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Spatiotemporal characterization of the annual rainfall variability in the Isser Watershed (Algeria)

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Abstract

Wadi Isser watershed (4149 km^2), located in the North of Algeria, has experienced a significant rainfall variability during the last four decades. In order to characterize this variability and determine its spatial extension, by means of the analysis of the rainfall data measured in twenty-seven (27) stations, the following study was conducted. The analysis of the long rainfall series of the reference stations of Bni Slimane (1920–2014) and Djebahia (1923–2014) through the application of three statistical tests (Pettitt, Buishand and Lee and Heghinian) revealed an episode of low rainfall from 1973 to 2001 for the Djebahia station and from 1975 to 2001 for the Bni Slimane station. This period was characterized by a decrease in annual rainfall varying between 14 and 43%, followed by a rainy phase in the watershed with an increase in annual rainfall (35.8%) at the Khebouzia station. The analysis of the kriged maps, developed by geostatistical modeling of the spatial structure of precipitation (1975–2014), supported and corroborated the results of the statistical tests. Indeed, the spatial interpolation based on decadal averages of rainfall from 1975 to 2014 illustrates a well-contrasted spatial variability for the four decades. The northern part of the watershed is characterized by a higher rainfall than the central and southern parts of the watershed. In the light of the results obtained by applying the two approaches mentioned above, a decreasing trend in rainfall is clearly evident from the beginning of the decade 1985–1994. A double rainfall gradient is highlighted with an increase in rainfall from east to west and from north to south. At the same time, there was a surplus towards the end of the third decade and the fourth decade. A return of precipitation is thus highlighted as well as the different breaks in the series. Through this research, the statistical study and the geostatistical mapping have enabled the elaboration of a relevant tool for decision support to the managers in the field of environment and hydraulics, in a general way, and in a context of global warming. In fact, it will allow them to better understand the developments of wadis, the integrated management of water resources in order to guarantee current and future needs for drinking, industrial, and agricultural water in this semi-arid region.

Keywords Isser · Watershed · Rainfall · Variability · Evolution · Break · Geostatistical approach · Kriging

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Introduction

Climate variability and its fluctuations are a real concern for the entire world population for nearly four decades. Indeed, climate change can lead to major disruptions that will have a negative impact on humanity and the planet as a whole (Donald 2008). Water availability, both in terms of quantity and quality, will be a major social challenge of the twenty-first century.

According to the recent work of the Intergovernmental Panel on Climate Change (IPCC.2021), climate change, which affects many countries around the world, is recognized as one of the major global problems. It should be noted that, according to the IPCC.2021, humanity has

also caused changes in the frequency of extreme weather and climate events such as soil droughts in some regions, particularly around the Mediterranean basin, southern and western Africa, and western North America.

As a result, these climatic events will have negative consequences on the satisfaction of water needs, as well as on the socio-economic sector (agriculture, industry, and constructions), which are weakened by global warming such as temperature increase (Zadehmohamad and Bolouri Bazaz. 2017; Alimohammadi et al 2020; Zadehmohamad 2020). However, precipitation is one of the most important factors in the climate. Climate change will therefore lead to an intensification of the hydrological cycle where rainfall will be more abundant overall, in the high latitudes, the tropics, and most monsoon regions, but more variable over a season and from one year to the next. Some regions will receive less rain in the future, however, such as the Mediterranean and several subtropical regions (IPCC.2021).

In recent years, climate variability on a global scale has been the subject of much research. These studies have focused on the decrease in precipitation on different time scales, particularly in the Mediterranean region, one of the most sensitive regions, especially its southern shore, considered particularly vulnerable (Jemai et al. 2017; Hafez 2018; El-Hagrsy et al 2018; Galgano 2018; Cos Espuna et al 2021). Indeed, the Mediterranean basin constitutes a major transition zone between the tropical climate and the temperate climate of the middle latitudes. The latter has been identified as a "hot spot" of climate change with a drastic decrease in rainfall.

Algeria, which is one of the countries on the southern shore of the Mediterranean, has been affected by the consequences of this decrease in rainfall in several northern regions, particularly the northwestern zone (Meddi and Meddi 2009; Meddi and Toumi 2013; Ghenim and Megnounif 2013; Taibi et al. 2015; Elouissi et al. 2017; Drouiche et al. 2019; Khedimallah et al. 2020).

In this context of variability and instability of the rainfall regime, highlighted in the IPCC report in 2021 as well as in several research works at the scale of the Mediterranean basin, the present research will contribute to the characterization of the spatio-temporal evolution of rainfall in the Isser watershed.

In order to objectively appreciate this latter, we will use statistical interpolation, cartography assisted by GIS as well as geostatistical modeling in order to provide tools to assist decision making by managers of water resources and the environment, namely, the realization of kriged maps of precipitation and the identification of the breaks in the rainfall regime in the Isser watershed.

Study area

Wadi Isser watershed with an area of 4149 Km^2, is located in the central part in the north Algeria, between 35°53′50″ and 36°54′50 North and meridians 2°24′ 25″ and 4°6′5″ East. It is delimited in the north by the Mediterranean Sea and the Algerian coastal watershed, in the south-west by the Cheliff watershed, in the south-east by the Chott Hodna watershed, and in the east by the Soummam wadi watershed. A wide plain, oriented East–West, characterizes the Bni Slimane region. The catchment area is partially drained by the Mellah wadi and the Zeroua wadi, the convergence of the two wadis constitutes the Isser wadi (Fig. 1). The watershed is characterized by a humid Mediterranean climate in the north and a semi-arid to dry climate in the south, with high temperature differences and a considerable difference in rainfall between the northern and southern parts of the watershed.

For a better overview of the region's climate, two weather stations were considered, Baghlia (Bouderbala 2017) located in the north of the watershed, and Bni Slimane (ANRH 2014) located in the south, but the observation period was not the same due to the unavailability of data. The same is true for the rainfall stations; two stations were considered, namely, Chabet el Ameur in the north (090512) and Bni Slimane in the south (090302). All the results are summarized in Tables 1 and 2 below.

Material and method

Statistical approach

The study focused on the analysis of the series of annual rainfall recorded in twenty-seven (27) rainfall stations in which twenty (20) stations are located inside the catchment and 7 stations around the watershed. The stations have been selected on the basis of the extent of their series of measures and their actuality. These stations are relatively homogeneously distributed throughout the watershed (Fig. 1, Table 3).

The rainfall database was provided by the National Agency of Hydraulic Resources of Algiers (ANRH), with monthly and annual time steps. We removed the values that appeared anomalously high and then proceeded to fill the gaps using the Multiple Monte Carlo Markov Chain Interpolation (MCMC) method, also known as fully conditional specification (FCS) (BUUREN 2007). Several research works have relied on it to fill in gaping time series (Glasson-Cicognani & Berchtold 2010; Yim. 2015; Drouiche 2019).

The MCMC multiple imputation methods, based on the FCS algorithm (Takahashi 2017), an iterative method, are
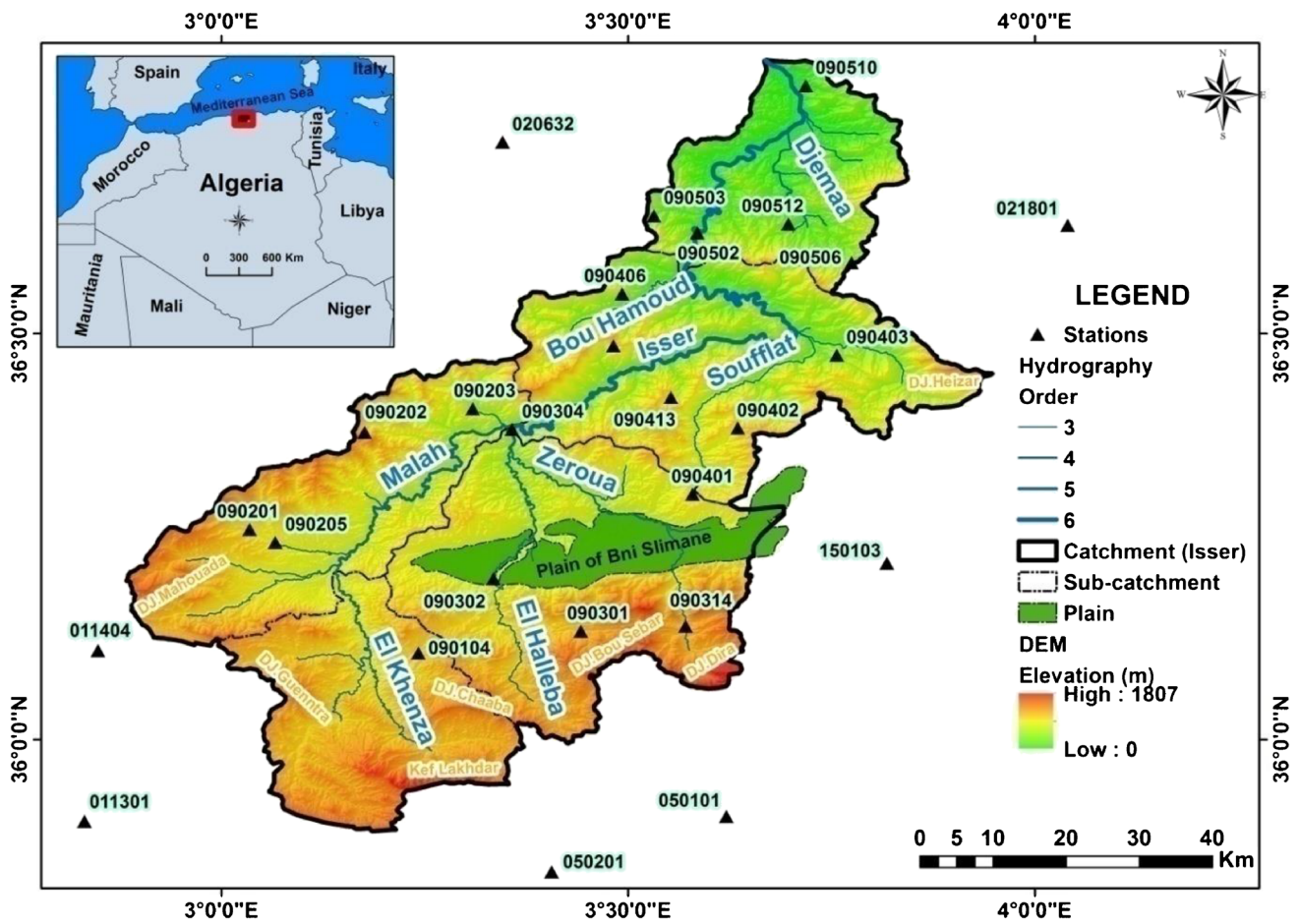
Fig. 1 Location of rainfall stations in the watershed of Wadi Isser

Table 1 Characteristics of the climate stations collected. Characteristic of temperature for the two weather stations collected

Stations	Latitude (DMS)	Longitude (DMS)	Altitude (m)	Period	Temperature (°C)		
					Minimal	Average	Maximal
Baghlia	36°48′19″N	3°52′51″E	50 m	1980–2014	6.3	17.7	33.8
Bni Slimane	36°23′42″N	3°29′21″E	625	1982–2014	1.0	14.0	32.0

used when the missing data pattern is arbitrary (monotonic or not). For each iteration and for each variable, an univariate model is fitted (single dependent variable) considering the other variables of the latter as predictors. Then, the missing values will be imputed for the variable to be

fitted. This operation ends when the maximum number of iterations is reached. At the maximum iteration, the imputed values will be stored in the dataset.

