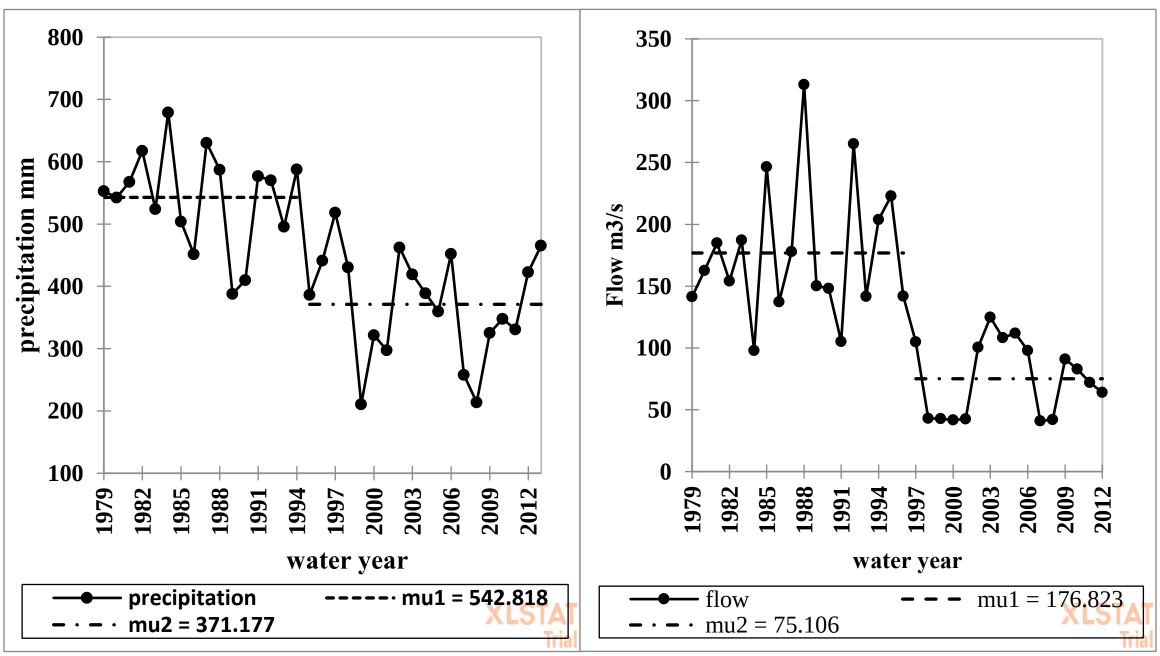

Fig. 4.5 a- Pettitt's test for precipitation. b- Pettitt's test for flow

To know the effects of climate and human interventions on surface runoff more clearly, the data of the runoff were analyzed for the Darbandikhan Dam area, which was built in 1962 and for a long period that extends before its construction (1931-2000) (Elhance, Arun P. 1999).

Pettitt test for (flow):

K	503
t	1967
ρ-value	0.030
α	0.05

Interpretation of the test:

H0: The data is homogeneous.

Ha: There is a point in time when the data changes.

null hypothesized H0 should be rejected, and accept the alternative hypothesized Ha because ρ-value < α= 0.05.

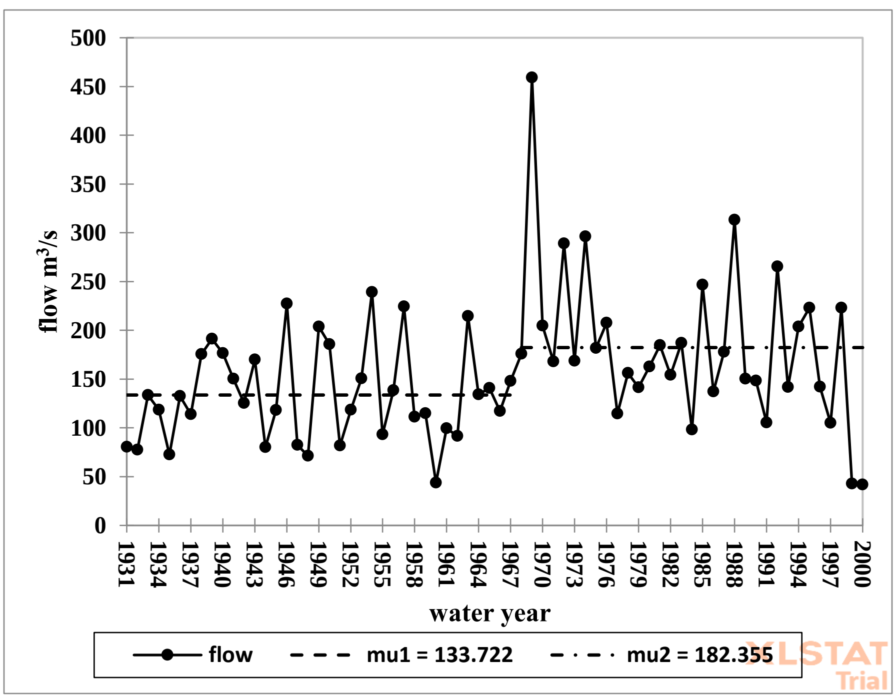

Fig. 4.6 pettitt test for flow in darbandikhan dam area.

The water year 1967 was the point of change, which is considered one of the wet years (1967, 1968, 1969, 1988, 1994). Because of the heavy rain this year, which lasted for seven days, a landslide occurred on the right side of the lake, where the rain amounted to 126 mm. (Abdullah, Mukhalad & Al-Ansari, Nadhir & Laue, Jan. 2019).

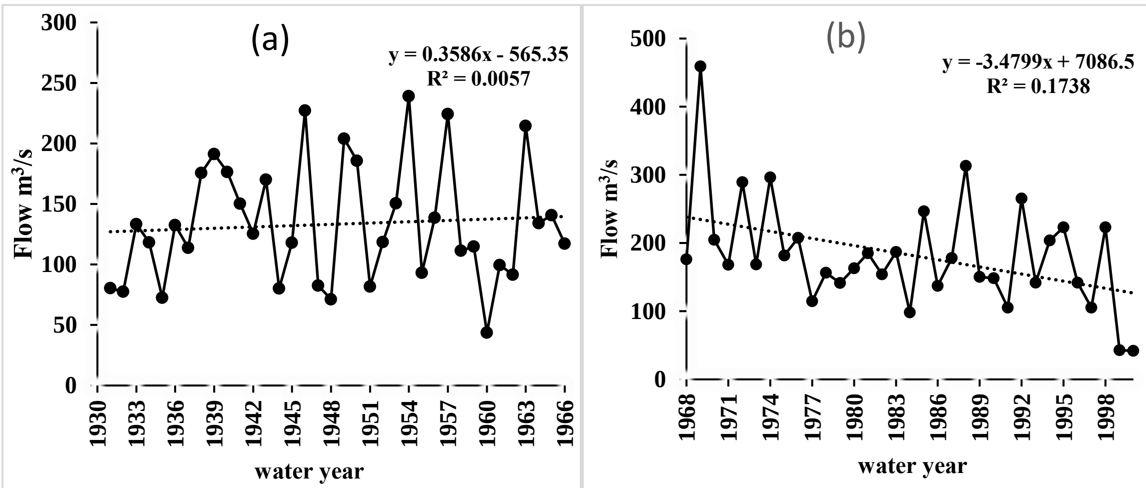

Fig. 4.7 a-flow trend before the change point. b-flow trend after the change point.

In Figure 4.7 there are two hydrological periods 1931-1966 and 1968-2000. During the first period (1931-1966), we notice a relative increase in flow by 3.6 m3/s per decade. The amount of increase in the flow during this period was 12.5 m3/s.

In the second period (1968-2000) there was a noticeable decrease in the values of the flow, where the amount of decrease was -34.8 m3/s per decade, and the amount of decrease during this period (1968-2000) was approximately 111.3 m3/s, this change in the water flow rate was due to human interventions and climate change, as the study period (1979-2012) dealt with climate changes after the year of change (1967) and their impact on flow rate fig 4.7 b, which suffered from high rates of temperature, evapotranspiration and a noticeable decrease in the rate of precipitation led to a noticeable decrease in water flow rate, as will be clarified later in each station in the Diyala River Basin.

The flow of water for the first period (1931-1966) before the year of change (1967)(fig 4.7 a) was compared to the precipitation (google earth pro) for the period (1901-1957) to see the impact of climatic changes that led to this increase, it was found that the precipitation that decreased during the second period (1968-2000) after the year of change (1967) was increasing during the period (1931-1966) before the year of change (1967). The increase in precipitation was 3.34 mm per decade (Fig. 4.8).

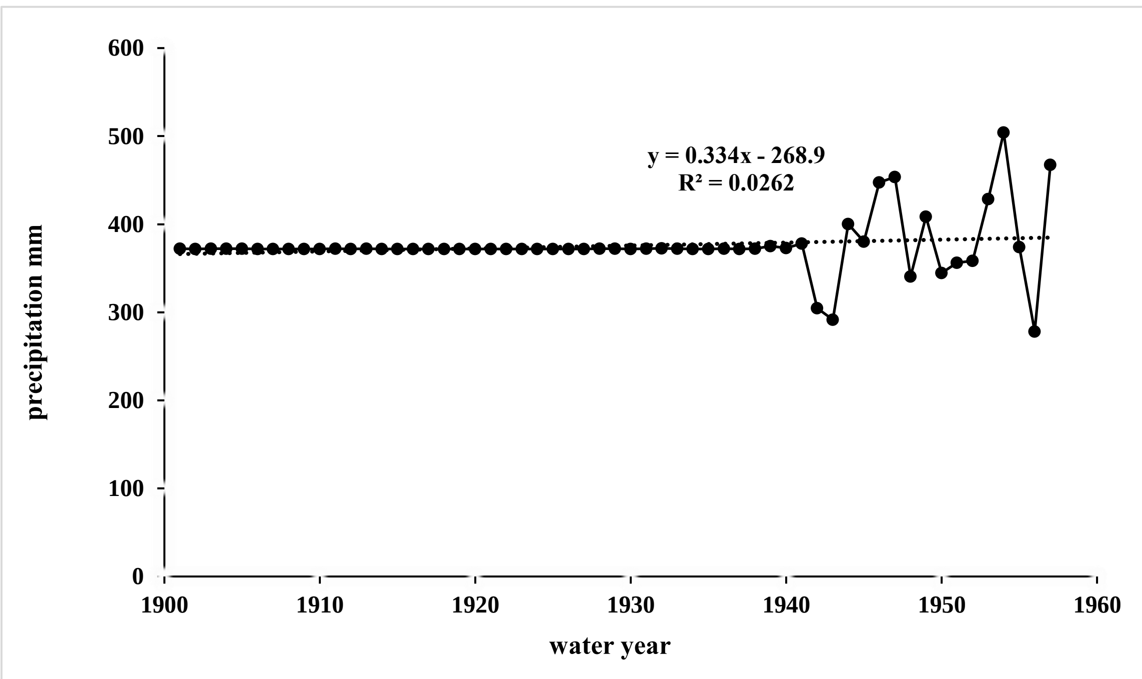

Fig. 4.8 Precipitation for the period (1901-1957) in the Darbandikhan dam area

4.3 Temporal variation of trend in the time-series

The stations in the basin were divided according to the nature of the land, the symmetry of the climate, and their location in relation to the Darbandikhan Dam and the Hamrin Dam. A temporal trend analysis was done for all of the stations under consideration, utilizing the Mann-Kendall test and the Pettitt test significant criterion.