Any statistical approach begins with an observation of the temporal evolution of the observed annual precipitation,

Table 2 Characteristic of rainfall for the two rain gauge stations selected

Stations	Latitude (DMS)	Longitude (DMS)	Altitude (m)	Period	Precipitation (mm)		
					Minimal	Average	Maximal
Chabet el Ameur	36°38′16″N	3°40′50″E	235 m	1973–2001	345.7	643.5	948.7
Bni Slimane	36°12′6″N	3°20′50″E	600	1973–2001	194.7	361.7	506.1

Table 3 Stations coordinates and periods of measuring

Station	ANRH code	Latitude (DMS)	Longitude (DMS)	Altitude (m)	Period
Ksar El Boukhari	011301	35°53′24.312″ N	2°44′26.180 ″ E	630	1967–2014
Zoubiria	011401	36°06′45.711″ N	2°50′54.570 ″ E	932	1971–2014
Reghaia	020632	36°44′20.285″ N	3°20′44.898 ″ E	20	1910–2014
Bouassam	021801	36°38′10.879″ N	4°02′26.440 ″ E	600	1939–2014
Ain Nessisa	050101	35°54′31.113″ N	3°37′15.911 ″ E	680	1954–2014
Draa El Hadjar	050201	35°44′35.473″ N	3°25′28.295 ″ E	710	1967–2014
Souagui	090104	36°06′35.142″ N	3°14′32.429″ E	810	1973–2014
EL Omaria	090201	36°15′43.144″ N	3°02′4.809″ E	790	1940–2014
Mahterre	090202	36°22′53.090″ N	3°10′34.336″ E	875	1968–2007
Tablat DRS	090203	36°24′38.039″ N	3°18′32.750 ″ E	450	1954–2014
El Omaria PEP	090205	36°14′42.834″ N	3°17′20.048″ E	659	1974–2014
Djouab	090301	36°08′13.529″ N	3°26′33.302″ E	825	1967–2014
Bni Slimane	090302	36°12′6.201″ N	3°20′5.061″ E	600	1920–2014
Pont de la Traille	090304	36°23′6.240″ N	3°21′28.643″ E	370	1945–2014
Dechmya	090314	36°08′36.391″ N	3°34′15.687″ E	850	1974–2014
Khebouzia	090401	36°18′20.390″ N	3°34′48.197″ E	720	1968–2014
Souk El Khemis	090402	36°23′12.632″N	3°38′6.132″ E	782	1968–2014
Djebahia	090403	36°28′35.201″ N	3°45′23.958″ E	320	1923–2014
Tazerout	090406	36°33′8.605″ N	3°29′34.341″ E	520	1968–2014
Ouled Touati	090413	36°25′27.879″ N	3°33′12.578″ E	831	1968–1997
Bsibsa	090419	36°29′16.793″ N	3°28′57.845″ E	820	1972–2014
Lakhdaria Gorges	090502	36°37′37.285″ N	3°35′7.193″ E	50	1967–2014
OuledBouhaddada	090503	36°38′53.280″ N	3°31′56.758″ E	400	1968–2014
Tizi Ghenif	090506	36°35′25.179″ N	3°46′29.833″ E	390	1951–2014
B.Menail Pépin	090510	36°48′30.683″ N	3°43′6.723″ E	27	1971–1996
Chabet El Ameur	090512	36°38′16.337″ N	3°41′50.303″ E	235	1951–2014
El Hachimia	150103	36°13′13.036″ N	3°49′5.941 ″ E	730	1967–2014

in the case of the present study; it will relate to 94 years of observation at the Bni Slimane station and 91 at the Djebahia station. Indeed, the latter represent less gaps; so they will constitute the database of reference stations in the Isser watershed. In order to detect breaks in the time series, we used three non-parametric statistical tests, namely, the Pettitt test (Pettitt 1979), the Buishand test (Buishand 1984), and the Lee and Heghinian test (Lee and Heghinian 1977).

Pettitt test

This test detects the point of change by the analysis of variance in the distribution of the data, i.e., the change in the mean of the variable in the time series. The Pettitt test, derived from the Mann–Whitney test, is based on ranks (non-parametric) and is reputed for its robustness (Dou et al 2009).

The test supposes that, at any time t varying from 1 to n, the series (x_i), with i varying from 1 to t and $t+1$ to n belong to the same population. This is tested by the statistic Ut, n considered for all values of t from 1 to n. The absence of a break in the time series (x_i) of size n constitutes the null hypothesis H_0 which allows testing the significance of the breaks.

$$U_{t,N} = \sum_{i=1}^{t} \sum_{j=t+1}^{N} D_{ij} \tag{1}$$

$$D_{ij} = sgn(x_j - x_i) \text{ with } D_{ij} = sgn(x_j - x_i)$$

where xi corresponds to the data vector and

$$\begin{cases} sgn(x_j - x_i) = 1, si(x_j - x_i) > 0 \\ sgn(x_j - x_i) = 0, si(x_j - x_i) = 0 \\ sgn(x_j - x_i) = -1, si(x_j - x_i) \leq 0 \end{cases}$$

to test H_0, we use the variable K_n with $k_n = \max|U_{t,n}|$

Buishand U-statistics

The Buishand test, Bayesian in nature, is based on the hypotheses of normality and variance consistency of the

series. Supposing an a priori uniform distribution for the position of the breakpoint, the U statistic is defined by:

$$U = [N(N+1)]^{-1} \sum_{K=1}^{N-1} \left(\frac{S_K}{D_X} \right)^2 \qquad (2)$$

$$Sk = \sum_{i=1}^{k} ((x_j - \bar{x}) \, for \, k = 1, 2, 3 \dots.$$

N and D_x are the standard deviation of the series.

The null hypothesis is the absence of a break in the series. If the null hypothesis is rejected, the test does not provide an estimate of the break date. Critical values of statics are given by Buishand (1982, 1984) from a method of Monte Carlo. This method gives less effect to the first and last values of the series and is more efficient for any change in the mean in mid-series. The U statistic is a strong statistic that remains valid even for distributions of the study variable that deviate from normality.

Lee and Heghinian test

It is a Bayesian method based on a parametric approach. It requires a normal distribution of the values of the series. The absence of breaks in the series is the null hypothesis. The basic model of the process is as follows:

$$x_i \begin{cases} \mu + \in_i si \, i = 1, \dots \dots, \tau \\ \mu + \delta + \in_i si \, i = \tau + 1 \dots., N \end{cases} \qquad (3)$$

- the $\in_i$ are independent and normally distributed, with null mean and variance σ2;
- τ and δ represent, respectively, the position in time and the amplitude of a possible change in the mean.

The method allows to establish the probability distribution a posteriori of the position in time of a change. Note that, when the distribution is unimodal with a low dispersion, the date of the break is estimated with high precision.

Gap filling and homogeneity tests (Pettitt test and Buishand statistic) were performed under Xlstat (trial version on https://www.xlstat.com/fr/).

Lee and Heghinian's test was performed with Khronostat (open source software, from the Department of Hydroscience, University of Montpellier, 1998).

Geostatistical approach

We used the kriging method in the geostatistical approach with the open-source software Qgis 3.10.12–1 with spatial analysis extensions. The "analysis" extension geostatistics has an exploratory spatial data analysis module that allows data to be visualized and analyzed using statistical techniques. Kriging is a stochastic method for spatial interpolation that predicts the value of a natural occurrence at non-sampled sites by a linear combination without any bias and with minimal variance of observations of the occurrence at neighboring sites (Baillargeon 2005).

Since it is a stochastic method, kriging estimates forecast errors and takes into account the spatial dependence structure of the data.

The application of geostatistical estimation techniques requires a prior in-depth analysis of the experimental data in order to clearly identify the characteristics of these data and to describe the spatial structure of the studied variable. The experimental variogram is the principal indicator of this structure, which we want to translate mathematically (Chauvet 1999).

Followed by modeling, based on a mathematical expression that adjusts the few points of the experimental variogram, thus constructing an interpolation function (Chauvet 1999). A semi-variagram measures spatial variability of a variable region Z on the assumption that the variable is stationary or intrinsic (Armstrong 1998).

In order to perform the spatial interpolation of precipitation over 40 years, we calculated the experimental semivariogram based on the following formula:

$$\hat{\gamma}(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(b_i) - z(b_i + h)]^2 \qquad (4)$$

where $N(h)$ is the number of pairs of data locations remotely located h.

The most commonly used standard variograms in hydrology are the following Gaussian models.

Kriging requires the hypothesis of a theoretical semivariogram model adapted to an experimental model. The ruggedness of kriging depends strongly on the choice of a variogram model that demonstrates the degree of spatial autocorrelation in the data set.

The variogram model is used to determine the sample weights that will be used for kriging.

Ordinary kriging is used here for the interpolation of rainfall mapping over four decades. The basic equation of Ordinary Kriging is the following:

$$Z^*(b_0) = \sum_{i=1}^{n} W_i Z(b_i) \qquad (5)$$

where $Z^*(b_0)$ is the estimator of the random variable Z at point b_0, Wi are the weights of the Kriging, and $Z(b_i)$ is the observed value of the random variable Z at point bi; n is the number of points neighbors that will be used for the estimation of $Z^*(b_0)$.
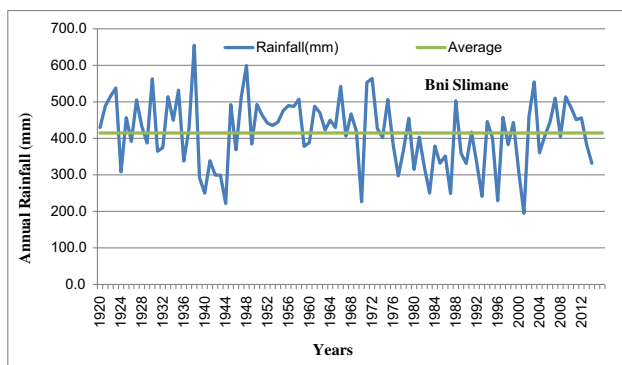
Fig. 2 Evolution of annual precipitation at the Bni Slimane station (1920–2014)

Experimental variograms and variogram models were constructed for each of the four decades as well as for the whole period under consideration.

Results

Evolution of annual rainfall

In order to better understand the temporal rainfall variability, the analysis of the annual mean rainfall evolution curves of the two (02) stations of Bni Slimane and Djebahia which have the longest observation series was carried out (Figs. 2 and 3).

The mean of the series is 414 mm and 680 mm, respectively, for Bni Slimane and Djebahia. The variations are notable compared to the average of each series.

The periods of low rainfall and high rainfall, relative to the respective means of the two series, are almost identically:
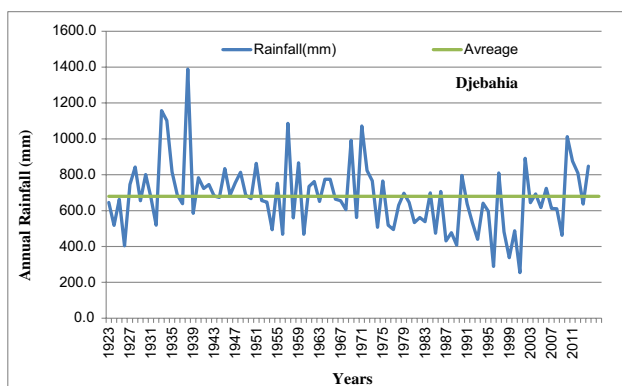
Fig. 3 Evolution of annual rainfall at the Djebahia station (1923–2014)

- the Bni Slimane station is characterized by a period of high rainfall before 1976 and a period of low rainfall between 1976 and 2002 with a minimum value of 194 mm in 2001.
- the station of Djebahia presents a sequence of high rainfall before 1974 while its sequence of low rainfall extends from 1974, two (02) years before Bni Slimane, to 2002 with a minimum value of 254 mm in 2001.

Break detection tests

Statistical tests by Pettitt (1979), Buishand (1984), and Lee and Heghinian (1977) have made possible detection of the year of rupture. However, these tests, applied with $p = 0.05$, can only detect one break at a time (Table 4, Figs. 4 and 5).

Most of these breaks seem to have taken place during the 1970s, and most of them show a downward trend.

Seventeen (17) stations out of 27 (twenty-seven), representing nearly 63% of the series of measures, are characterized by a downward trend with a reduction rate that varies from 43% at the Souk El Khemis station to 14% at the station of Bni Slimane and Chabet El Ameur. At the Souagui station, the break was detected in 1989 with an increased rate of 21%.

Six rainfall stations (22%) have experienced an upward trend since 2001, with a rate of increase of nearly 25% on average; at the Omaria Pep station, the upward trend was seen in 2003 with a rate of increase of 17% and Bsibsa in 2009, with an increase of 19%.

Zoubiria, Reghaia, Bouassam, and El Hachimia stations are distinguished by a zero (0) trend and show no break in their series of measures.

It should be noted that these tests can only detect one break at a time. It is advisable, therefore, to repeat these series at the first break in the 1970s in order to highlight the end of the period of decline and the upward recovery of precipitation.

Application of tests after the first break

In this step, we are interested in determining the end of the dry period; for this, we apply the statistical tests on the observation period that begins after the first break which took place in the 1970s, and which extends to 2014. Therefore, fifteen stations will be concerned by these tests to determine a second break. The six stations which represent increasing trends are also taken into consideration given that they give supports and information on monitoring the rainfall regime. The stations which do not show a break (N.B.) will not be concerned by this step as well as the stations Mahterre, Ouled Touati, and Borj Menail Pepin which present series with an insufficiently high number of measures (< 30 observations).

Table 4 Results of statistical tests for Pettitt, Buishand, and Lee Heghinian. Where NB, no break; Avg.B.B, average before break; Avg.A.B, average after break. Difference(%) = (avg. after break–avg. before break)/avg. after break

Station	Period	Pettitt	Buishand (H_0)	Lee Heghinian	Trend	Avg.B.B	Avg.A.B	Difference%
Ksar El Boukhari	1967–2014	NB	NB	1972	Down	434.8	309.2	-40.62
Reghaia	1910–2014	NB	NB	NB	0	-	-	-
Zoubiria	1971–2014	NB	NB	NB	0	-	-	-
Bouassam	1939–2014	NB	NB	NB	0	-	-	-
Ain Nessisa	1954–2014	1976	1976	NB	Down	264.4	218	-21,28
Draa El Hadjar	1967–2014	NB	NB	1970	Down	285.1	203.5	-40.09
Souagui	1973–2014	NB	1989	NB	Down	349.48	289.16	-20,86
EL Omaria	1940–2014	NB	1971	1971	Down	557.52	474.25	-17,55
Mahterre	1968–2007	NB	NB	1973	Down	707.6	554.9	-27,51
Tablat DRS	1954–2014	1973	1973	1973	Down	725.24	579.58	-25,13
El Omaria PEP	1974–2014	NB	NB	2003	Rise	344.1	412,6	16,6
Djouab	1967–2014	2001	2001	2001	Rise	505	696.07	27,44
Bni Slimane	1920–2014	1975	1975	1975	Down	437.79	383.45	-14,1
Pont de la Traille	1945–2014	NB	1973	1973	Down	565.43	477.89	-18,31
Dechmya	1974–2014	NB	2001	NB	Rise	434.19	556.84	22,02
Khebouzia	1968–2014	2001	2001	2001	Rise	373.72	582,4	35,83
Souk El Khemis	1968–2014	NB	1975	1975	Down	736.97	515.53	-42,95
Djebahia	1923–2014	1973	1973	NB	Down	737.11	605.49	-20,5
Tazerout	1968–2014	NB	NB	1970	Down	1032.3	783.6	-31,73
Ouled Touati	1968–1997	NB	NB	1975	Down	701.5	572.9	-22.44
Bsibsa	1972–2014	NB	NB	2009	Rise	686.9	852.6	19,43
Lakhdaria Gorges	1967–2014	NB	NB	1973	Down	874.7	700.7	-24,83
OuledBouhaddada	1968–2014	2001	NB	2001	Rise	741.7	922.33	19,58
Tizi Ghenif	1951–2014	1975	1975	1975	Down	894.12	727.4	-22,91
B.Menail Pépin	1971–1996	NB	NB	1973	Down	1001.3	729.8	-37.20
Chabet El Ameur	1951–2014	1971	1975	1975	Down	800.29	701.35	-14,1
El Hachimia	1967–2014	NB	NB	NB	0	-	-	-

Fig. 4 Break detection (Pettitt and Buishand on the Bni Slimane series (1920–2014). Where mu1 and mu2 = annual average rainfall before and after the break
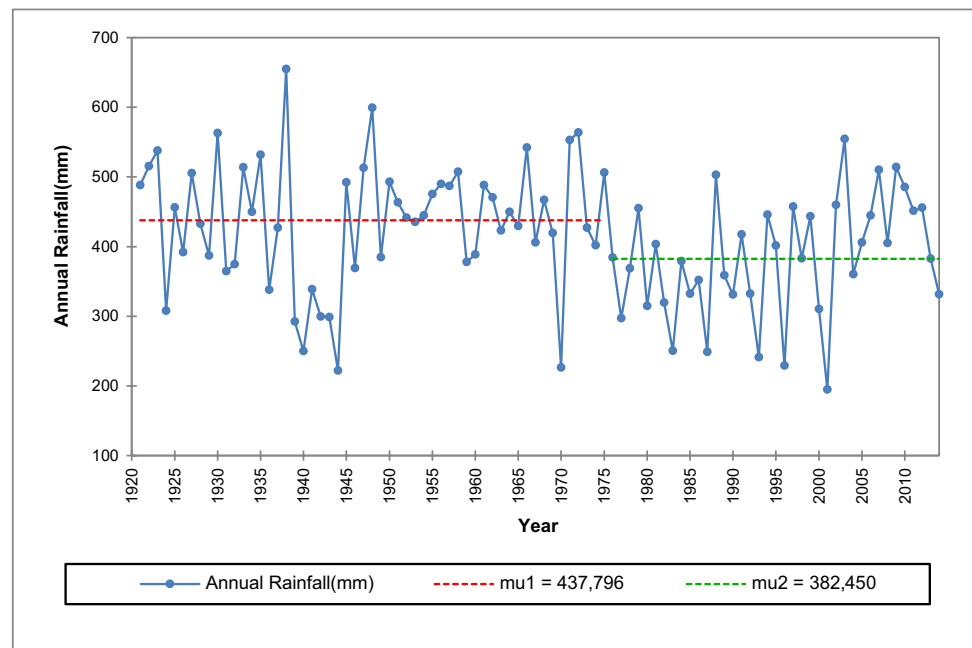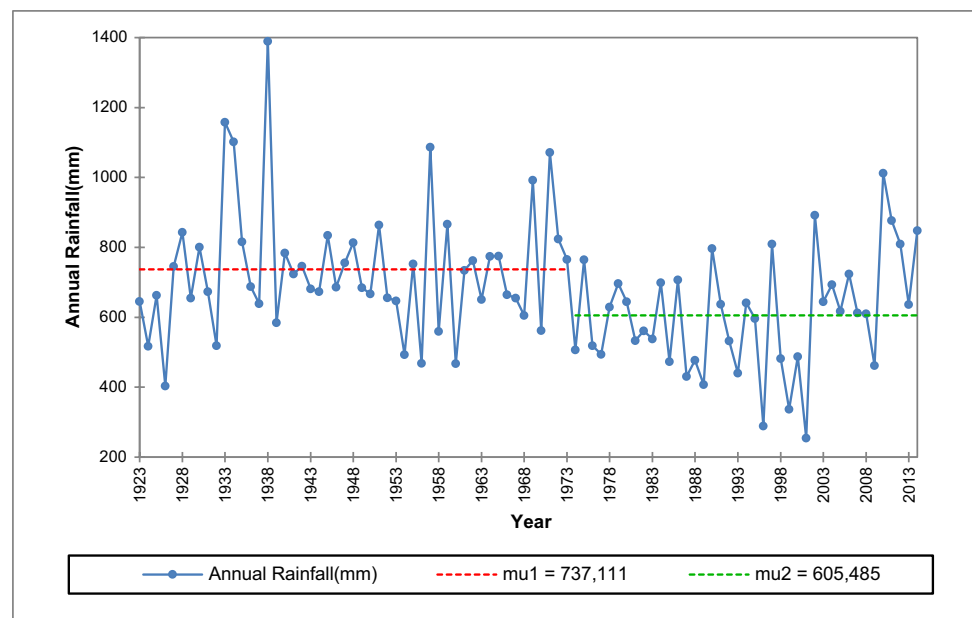
Fig. 5 Break detection (Pettitt and Buishand on the Djebahia series (1923–2014). Where mu1 and mu2 = annual average rainfall before and after break


This second test indicated a break in fifteen (15) rainfall stations in the early 2000s (Table 5). The increase in rainfall varies from 14.37% at the Pont de la Traille station to 35.83% at the Khebouzia station. The stations of Bni Slimane and Djebahia recorded an increase of 18.32% and 23.45% respectively (Figs. 6 and 7).