Where the interpretation of the Mann Kendall test is as follows;

H0: No trend.

Ha: There's a trend.

null hypothesized H0 should be rejected, and accept the alternative hypothesized Ha if ρ-value < α= 0.05.

So is the interpretation of the Pettitt test:

H0: The data is homogeneous.

Ha: There is a point in time when the data changes.

null hypothesized H0 should be rejected, and accept the alternative hypothesized Ha if the calculated ρ-value is less than alpha=0.05.

4.3.1 Upstream Stations.

It includes the stations where the tributaries of the Tigris River are under the control of the Darbandikhan Dam, the results of the Mann-Kendall and Pettitt tests for precipitation, evapotranspiration and temperature in each station are shown in Table 4.3 and 4.4, respectively, and Figures below.

Table 4.3 results of the Mann-Kendall test for upstream stations.

Station Name	M-K (Precipitation)				
	K-tau	S	Var(S)	ρ-Value	α
Sanandaj	-0.422	-237	4550	0.00046	0.05
Kermanshah	-0.35	-197	4550	0.004	0.05
Ghorveh	-0.504	-283	4550	<0.0001	0.05
Ravansar	-0.455	-255	4550	0.00016	0.05
Marivan	-0.537	-301	4550	<0.0001	0.05
Sulaymaniyah	-0.351	-197	4550	0.004	0.05
Halabcha	-0.451	-253	4550	0.00019	0.05
Station Name	M-K (Evapotranspiration)				
	K-tau	S	Var(S)	ρ-Value	α
Sanandaj	0.537	301	4550	<0.0001	0.05
Kermanshah	0.376	211	4550	0.002	0.05
Ghorveh	0.469	263	4550	0.0001	0.05
Ravansar	0.443	249	4550	0.0002	0.05
Marivan	0.54	303	4550	<0.0001	0.05
Sulaymaniyah	0.597	335	4550	<0.0001	0.05
Halabcha	0.59	331	4550	<0.0001	0.05
Station Name	M-K (Temperature)				
	K-tau	S	Var(S)	ρ-Value	α
Sanandaj	0.312	175	4550	0.010	0.05
Kermanshah	0.362	203	4550	0.003	0.05
Ghorveh	0.355	199	4550	0.003	0.05
Ravansar	0.405	227	4550	0.001	0.05
Marivan	0.430	241	4550	0.0003	0.05
Sulaymaniyah	0.383	215	4550	0.002	0.05
Halabcha	0.522	293	4550	<0.0001	0.05

Table 4.4 results of the Pettitt test for upstream stations.

Station Name	Pettitt test (Precipitation)			
	K	t	ρ-Value	α
Sanandaj	212	1998	0.001	0.05
Kermanshah	206	1998	0.002	0.05
Ghorveh	242	1998	0.0002	0.05
Ravansar	220	1998	0.001	0.05
Marivan	242	1994	< 0.0001	0.05
Sulaymaniyah	204	1994	0.001	0.05
Halabcha	234	1994	< 0.0001	0.05
Station Name	Pettitt test (Evapotranspiration)			
	K	t	ρ-Value	α
Sanandaj	277	1997	< 0.0001	0.05
Kermanshah	251	1997	< 0.0001	0.05
Ghorveh	274	1998	< 0.0001	0.05
Ravansar	273	1997	< 0.0001	0.05
Marivan	283	1997	< 0.0001	0.05
Sulaymaniyah	277	1997	< 0.0001	0.05
Halabcha	273	1997	< 0.0001	0.05
Station Name	Pettitt test (Temperature)			
	K	t	ρ-Value	α
Sanandaj	197	1997	0.004	0.05
Kermanshah	209	1997	0.001	0.05
Ghorveh	212	1998	0.001	0.05
Ravansar	225	1993	0.0004	0.05
Marivan	225	1993	< 0.0001	0.05
Sulaymaniyah	237	1997	< 0.0001	0.05
Halabcha	254	1996	< 0.0001	0.05

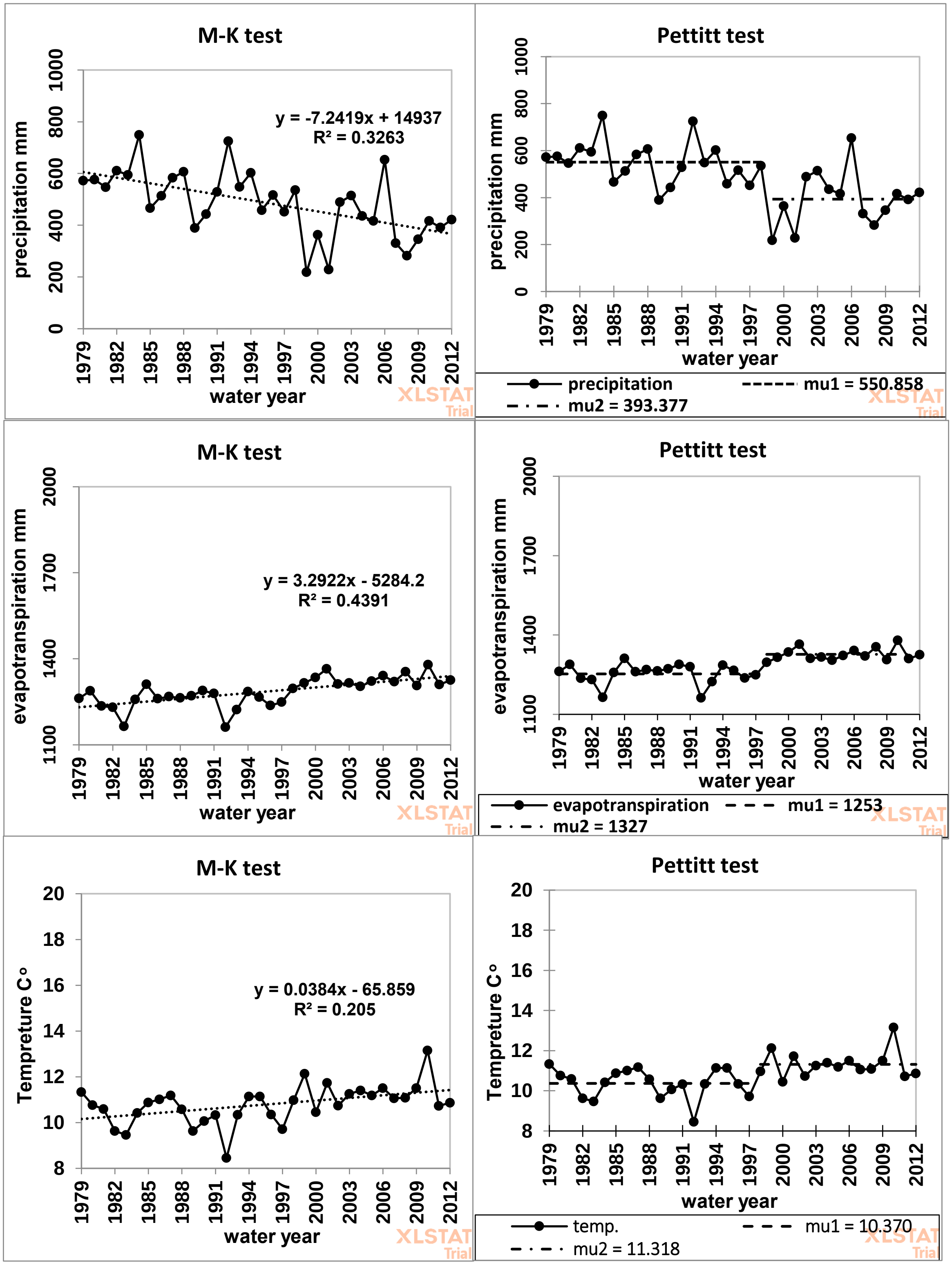

Fig. 4.9 M-K trend test (Sen's slope) and Pettitt test for precipitation, temperature and evapotranspiration at Sanandaj station.

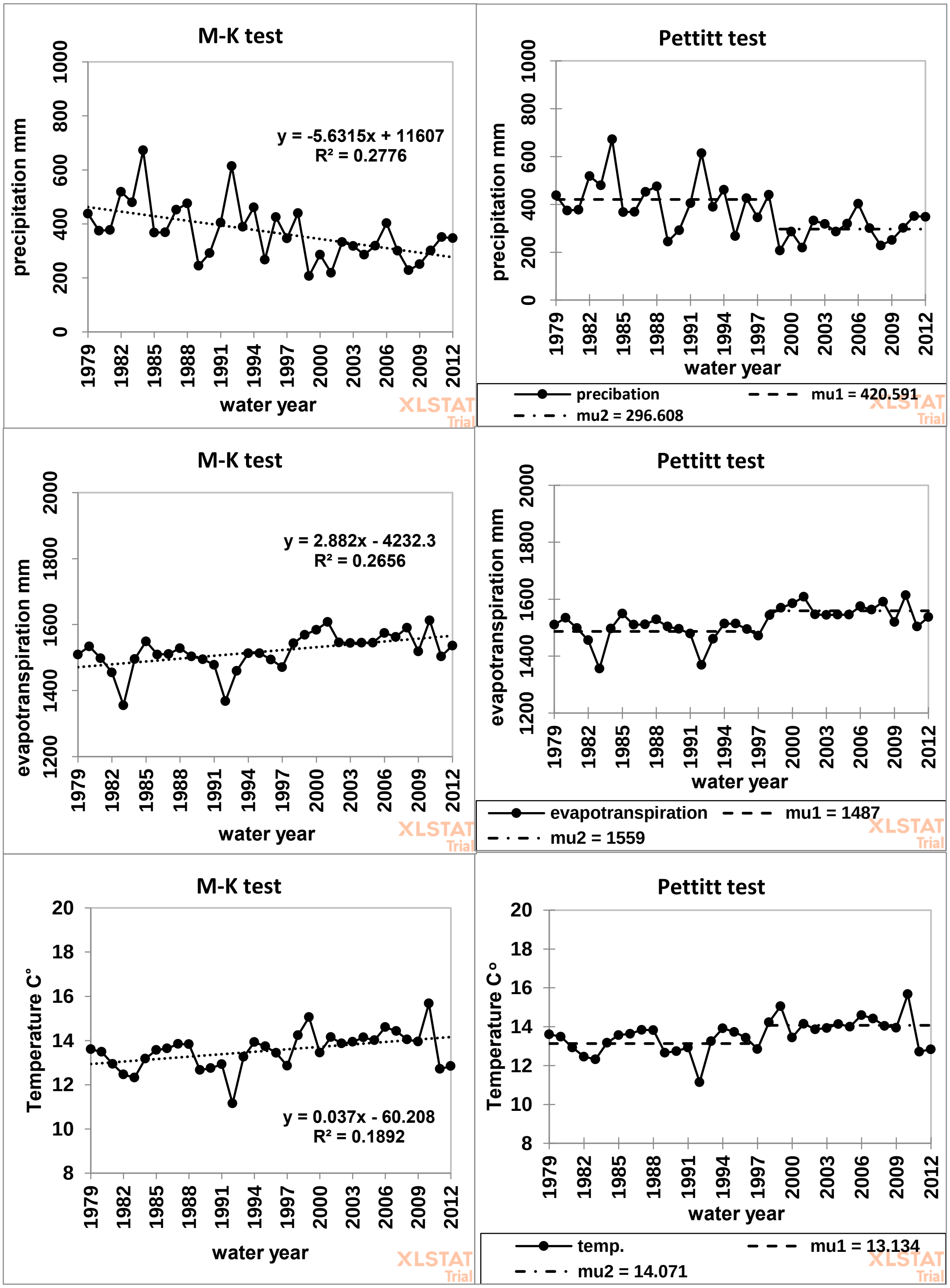

Fig. 4.10 M-K trend test (Sen's slope) and Pettitt test for precipitation, temperature and evapotranspiration at Kermanshah station.