This therefore makes it possible to note an increase in rainfall in the 2000s, a similar and comparable observation already established by various studies on the Maghreb (Nouaceur and Murărescu 2016)—in Algeria: on the north (Nouaceur 2011), the coast (Nouaceur et al 2013), the northeast (Nouacer & Laignel 2015), Medjerda (Khoualdia et al

Table 5 Results of the statistical tests of Pettitt, Buishand, and Lee and Heghinian (second test). Where NB, no break; Avg.B.B, average before break; Avg.A.B, average after break. Difference(%) = (avg. after break–avg. before break)/avg. after break

Station	Period	Pettitt	Buishand (H_0)	Lee Heghinian	Trend	Avg.B.B	Avg.A.B	Difference%
Ksar El Boukhari	1972–2014	NB	NB	1972	0	371,9	371,9	0
Ain Nessisa	1976–2014	1976	1976	1976	0	314	314	0
Draa El Hadjar	1970–2014	NB	NB	1970	0	184.6	184.6	0
Souagui	1989–2014	NB	1989	NB	0	376.3	376.3	0
EL Omaria	1971–2014	NB	1971	1971	0	920	920	0
Tablat DRS	1973–2014	NB	NB	2001	Rise	546.6	658	16.93
El Omaria PEP	1974–2014	NB	NB	2003	Rise	344.1	412.6	16.6
Djouab	1967–2014	2001	2001	2001	Rise	505	696.07	27.44
Bni Slimane	1975–2014	2001	2001	2001	Rise	357.79	443.18	18.32
Pont de la Traille	1973–2014	NB	NB	2001	Rise	453.9	530.1	14.37
Dechmya	1974–2014	NB	2001	NB	Rise	434.19	556.84	22.02
Khebouzia	1968–2014	2001	2001	2001	Rise	373.72	582.4	35.83
Souk El Khemis	1975–2014	2001	2001	2001	Rise	473.38	606.61	21.17
Djebahia	1973–2014	2001	2001	2001	Rise	557	726	23.45
Tazerout	1970–2014	NB	NB	2009	Rise	759	976.2	22.24
Bsibsa	1972–2014	NB	NB	2009	Rise	686.9	852.6	19.43
Lakhdaria Gorges	1973–2014	2001	2001	2001	Rise	654.24	814.71	19.71
OuledBouhaddada	1968–2014	2001	NB	2001	Rise	741.7	922.33	19.58
Tizi Ghenif	1975–2014	2001	2001	2001	Rise	680	827.5	17.82
Chabet El Ameur	1975–2014	2001	2001	2001	Rise	641.8	825	22,2

Fig. 6 Break Detection (Pettitt and Buishand on the Bni Slimane series (1975–2014) where mu1 and mu2 = annual average rainfall before and after the break
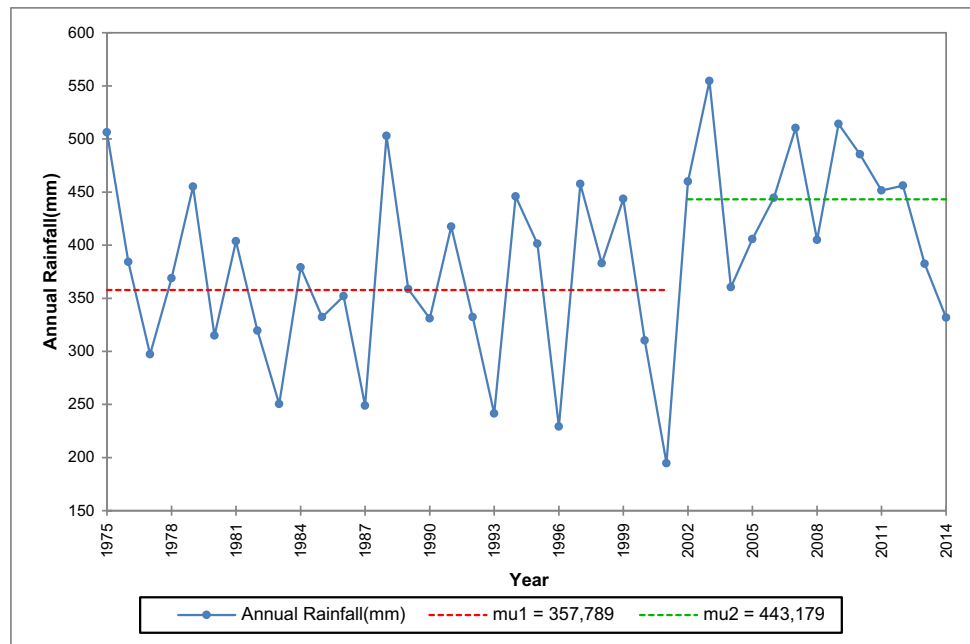
2014), Seybousse (Balah and Amarchi 2016), and Timgad (Regad and Tatar 2019).

Geostatistical approach

Variographic analysis

By using geostatistics and geographic information systems (with the QGIS software available on https://www.qgis.org/fr/site/about/index.html as a Free and Open Source download), the process in each watershed, considering its structure and correlation in space, gives optimal estimates.

The study is based on the theory of random functions and approaches the analysis of the phenomenon in probabilistic terms. This approach to geostatistics requires a thorough preliminary analysis of the experimental data in order to clearly identify the characteristics of the data and to describe and model the spatial structure of the variable studied.

It allows to obtain, by kriging, a robust mapping; to quantify uncertainties; and to evaluate risks (Djoudar et al 2019). These maps then enable the user to identify and process data anomalies and anisotropies using appropriate statistical representations (base map, histogram, variogram, variographic cloud).

Fig. 7 Break detection (Pettitt and Buishand on the Djebahia series (1973–2014) where mu1 and mu2 = annual average rainfall before and after break
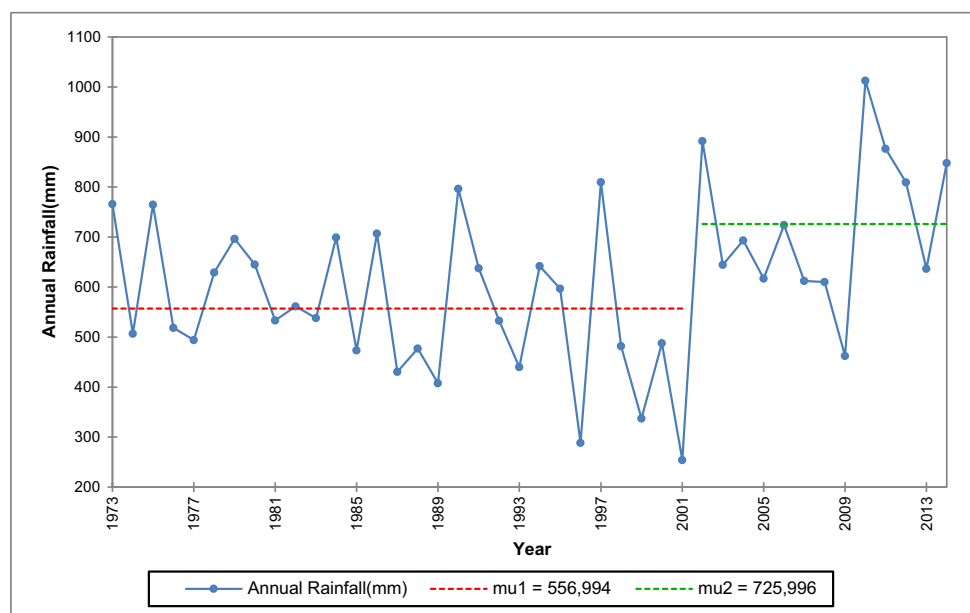
Fig. 8 Surface variograms for the four decades and the common period
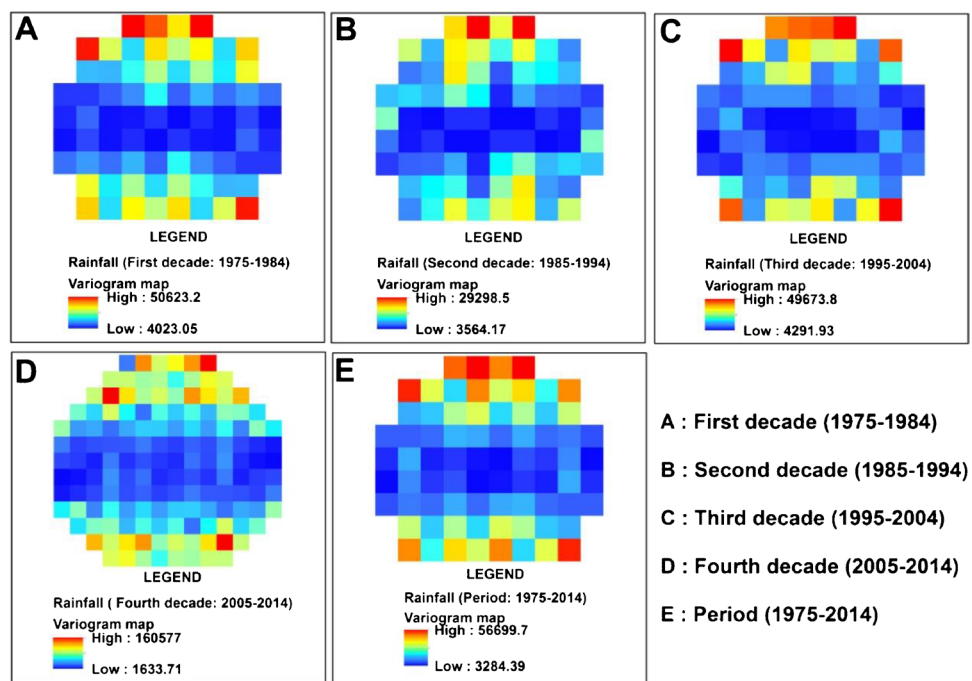
A : First decade (1975-1984)

B : Second decade (1985-1994)

C : Third decade (1995-2004)

D : Fourth decade (2005-2014)

E : Period (1975-2014)

The variogram is generally used to analyze the spatial dependence of observations (Önsoy and Bocquillon 1980).

The omnidirectional experimental semi-variograms were calculated with 05 steps of 10,000 m respectively for the four (04) periods (first, second, third, and fourth decades) and the reference period (1975 to 2014) with 07 steps of 8000 m for the fourth decade. Due to the erratic directional behavior of the EVS, they were thus calculated in the case of isotropy (Fig. 8).

Table 6 shows the number of pairs and type of structure, the span in meters, and the models adapted to these experimental variograms for each period.

All periods show a well-structured Gaussian variability showing a perfect spatial continuity particularly when $C0 = 0$ (Fig. 9). The cross-validation permitted to verify the robustness of the models.

The results show that the distribution of standardized errors is Gaussian with a mean of standardized errors (MES) equal to zero (0) and a variance of standardized

Table 6 Modeling parameters of the experimental semi-variograms and models equipped with the studied variables with the corresponding parameters (range, threshold, nugget effect)

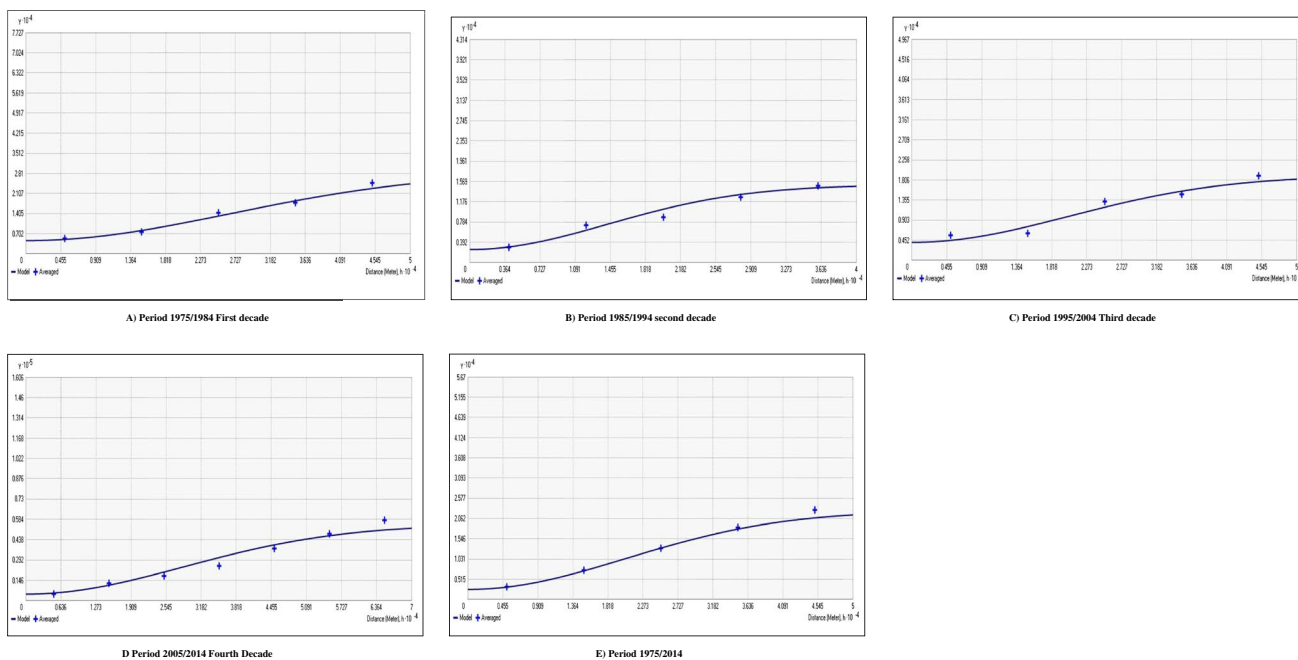| Periods	Experimental semi-variogram omnidirectional (ESV)		Number and type of structure		Range (m)	Sill	Cross-validation	
	Lag distance (m)	Number of lag distance					MES	VES
A-Period 1975/1984 First decade	05	10,000	1	Nugget effect model	-	4500	0.039	0.97
			2	Gaussian model	65,000	24,000		
B-Period 1985/1994 Second decade	05	10,000	1	Nugget effect model	-	2500	0.078	0.98
			2	Gaussian model	35,000	12,500		
C-Period 1995/2004 Third decade	05	10,000	1	Nugget effect model	-	4000	0.06	1
			2	Gaussian model	50,000	15,000		
D-Period 2005/2014 Fourth decade	07	8000	1	Nugget effect model	-	4500	0.013	1.13
			2	Gaussian model	70,000	50,000		
E-Period 1975/2014	05	10,000	1	Nugget effect model	-	2500	0.062	0.96
			2	Gaussian model	50,000	20,000		

Fig. 9 Model semi-variograms (curves) fitted to the experimental semi-variograms (points) (the numbers on the points correspond to the number of sample pairs used in the calculation of γ (h) at this distance)

errors (VES) equal to one (1), which indicates that the selected models are robust and corroborate the results of the Buishand, Pettitt, and Lee and Heghinian statistical tests.

Modeling the spatial evolution of annual rainfall

In order to illustrate the chronological evolution of the annual rainfall totals, we took the period 1975–2014, common to the majority of the stations, calculated the rainfall totals, and then subdivided this period into four decades (sub-periods), respectively, 1975–1984, 1985–1994, 1995–2004, and 2005–2014.

The spatial distribution of the inter-annual means rainfall shows a decreasing trend from north to south and from east to west.

In order to model the spatial continuity of rainfall, we proceeded with the kriging operation for each of the four decades as well as for the common period (Fig. 11A–E).

First decade (1975–1984)

During this decade, the coastal zone, in the north, is rainier than the central and southern part, probably due to the effect of the proximity of the sea. Thus, rainfall decreases from north to south and from east to west.

The rainiest stations are Lakhdaria Gorges (090502), Ouled Bouhaddada (090503), Tizi Ghenif (090506), and Chabet el Ameur (090512) (Fig. 1) with a rainfall of 761 mm.

Isohyets ranging from 720 to 750 mm (Fig. 11A) cover only a small area in the north, while weaker isohyets such as those ranging from 390 to 480 mm are located in the south and cover a larger area.

The histogram of statistical parameters shows an average of about 500 mm (Fig. 10A). The rainfall thresholds show values ranging from 286 to 761 mm, which indicates a decrease in rainfall from north to south and east to west.

Concerning the variance estimation, when the variance is high, it corresponds to areas where there is little data, and while when values are low, data are more abundant. In this case, the values are low and vary from 30 to 100 (Fig. 12A) compared to the average standard deviation (Std Dev) revealed by the histogram (Fig. 10A).

Second decade (1985–1994)

The highest isohyet is here, the 660-mm isohyet, while the 750-mm isohyet is no longer on the map (Fig. 11B). Some isohyets have even reduced in area compared to the map of the previous decade (Fig. 11A).

However, the main characteristics of rainfall remain unchanged: the rainfall gradient, rainy regions, and dry regions. The highest rainfall values are still in the northern part of the watershed where the stations of Lakhdaria
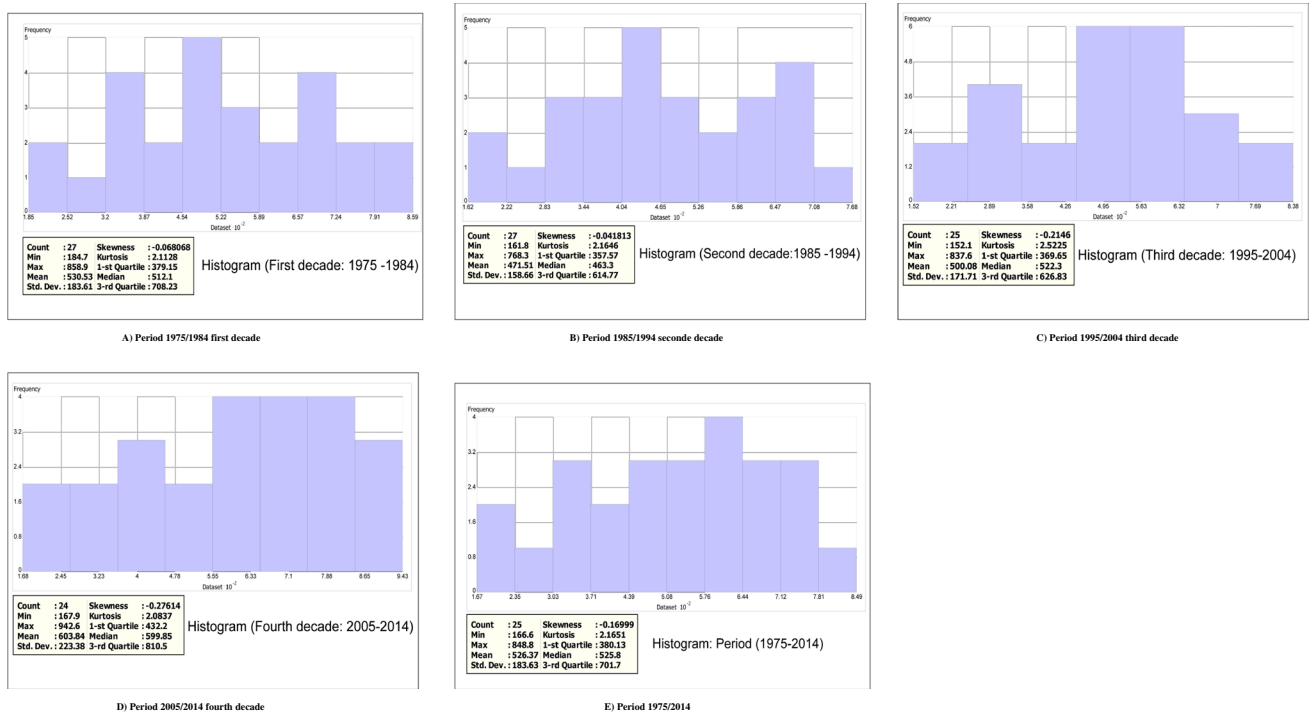
Fig. 10 Statistical parameters for the different periods. **A** Period 1975/1984 first decade. **B** Period 1985/1994s decade. **C** Period 1995/2004 third decade. **D** Period 2005/2014 Fourth decade. **E** Period 1975/2014

Gorges (090502), Ouled Bouhaddada (090503), Tizi Ghenif (090506), and Chabet el Ameur (090512) are located, while the central and southern parts of the watershed are still less rainy. The rainfall thresholds decrease from 677 in the north to 277 in the south.

The average rainfall is therefore around 400 mm (Fig. 10B), and the variance of kriging is low (Fig. 12B) with thresholds ranging from 31 to 120 clearly low compared to their SD estimated at 158.6 mm (Fig. 10B).