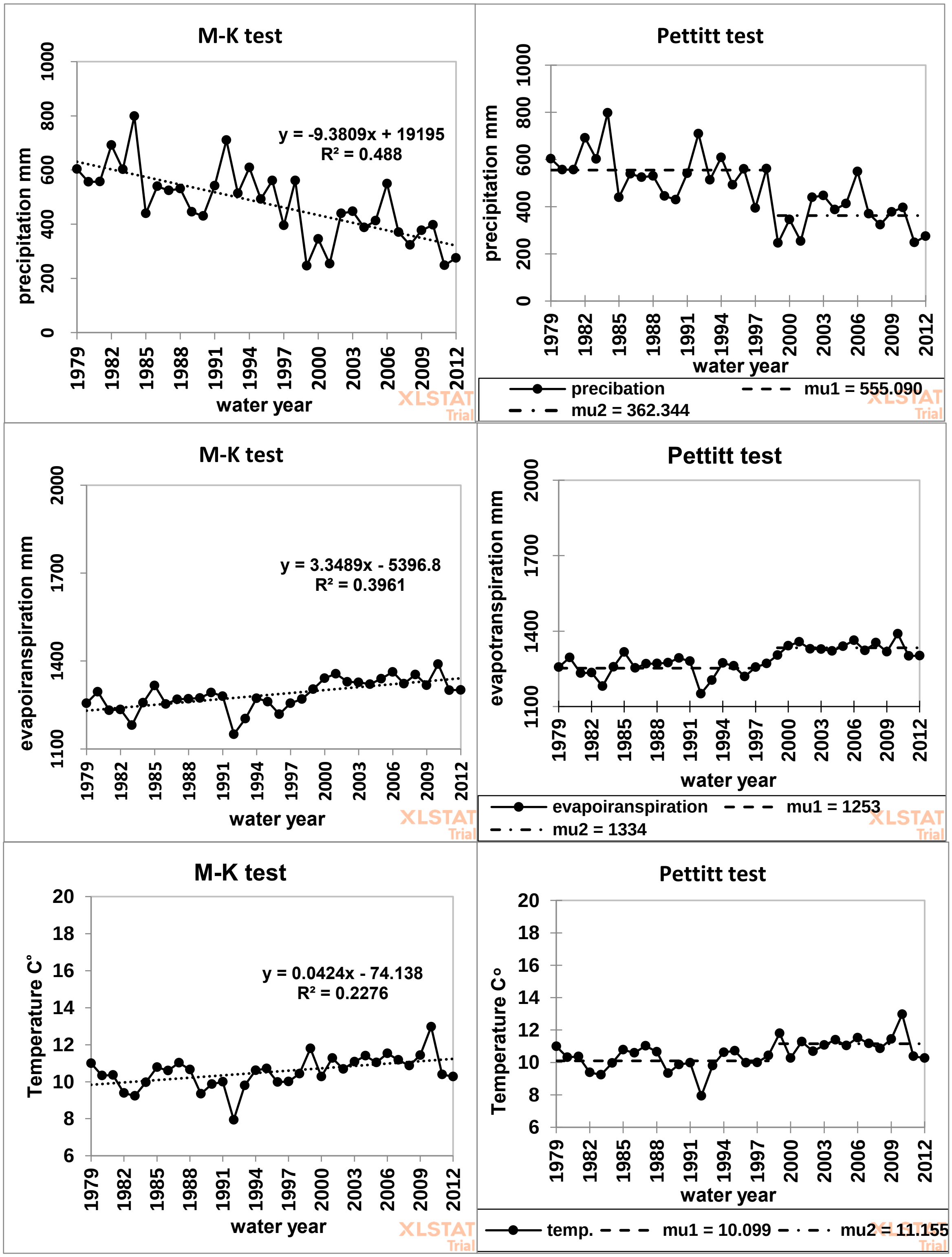

Fig 4.11 M-K trend test (Sen's slope) and Pettitt test for precipitation, temperature and evapotranspiration at Ghoveh station.

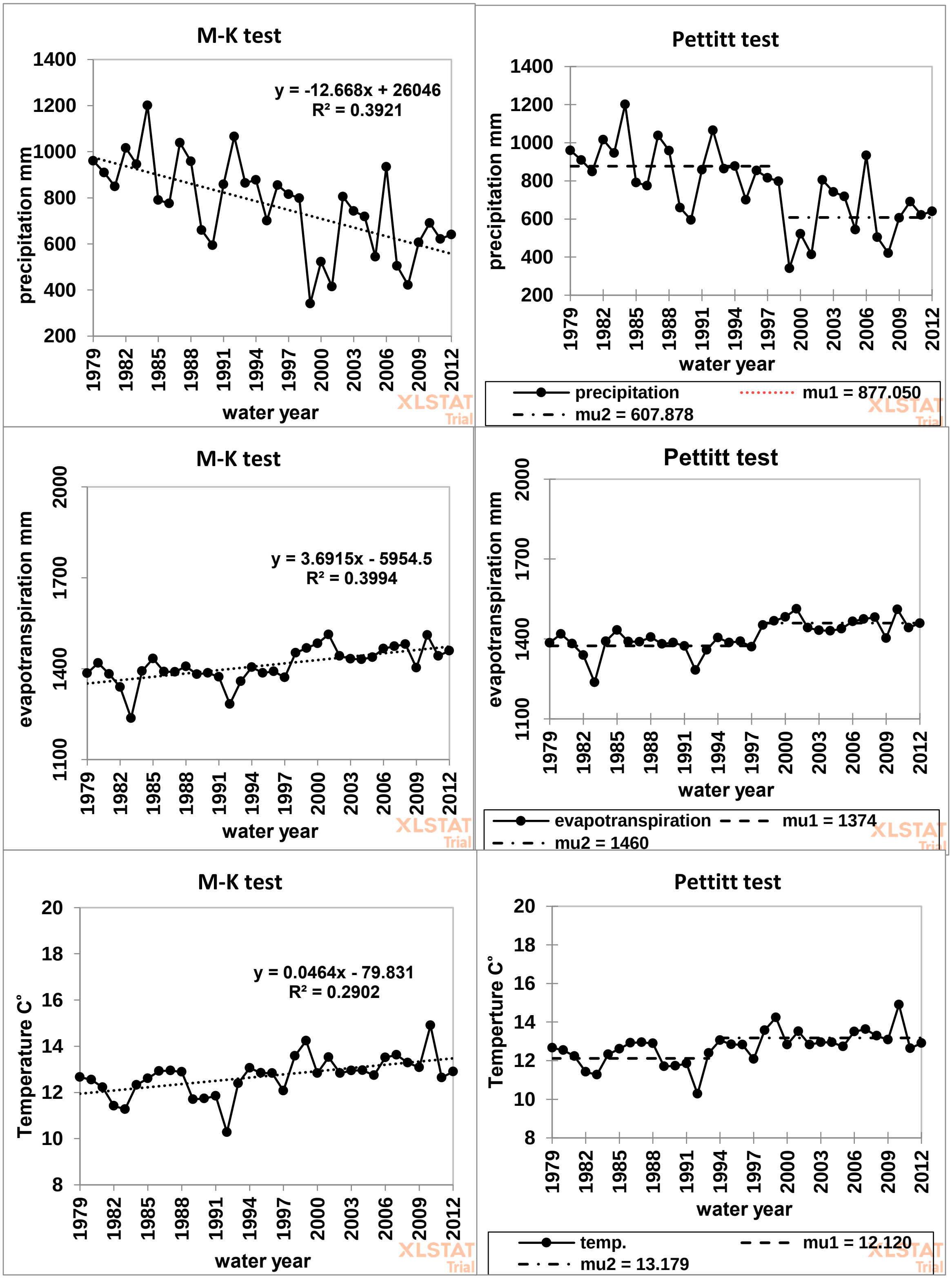

Fig 4.12 M-K trend test (Sen's slope) and Pettitt test for precipitation, temperature, and evapotranspiration at Ravansar station.