Third decade (1995–2004)

The remarkable fact during this decade is the clear increase in annual rainfall (Fig. 11C), corroborating the results highlighted by the statistical tests. In fact, several rainfall stations recorded a significant upward trend in the resumption of the rainfall regime in 2001, particularly in the northern part of the watershed. The rainfall gradient and the areas that received the most and the least rain are still unchanged.

The average annual rainfall over the entire watershed is 501 mm, with rainfall thresholds ranging from 278 to 699 mm. The kriging variance varies from 32 to 110 (Fig. 12C), always low values compared to the corresponding Std Dev mean of 171.7 (Fig. 10C).

Fourth decade (2005–2014)

The isohyets of the annual rainfall totals attain values of 720 and 750 mm (Fig. 11D) close to those of the first decade (Fig. 11A) and reach a peak at 870 mm.

In the southern part of the catchment area, the annual rainfall has decreased to a minimum of 234 mm, while the average is around 600 mm (Fig. 10D). The variance of kriging remains low (Fig. 12D), varying from 32 to 140 compared to the average of 223.3 mm in SD (Fig. 10D).

The persistence of the decline in annual rainfall in the southern part of the watershed is well noted. However, fortunately, this situation is not the same in the north and in the center, rather characterized by a return of rainfall where values of 881 mm were registered.

Over the whole common 40-year or 4-decade period (1975–2014), the kriging map of annual rainfall (Fig. 11E) is not fundamentally different from the four maps of kriging decadal periods (Fig. 11A–D), although it shows more similarity with the map of the first (Fig. 11A) and the last (Fig. 11D) decade.

The map nevertheless shows a change between the west and east facade of the watershed, certainly due to the contrasting geographical position of the watershed. Its proximity to the coastal zone explains and justifies the increase in rainfall in the north compared to the south.

Fig. 11 Mapping of annual rainfall totals for different time periods. **A** Period 1975/1984 first decade. **B** Period 1985/1994s decade. **C** Period 1995/2004 third decade. **D** Period 2005/2014 fourth decade. **E** Period 1975/2014
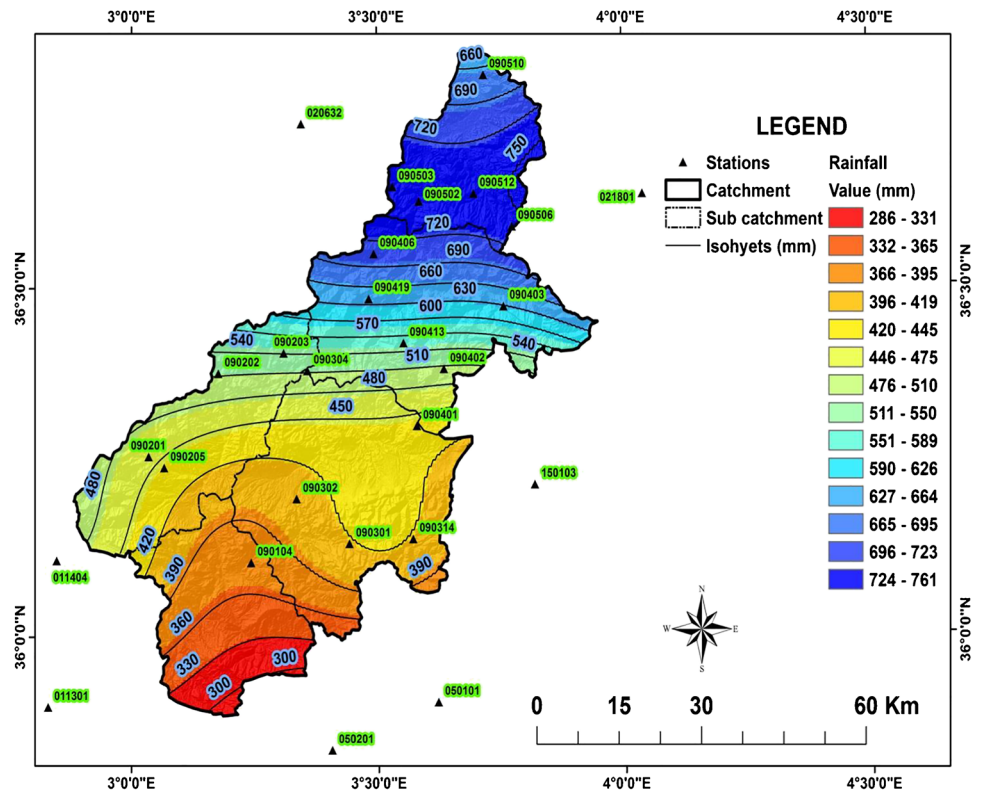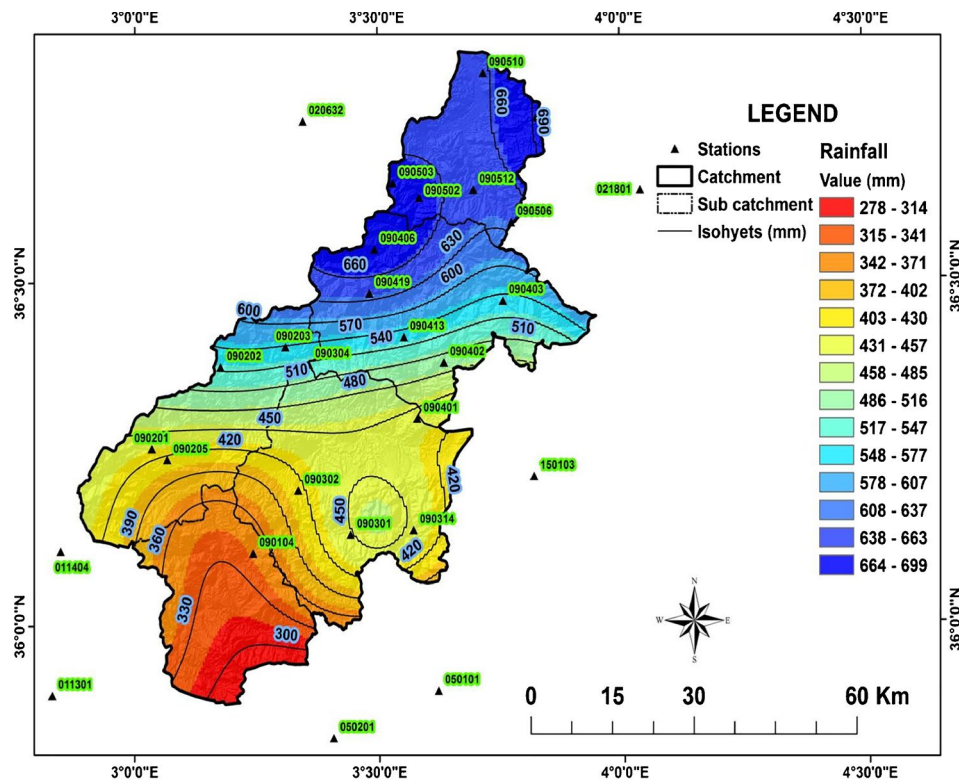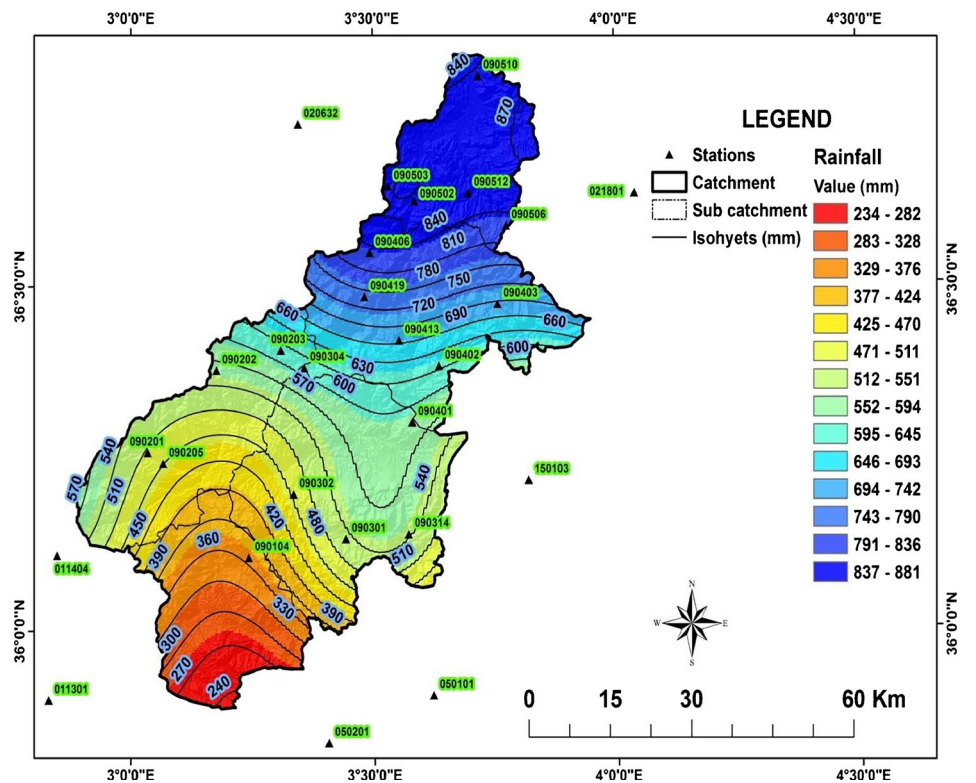