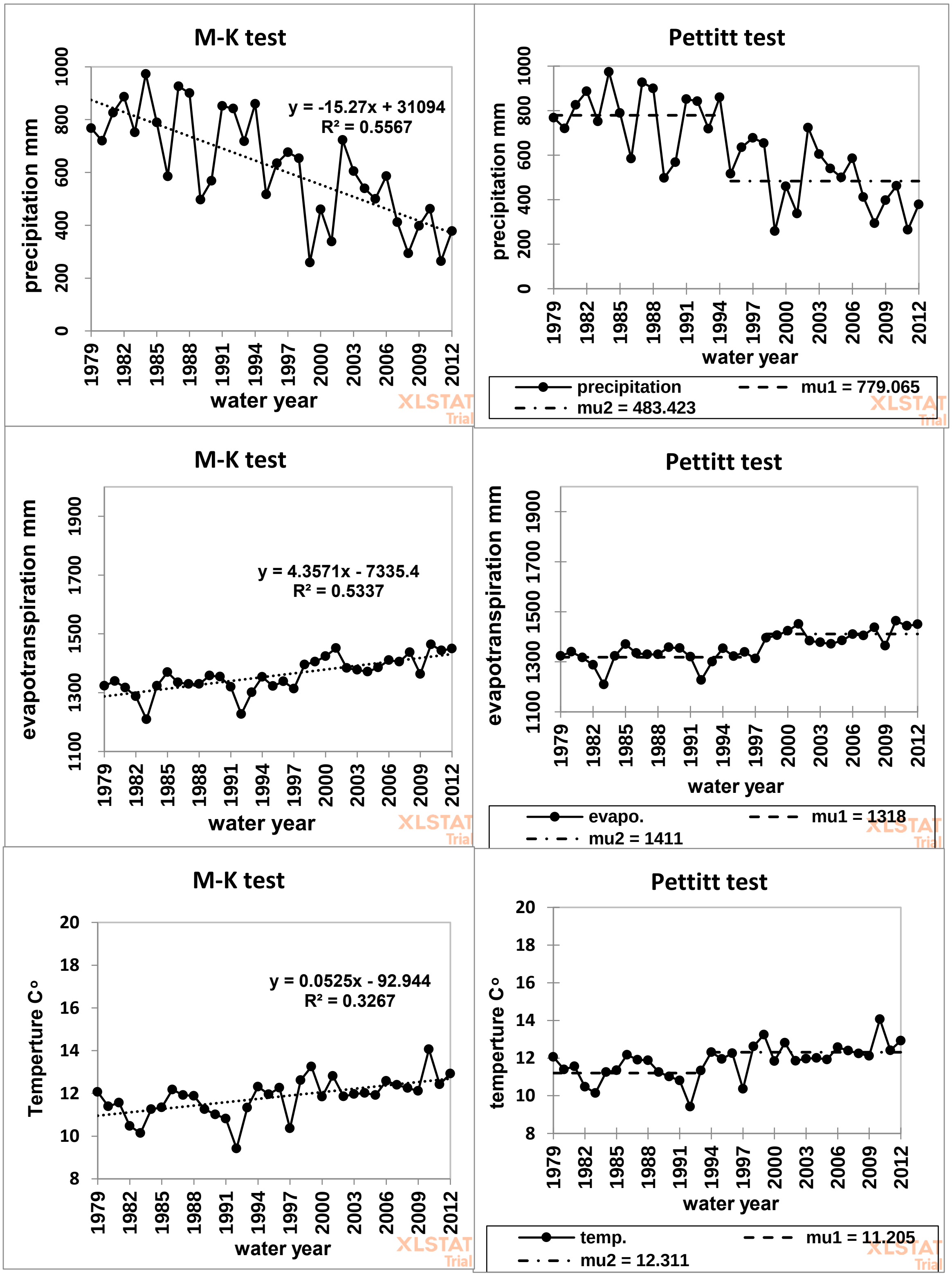

Fig. 4.13 M-K trend test (Sen's slope) and Pettitt test for precipitation, temperature and evapotranspiration at marivan station.

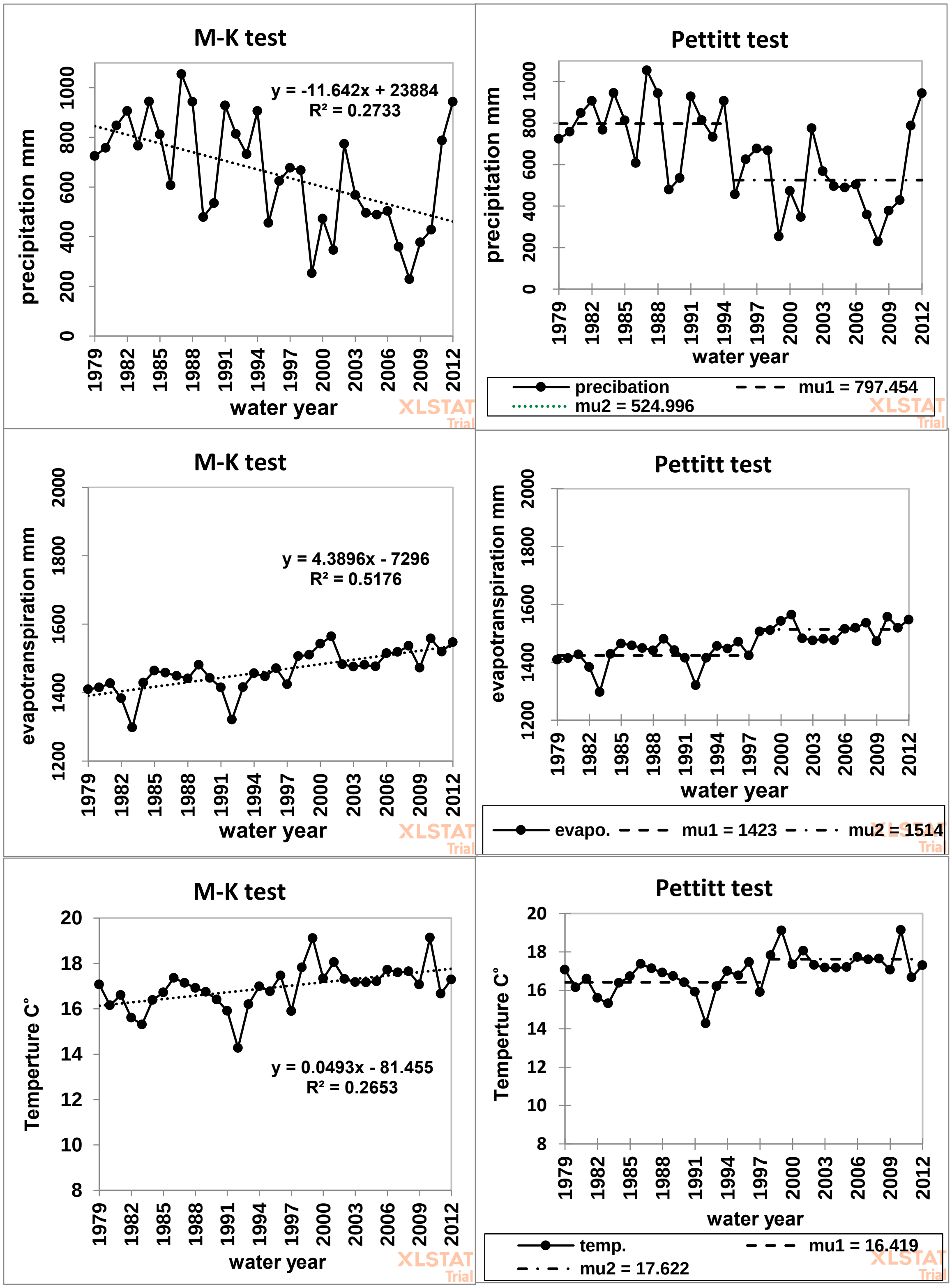

Fig. 4.14 M-K trend test (Sen's slope) and Pettitt test for precipitation, temperature, and evapotranspiration at Sulemanyih station.

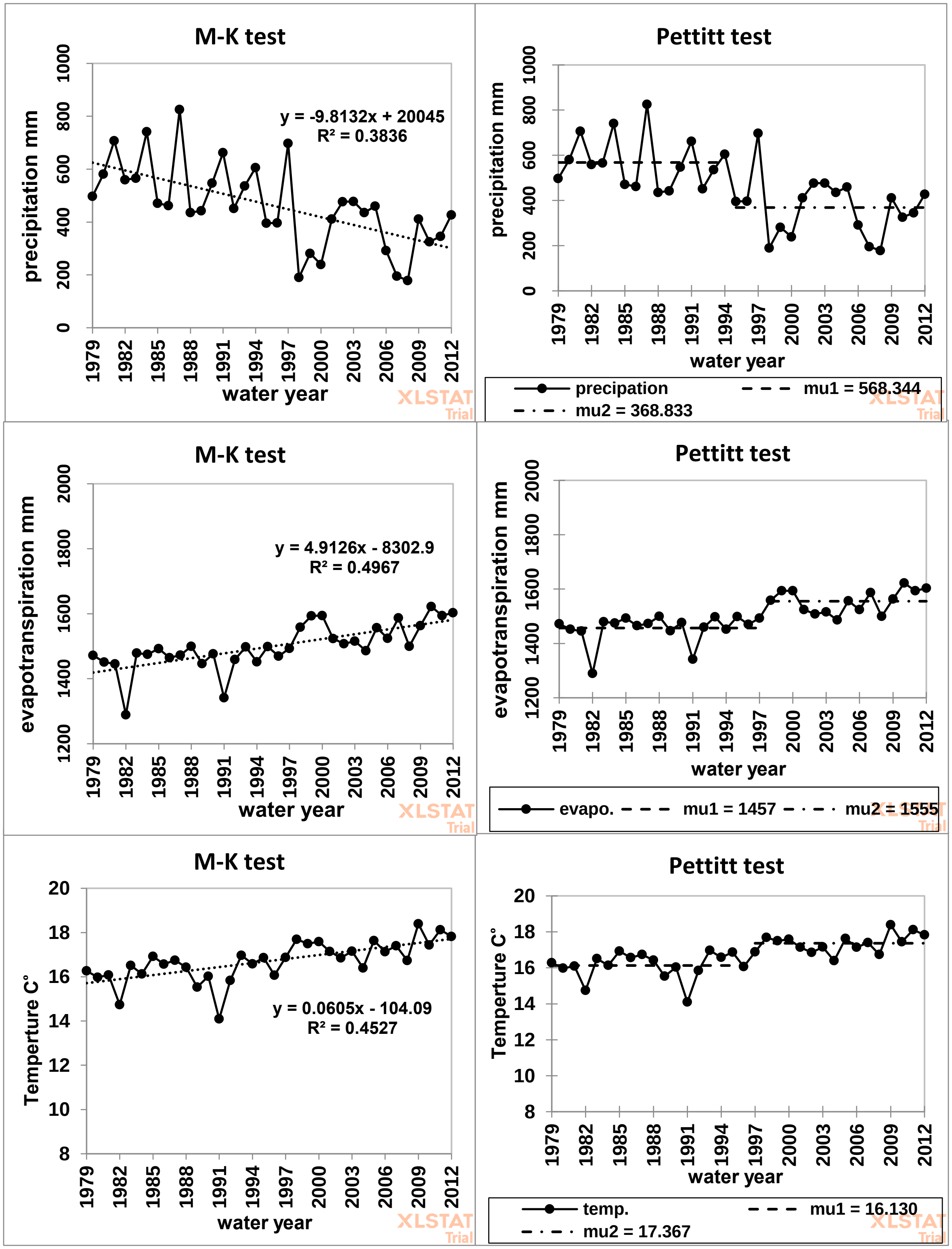

Fig. 4.15 M-K trend test (Sen's slope) and Pettitt test for precipitation, temperature, and evapotranspiration at Halabcha station.