A) Period 1975/1984 First decade
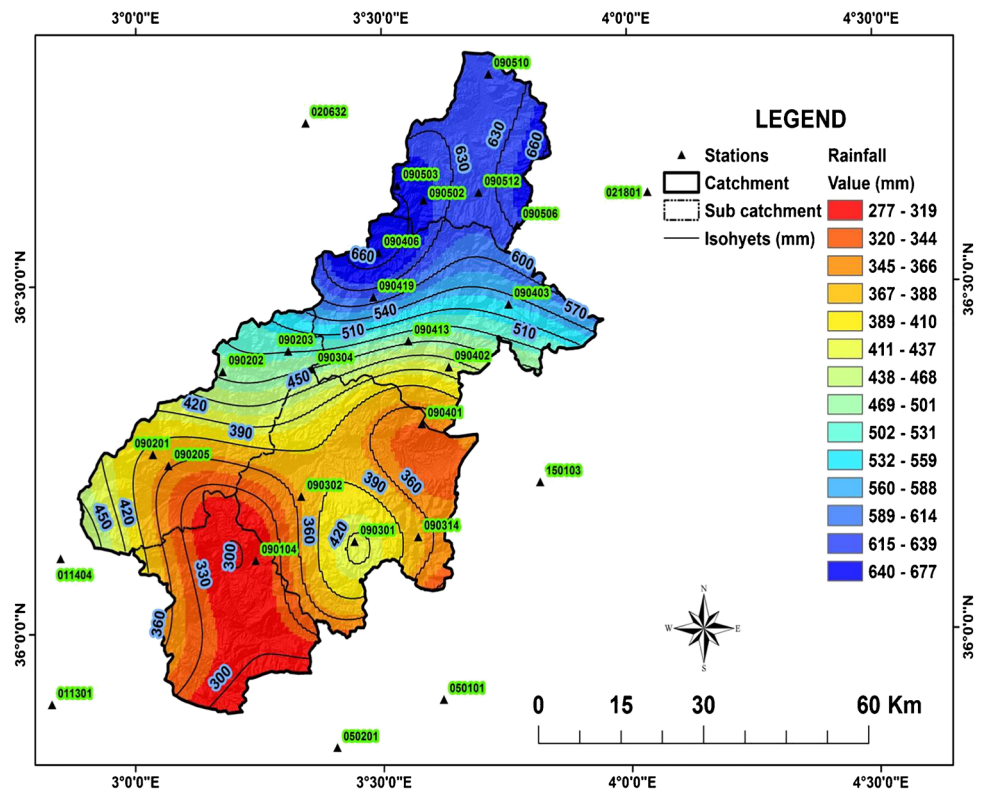
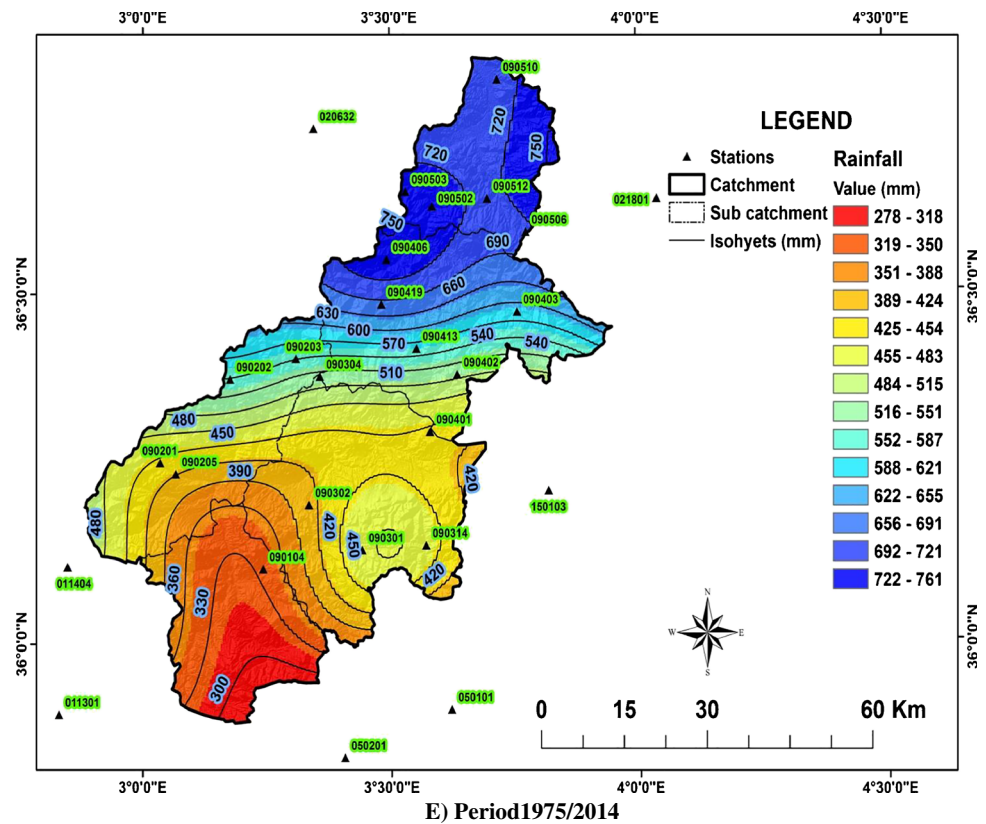
B) Period 1985/1994 seconde decade

Fig. 11 (continued)

C) Period 1995/2004 Third decade

D) Period 2005/2014 Fourth decade

Fig. 11 (continued)

E) Period1975/2014

The average rainfall over the period 1975–2014 is 526 mm (Fig. 10E). The variance of kriging varies from 27 to 130, always low compared to the SD mean estimated at 183.6 (Fig. 10E).

Analysis and discussion of the results

The study of the spatio-temporal variability of annual average rainfall series of a watershed, as well as the evolution of its rainfall regime, is based on the good spatial distribution of the rainfall network, the length of the observation series, and their continuity. This study shows a change in the mean annual precipitation from the beginning of the 1970s. Furthermore, the alternation of dry and wet sequences was assessed by means of statistical tests of homogeneity, revealing a first break deduced in the 1970s for a number of stations, with a reduction rate that reached 43%. This critical situation lasted for three decades in Isser, which experienced a drought between the beginning of the 1970s and the beginning of the 2000s. According to Zeggane 2017, a decreasing trend in annual precipitation is around 20%, over the whole study area. While the second break in the rainfall series corresponds to a reappearance of the wet sequence after a long drought and was identified in most measuring stations in 2001, the rate of rise in rainfall varied from 14 to 35%.

The geostatistical approach reinforced the statistical approach by variographic analysis and modeling of the spatial structure of precipitation for 40 years of observation and for each decade. The analysis of the kriging maps, elaborated using QGIS3.10.12–1 software, allowed and corroborated the results of the statistical tests of Buishand, Pettitt, and Lee and Heghinian, reinforced by the geostatistical modeling through the ordinary kriging adopted. The spatial interpolation carried out on the decadal averages of precipitation illustrates a well-contrasted spatial variability for the four decades. The concentration of the highest values of precipitation in the north of the Isser watershed can be explained by the influence of the orography and the proximity to the sea, while the central and southern part of the study area is characterized by low rainfall. Remember that the precipitation in northern Algeria varies greatly from one watershed to another. It increases from north to south and from east to west (Meddi and Toumi 2013).

Many authors have been interested in the problem of climate variability. By way of comparison with the results obtained in our work, we cite certain works carried out at different scales. It is important to note that the drought identified in Isser was spread across the Algerian northwest. As a result, Elouissi et al. in 2017 demonstrated a rainfall reduction from 13 to 25% in the Macta watershed, in the Tafna watershed; Ghenim and Megnounif in 2013 estimated it from 23 to 36%, and also in the West Mitidja, Drouiche et al.

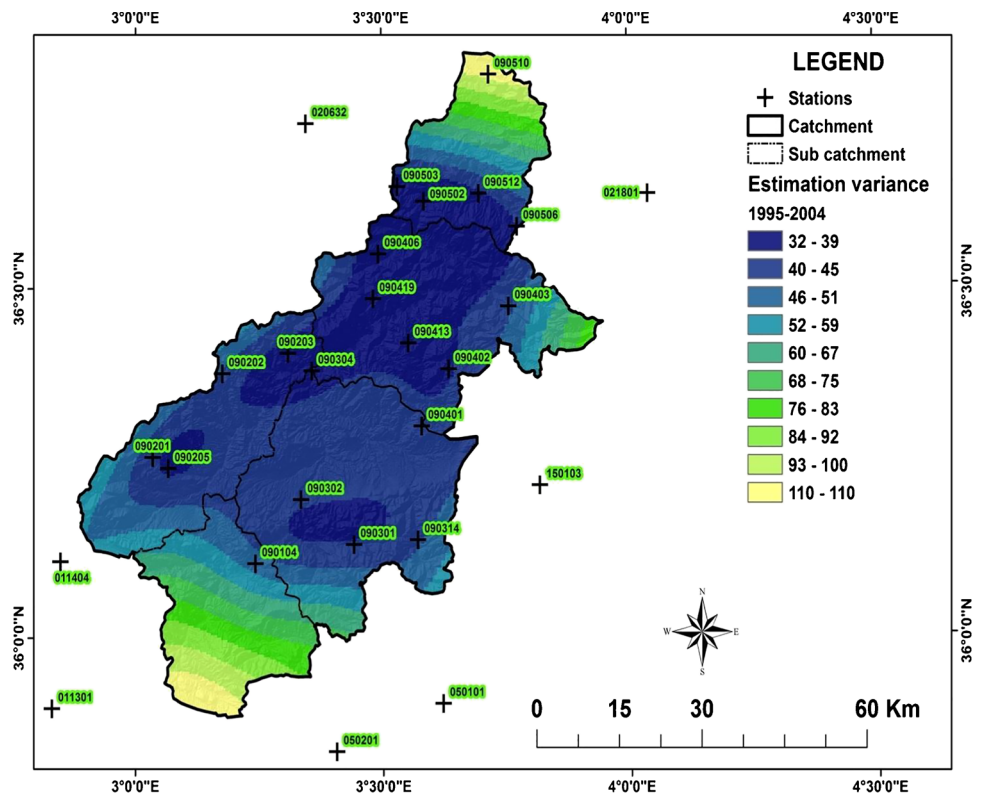**Fig. 12** Mapping of variance estimation for the different periods
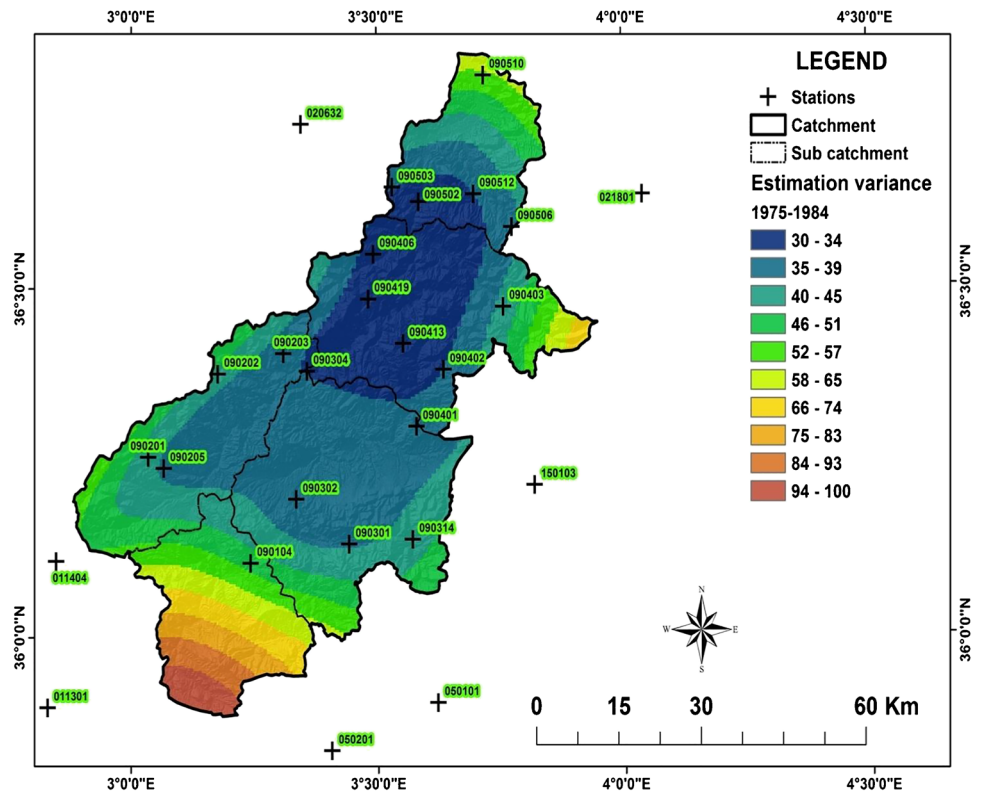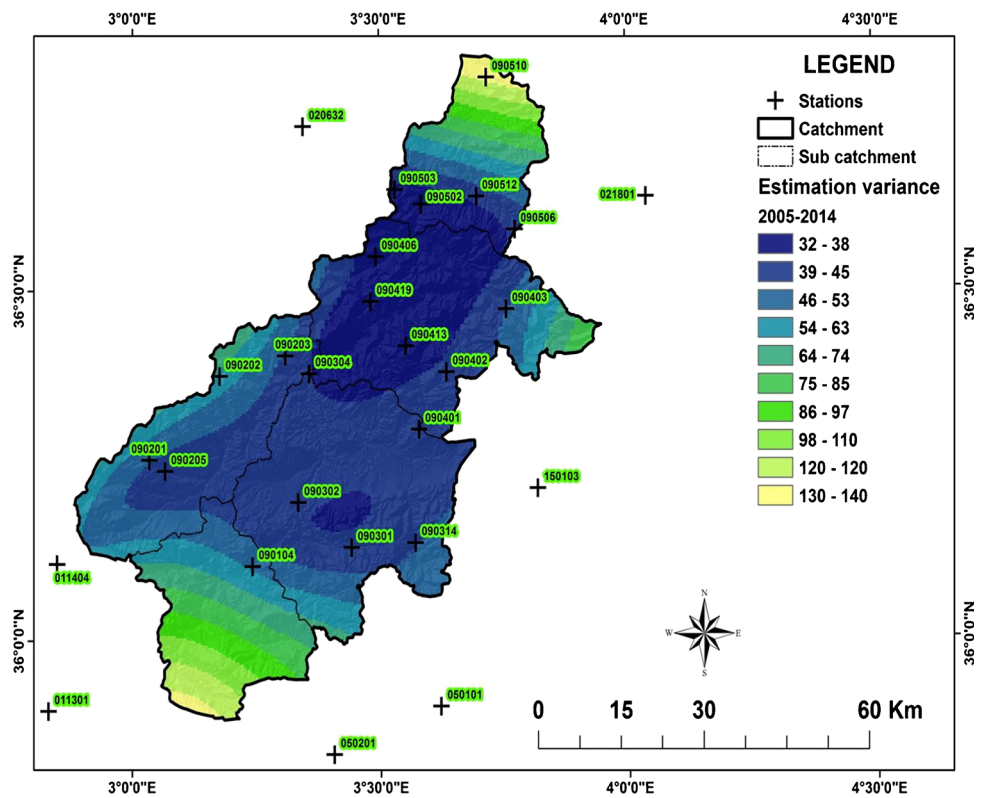