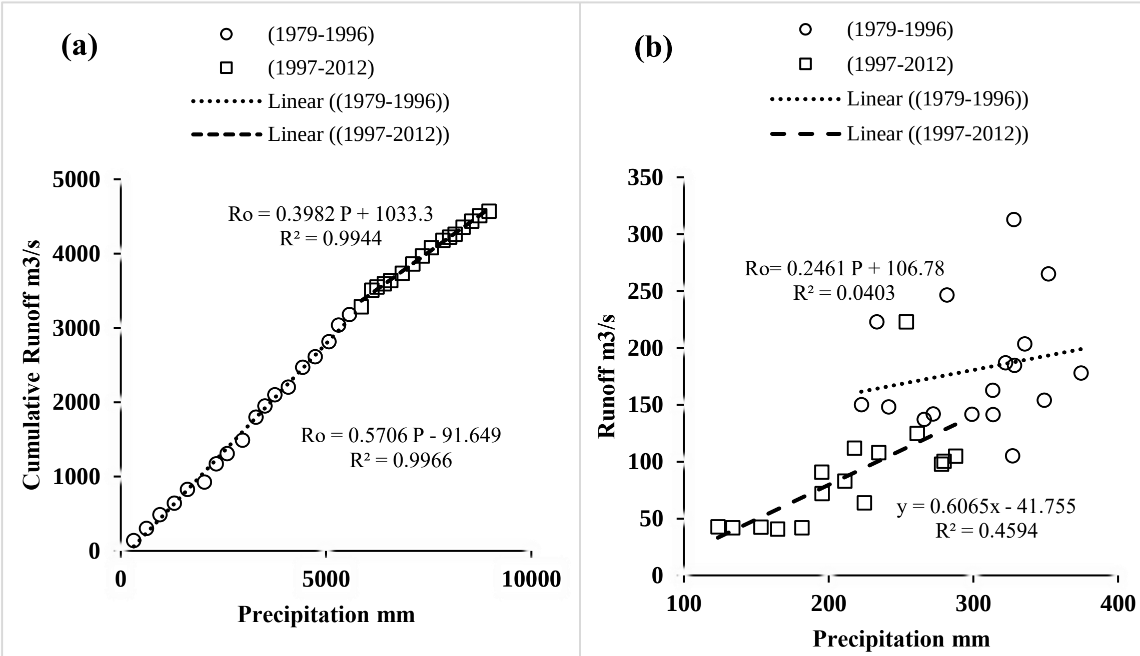

Fig. 4.16 a- Precipitation-runoff double cumulative curve (PRDCC) of annual precipitation and runoff in the DRB; **b-** The correlation between precipitation and runoff for the two considered time period.

The cumulative yearly runoff and precipitation in the upstream part of DRB displayed in (Fig. 4.16a) show that runoff and precipitation were relatively regular before 1996, but their attributes changed after 1996. The year 1996 might be considered as the change point representing the impact of both climatic changes and human interventions on runoff and precipitation, if the Precipitation-runoff double cumulative curve (PRDCC) analysis and the Pettitt test are combined. As a result, the period from 1979 to 1996 was used as the baseline period, during which the effects of human interventions on runoff were less noticeable. The fluctuations in the correlation between streamflow and precipitation were explored in order to fully grasp the effects of climate and other variables on streamflow during the two periods (Fig. 4.16b).

The average annual precipitation and runoff in this part of Diyala River Basin was (303.5 mm, 181.5 m3/s respectively) during the baseline period (1979-1996), and (212.2mm, 87 m3/s) during the period (1997-2012) that is, the change in average annual precipitation and runoff was (-91.3 mm, -94.5 m3/s). (Al-Ansari 2013; Al-Ansari et al. 2014).

4.3.2 Middle part station.

It includes the stations where the tributaries of the Tigris River are not under the control of the Darbandikhan Dam, and their location is between the Hamrin Dam and the Darbandikhan Dam, the results of the Mann-Kendall and Pettitt tests for precipitation, evapotranspiration and temperature in each station are shown in Table 4.5 and 4.6, respectively, and Figures below.

Table 4.5 results of the Mann-Kendall test for middle part stations.

Station Name	M-K (Precipitation)				
	K-tau	S	Var(S)	ρ-Value	α
Darbandikhan	-0.401	-225	4550	0.001	0.05
Eslamabad	-0.54	-338	5390	<0.0001	0.05
Khanaqin	-0.412	-231	4550	0.001	0.05
Tus	-0.483	-271	4550	<0.0001	0.05
Station Name	M-K (Evapotranspiration)				
	K-tau	S	Var(S)	ρ-Value	α
Darbandikhan	0.558	313	4550	<0.0001	0.05
Eslamabad	0.387	217	4550	0.001	0.05
Khanaqin	0.333	187	4550	0.006	0.05
Tus	0.419	235	4550	0.001	0.05
Station Name	M-K (Temperature)				
	K-tau	S	Var(S)	ρ-Value	α
Darbandikhan	0.298	167	4550	0.014	0.05
Eslamabad	0.190	120	5390	0.106	0.05
Khanaqin	0.066	37	4550	0.594	0.05
Tus	0.273	153	4550	0.024	0.05

Table 4.6 results of the Pettitt test for middle part stations.

Station Name	Pettitt test (Precipitation)			
	K	t	ρ-Value	α
Darbandikhan	228	1994	< 0.0001	0.05
Eslamabad	249	1997	< 0.0001	0.05
Khanaqin	201	1995	0.003	0.05
Tus	242	1994	< 0.0001	0.05
Station Name	Pettitt test (Evapotranspiration)			
	K	t	ρ-Value	α
Darbandikhan	273	1997	< 0.0001	0.05
Eslamabad	259	1997	< 0.0001	0.05
Khanaqin	225	1997	< 0.0001	0.05
Tus	257	1998	< 0.0001	0.05
Station Name	Pettitt test (Temperature)			
	K	t	ρ-Value	α
Darbandikhan	207	1997	0.002	0.05
Eslamabad	187	1995	0.007	0.05
Khanaqin	99	1997	0.661	0.05
Tus	172	1996	0.022	0.05

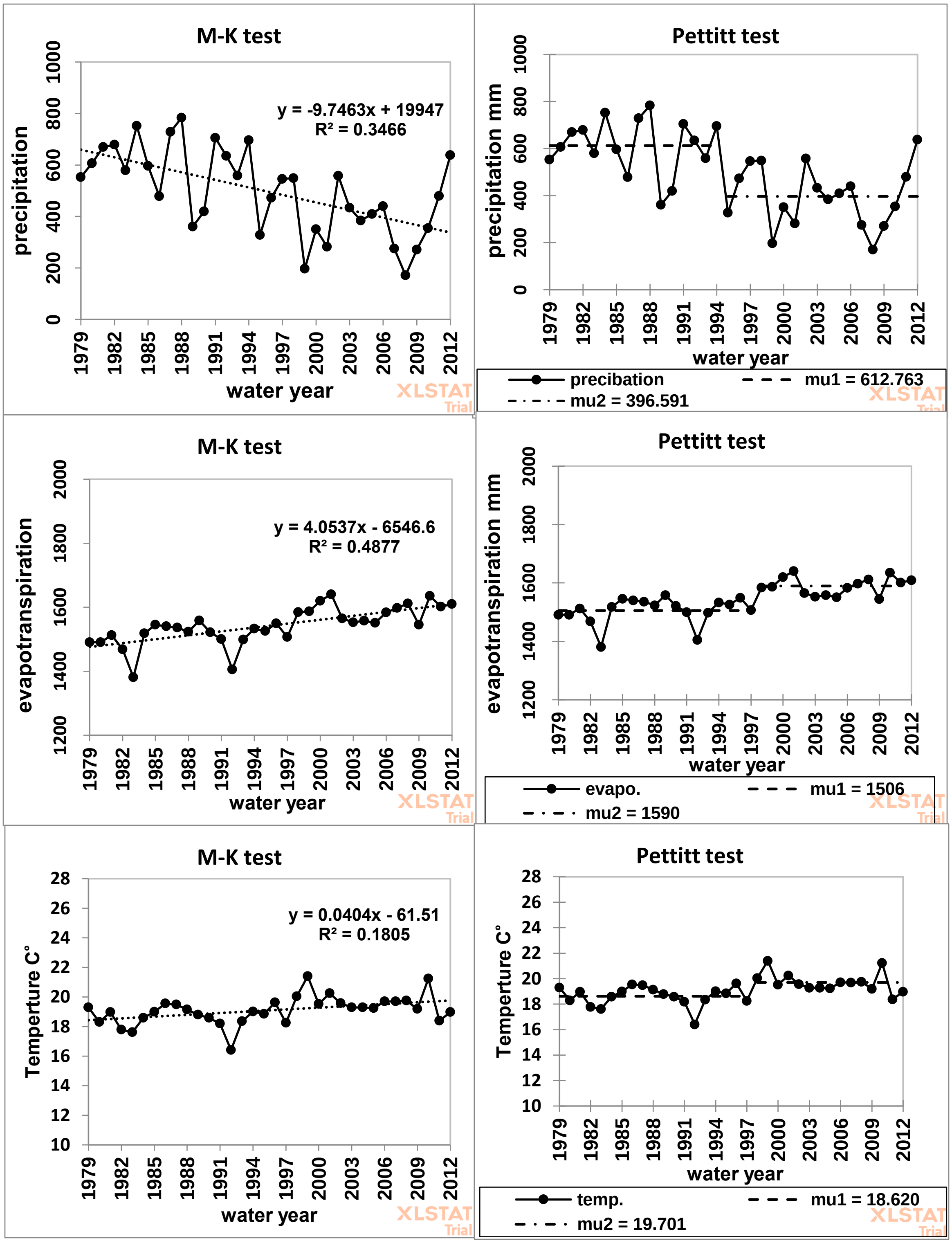

Fig. 4.17 M-K trend test (Sen's slope) and Pettitt test for precipitation, temperature, and evapotranspiration at Darbandikhan station.

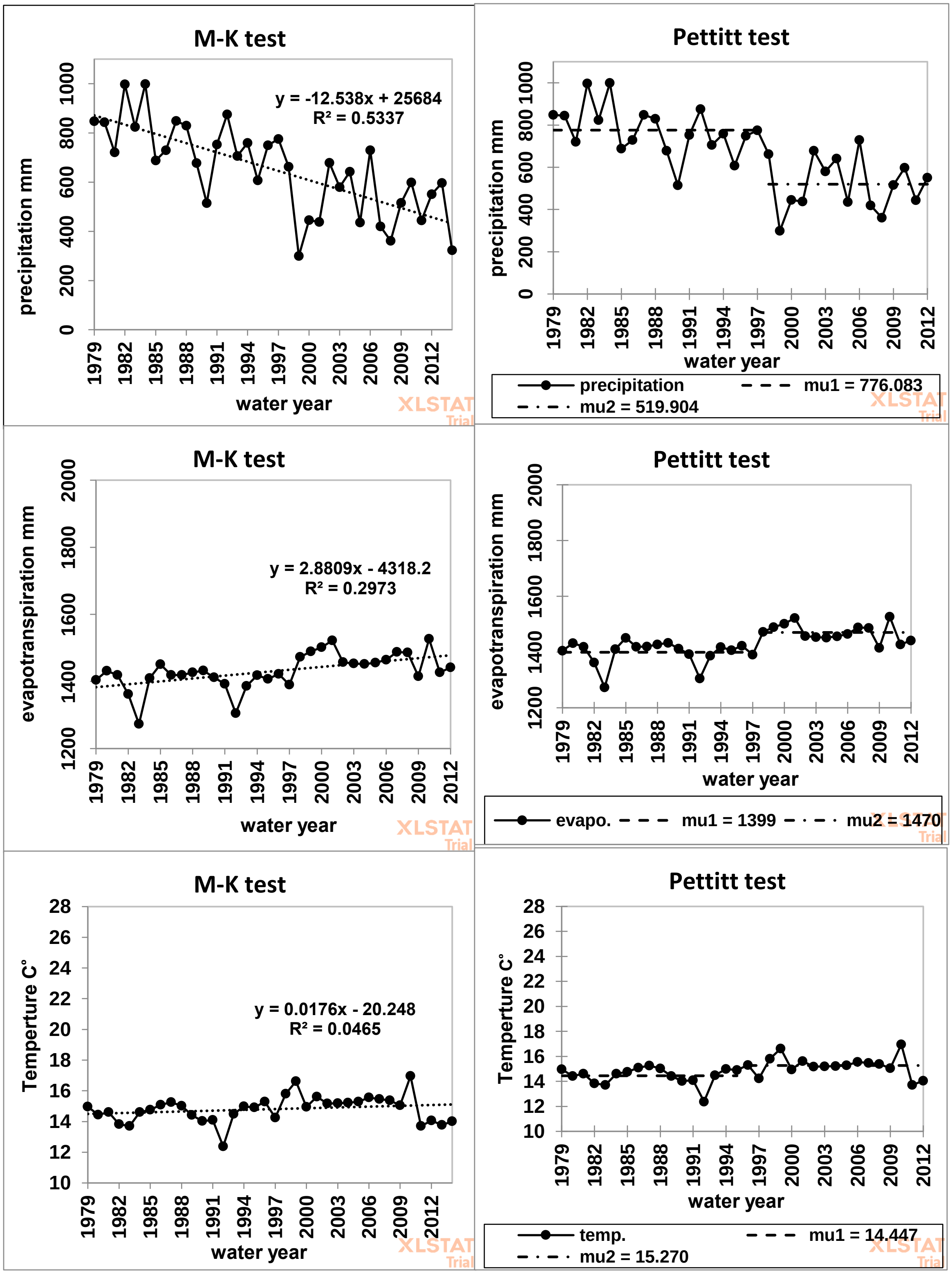

Fig. 4.18 M-K trend test (Sen's slope) and Pettitt test for precipitation, temperature and evapotranspiration at Eslamabad station.

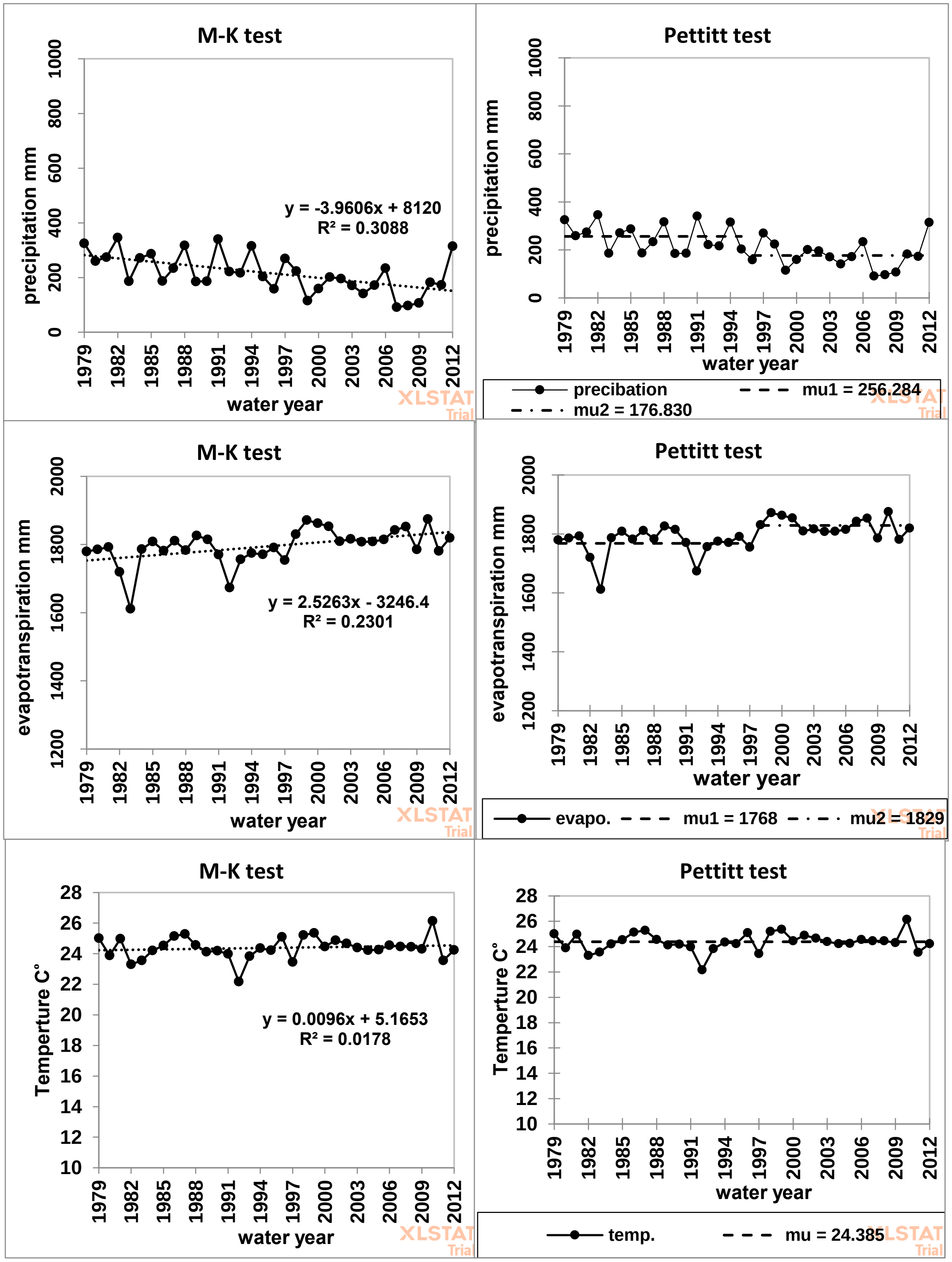

Fig. 4.19 M-K trend test (Sen's slope) and Pettitt test for precipitation, temperature, and evapotranspiration at khanaqin station.

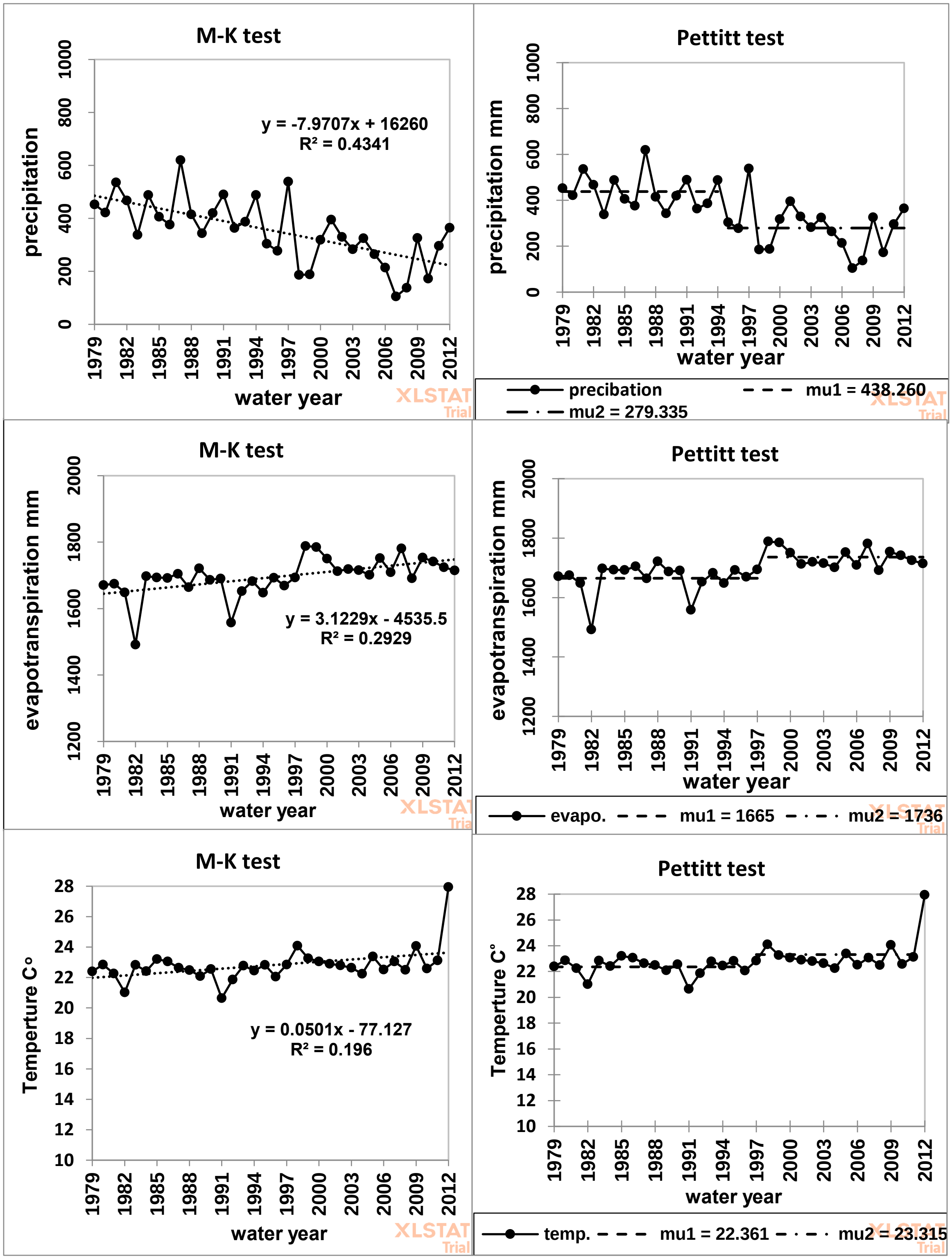

Fig. 4.20 M-K trend test (Sen's slope) and Pettitt test for precipitation, temperature, and evapotranspiration at Tus station.

4.3.3 Downstream stations.

It includes stations located after Hamrin Dam, the results of the Mann-Kendall and Pettitt tests for precipitation, evapotranspiration and temperature in each station are shown in Table 4.7 and 4.8, respectively, and Figures below.

Table 4.7 results of the Mann-Kendall test for downstream stations.

Station Name	M-K (Precipitation)				
	K-tau	S	Var(S)	ρ-Value	α
Balad	-0.351	-197	4550	0.004	0.05
Baquba	-0.422	-237	5390	0.0004	0.05
Baghdad	-0.355	-199	4550	0.003	0.05
Station Name	M-K (Evapotranspiration)				
	K-tau	S	Var(S)	ρ-Value	α
Balad	0.346	194	4550	0.004	0.05
Baquba	0.258	145	4550	0.033	0.05
Baghdad	0.262	147	4550	0.030	0.05
Station Name	M-K (Temperature)				
	K-tau	S	Var(S)	ρ-Value	α
Balad	0.064	35	4498	0.612	0.05
Baquba	0.059	33	4550	0.635	0.05
Baghdad	0.119	67	4550	0.328	0.05

Table 4.8 results of the Pettitt test for downstream stations.

Station Name	Pettitt test (Precipitation)			
	K	t	ρ-Value	α
Balad	194	1994	0.004	0.05
Baquba	190	1994	0.005	0.05
Baghdad	177	1989	0.017	0.05
Station Name	Pettitt test (Evapotranspiration)			
	K	t	ρ-Value	α
Balad	227	1996	0.0002	0.05
Baquba	203	1997	0.001	0.05
Baghdad	209	1997	0.002	0.05
Station Name	Pettitt test (Temperature)			
	K	t	ρ-Value	α
Balad	86	1996	0.971	0.05
Baquba	203	1997	0.001	0.05
Baghdad	99	1997	0.651	0.05

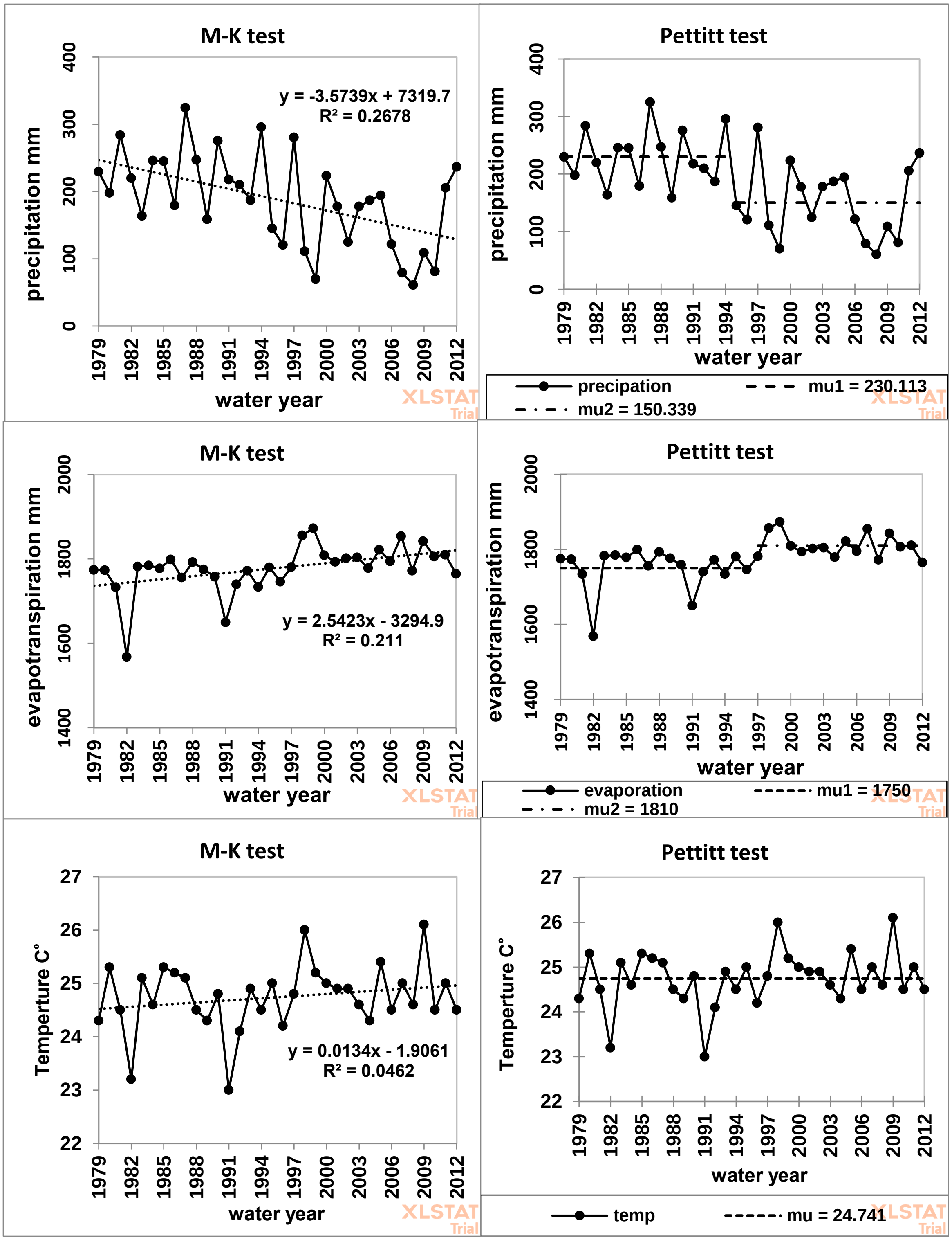

Fig. 4.21 M-K trend test (Sen's slope) and Pettitt test for precipitation, temperature, and evapotranspiration at balad station.

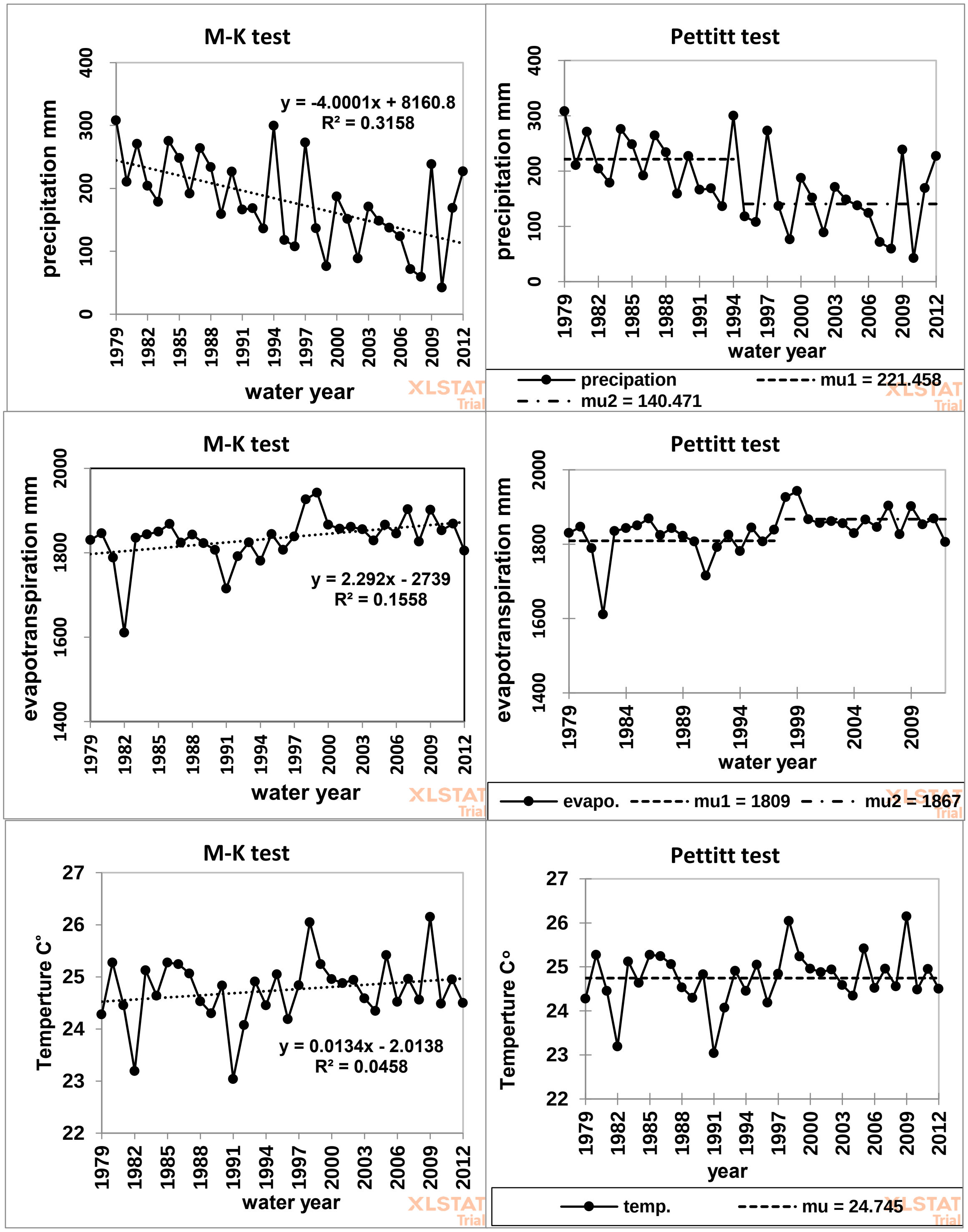

Fig. 4.22 M-K trend test (Sen's slope) and Pettitt test for precipitation, temperature, and evapotranspiration at Baquba station.

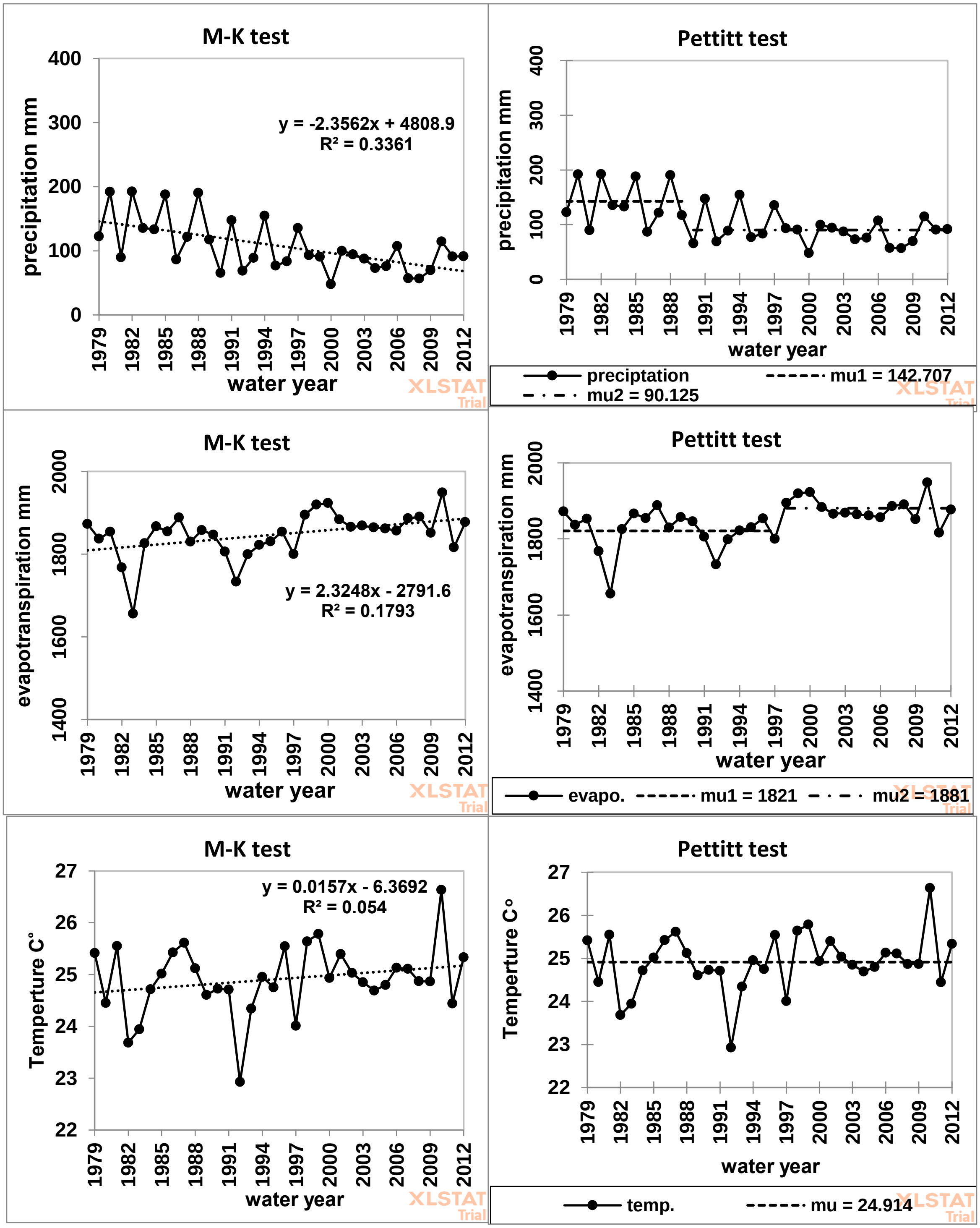

Fig. 4.23 M-K trend test (Sen's slope) and Pettitt test for precipitation, temperature, and evapotranspiration at Baghdad station.

4.4 Basin Average Precipitation Computation

Thiessen network has already been constructed to get an accurate estimate of the geographical distribution of precipitation and evapotranspiration across the DRB. Using this method, each station is given a weight based on the basin area that is the nearest to it. Table 4.9 demonstrates how the area of every station polygon was calculated using a Thiessen network (ai,km^2). The size of each polygon (ai, km) was multiplied by the precipitation amounts for each sampling station. Weather stations are spread within and without the basin polygons, as shown in Fig.4.23. The diagram shows how the entire basin is subdivided into fourteen sub-areas, each of which is assigned to a different meteorological station.

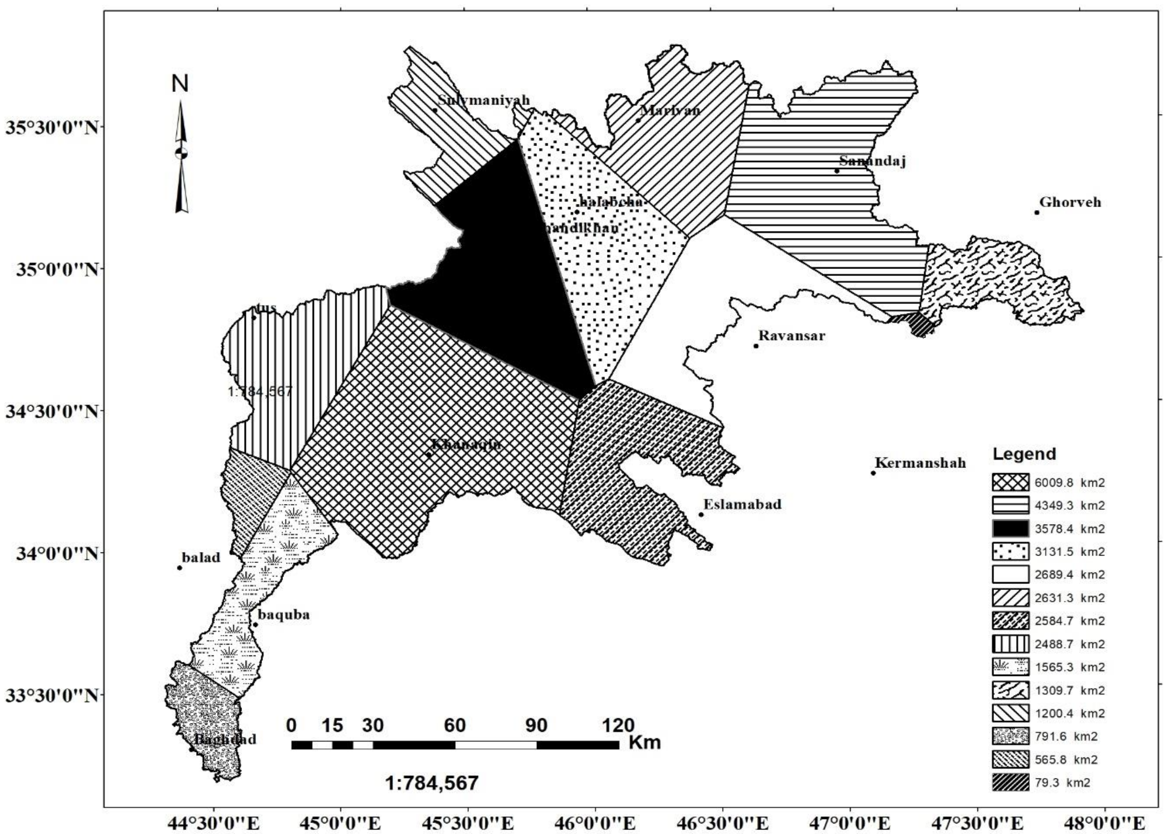

Fig. 4.24 Thiessen Polygon for DRB

Table 4.9 precipitation and evapotranspiration by Thiessen.

station	area (ai) (km2)	(pi) (mm)	pi × ai	(PETi) (mm)	PET i × ai
Sulaymaniyah	1200.4	662.2	895294.4	1463.3	1978381.6
Marivan	2631.3	618.5	1624799.5	1359.28	3570828.56
Sanandaj	4349.3	483.9	2113036.4	1285.46	5613192.47
Ghorveh	1309.7	468.8	615989.1	1285.92	1689660.3
Halabcha	3131.5	457.5	1408180.4	1500.22	4617662.15
Ravansar	2689.4	763.2	2051153.4	1411.9	3794580
Kermanshah	79.3	366.8	28111.55	1518.68	116391.63
Eslamabad	2584.7	661.1	1713240.6	1430.52	3707192.58
Darbandikhan	3578.4	504.6	1758152.55	1542.62	5374873.7
Tus	2488.7	354.1	883189.1	1696.24	4230727.8
Khanaqin	6009.8	219.8	1321681.5	1794.74	10791969
Balad	565.8	187.4	105461.2	1778.17	1000682.95
Baquba	1565.3	176.4	278119.3	1834.74	2892724.47
Baghdad	791.6	107.2	86384.9	1847.49	1488762.8
	$\sum 3297.62$		$\sum 14882794.3$		$\sum 50867630.34$

The following step was to calculate the average values of average potential evapotranspiration PETm (mm) and average precipitation Pm (mm) by adding all of the values from the previous step and dividing the resulting number by the total basin area using Eq.

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

Where; Pm = average precipitation of the catchment P (mm) or PET (mm) for the long term.

a_i = area of station calculated by Thiessen (km2)

p_i = the average value of the station (mm)

look at Table 4.9, The average precipitation Pm (mm) to the total basin area for long term is: $P_m = \frac{14882794.3}{32975.62} = 451.33 \text{ mm}$

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The current study explored time-based variations in runoff produced by the building of the Darbandikhan dam in Diyala River Basin. Accordingly, hydro-climatic data during two time-periods: pre-dam construction (1931–1966) and post-dam construction (1967–2000) were assessed through MK statistical process. The runoff data had significant increasing and decreasing trends before and after Darbendikhan dam construction, respectively. Correlation analysis indicated that the runoff alterations during the post-damming interval linked with the pre-damming interval were less subjective by climate variability compared to anthropological intervention. Dam building is considered as one of the most chief anthropological intervention that led to change in the stream flow. Annual average runoff values altered considerably between pre-damming and post-damming period; therefore, the annual average value of the excess rainfall during the interval of post-damming was lesser than that during the interval of pre-damming. The null theory H0 (no trend) established by the Mann–Kendall and Pettit tests were rejected at the 0.05 confidence level. The study results point out a reducing tendency in annual rainfall-runoff in the considered interval. Results of the Mann–Kendall and Pettit tests designated that dam building had caused an important alteration in the annual excess rainfall values, representing a significant decrease in the post-damming interval when compared to the pre-damming interval. Mean evaporation values exploration displayed that the water level rise produced by dam building and reservoir performance had caused a severe rise in mean evaporation values during post-damming interval.

5.2 Recommendations

Based on the results of current study, the following future works can be recommended:

1- Studying climate changes for a period extending to 2022 and comparing the results of changes in temperature, precipitation and evapotranspiration with their changes during the period (1979-2012).

2- Studying the correlation between precipitation in the middle part of the Diyala River Basin with surface runoff in the Hamrin Dam area for a recent time series and precipitation-runoff double cumulative curve (P-R DCC).

3- Studying the effect of Darbandikhan Dam and Hamrin Dam on water resources in the middle and southern regions of Iraq during the dry seasons.

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الخلاصة

يمكن اعتبار تقلب المناخ المرتبط بتدخل بشري من العوامل الرئيسية التي تؤثر على دورة المياه والنظام الهيدرولوجي. أصبحت هذه العوامل مصدر ضائقة رئيسية لمهندسي ومديري موارد المياه ، لا سيما في المناطق شبه القاحلة والجافة. يبحث هذا البحث في الاتجاهات الزمانية المكانية وأنماط المدى لمتغيرات المناخ المائي خلال الثلاثين عامًا الماضية ، والتي تشمل هطول الأمطار سنويًا وشهريًا ودرجة الحرارة والنتح والأمطار الزائدة ، لتقدير التأثير المحتمل لمثل هذه التغييرات على المستوى المحلي. تم اعتبار حوض نهر ديالى ، المنطقة الوسطى من العراق ، كمنطقة نموذجية. وفقًا لذلك ، تم استخدام طرق (مان كيندل وبيتيت) وطريقة منحنى الكتلة المزدوج لتحليل المتغيرات المائية المناخية من 1979 إلى 2012 في جابية الدراسة. حددت نتائج الدراسة أن التغيرات الزائدة في هطول الأمطار خلال فترتي الأمطار والجفاف بعد عام 1967 كان لها اتجاهات متشابهة إلى حد كبير في التناقص عند مستوى ثقة 0.05 بسبب بناء السد. من الواضح أن التغيرات السنوية في الجريان السطحي كانت ناتجة إلى حد كبير عن التدخل الأندروجيني المرتبط ببناء السد لتلائم متطلبات استخدام المياه للاستهلاكات الزراعية. تم تغيير علاقة جريان الأمطار في الحوض نتيجة تقلب الطقس وتكثيف الأنشطة البشرية. تم تحديد التغيرات المفاجئة في المتغيرات المائية المناخية وكذلك تم اكتشاف التأثيرات الرئيسية المسببة للتغيرات في الحوض المدروس. ستدعم نتائج الدراسة صانعي السياسات ومهندسي الموارد المائية لفهم المخاطر ونقاط الضعف المرتبطة بالتغييرات البيئية.

جمهورية العراق

وزارة التعليم العالي والبحث العلمي

جامعة بابل / كلية الهندسة

قسم الهندسة المدنية

تقييم التغيرات الزمانية المكانية للسلوك المناخي الهيدرولوجي في حوض نهر ديالى

بحث

مقدم الى كلية الهندسة / جامعة بابل

كجزء من متطلبات نيل درجة الدبلوم العالي في الهندسة / الهندسة المدنية/ منشآت هيدروليكية

من قبل

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باشراف

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2021