A) Period 1975/1984 first decade
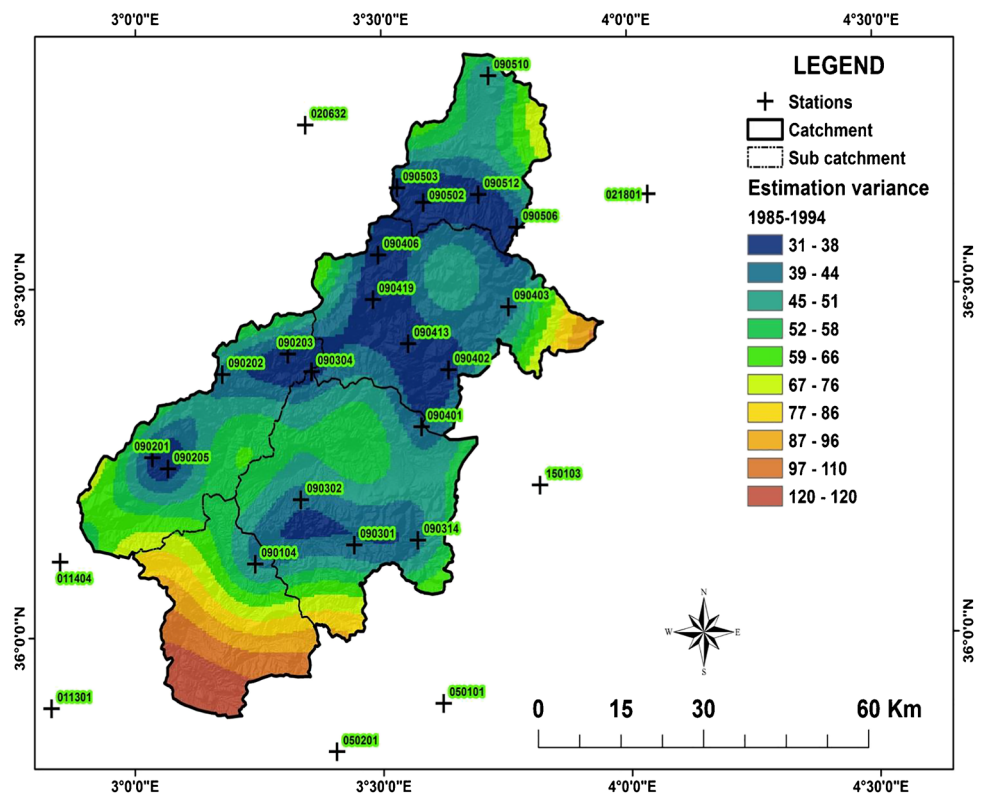
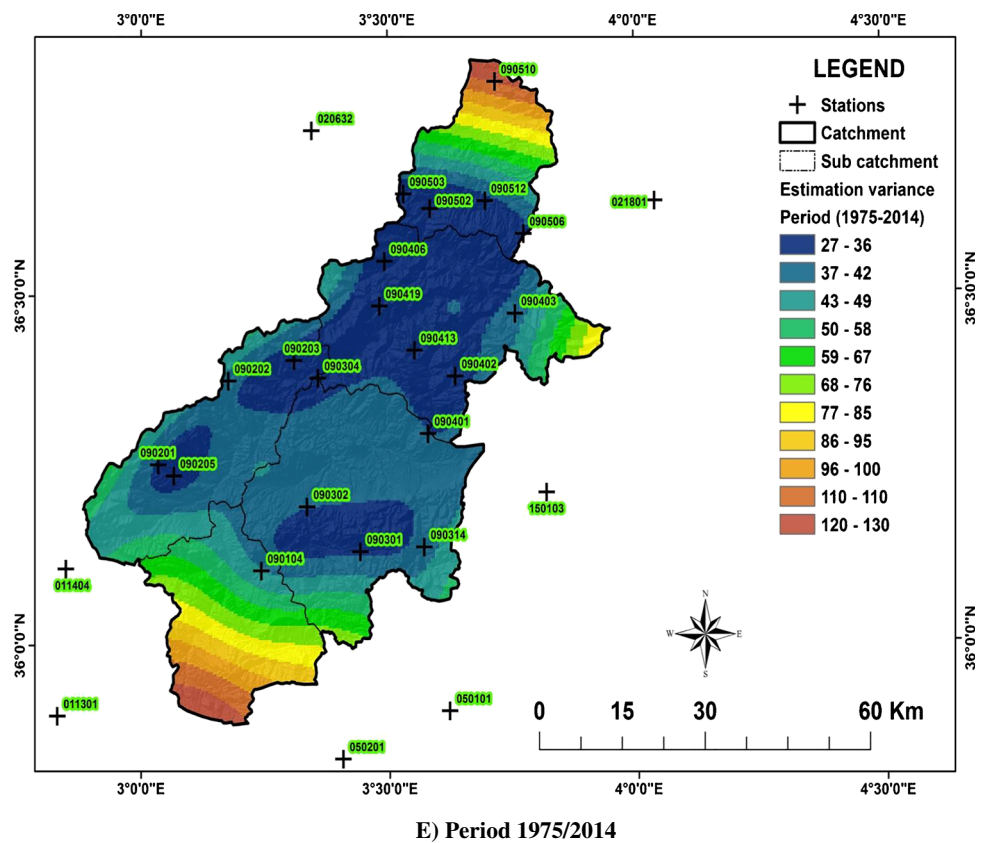B) Period 1985/1994 seconde decade

Fig. 12 (continued)

C) Period 1995/2004 third decade

D) Period 2005/2014 fourth decade

Fig. 12 (continued)

E) Period 1975/2014

in 2019 estimated it from 16 to 24%, finally, Khedimallah et al. in 2020 estimated it 30% in the Cheliff watershed and 36% in the Medjarda watershed. This trend in rainfall variability is explained by the relationship established between annual rainfall variability and the El Niño Southern Oscillation (ENSO) (Meddi et al 2010; Taibi et al 2015). This rainfall deficit (drought) has also been the subject of studies in Mediterranean and Maghreb countries (Jemai et al 2017; Hafez 2018; El-Hagrsy et al 2018; Galgano 2018; Taibi et al 2019; Cos Espuna et al 2021).

Note that Northern Algeria is characterized by a succession of deficits and excesses precipitation with three phases of rainfall evolution, namely, a high variability, a long period of drought, and rainfall return to the 2000s, attested by the results obtained compared to previous studies: in Northern Algeria (Nouaceur 2011) in the Algerian coast (Nouaceur et al 2013), in the North East of Algeria (Nouacer et Laignel 2015), in the Medjerda (Khoualdia et al 2014), in the Seybousse (Balah and Amarchi 2016), and also in the Timgad watershed (Regad and Tatar 2019).

Nouaceur in 2011 affirms that the long droughts observed in northern Algeria in the 1980s and 1990s confirm the return of rain during the last years of the series (2002–2006), and the observations from 2007 to 2010 also confirmed the prevalence of humid conditions. Indeed (Nouaceur and Murărescu 2016) have confirmed

the hypothesis of a return of rain marking at the end of the drought years in the central Maghreb.

Therefore, if, on the other hand, the Mediterranean climate seems fairly regular in terms of temperature; on the other hand, in terms of precipitation, the rainfall variations will show a wide range. During the last ten years of research, after nearly two decades of drought, a new humid phase has started, a new wet phase has started, hence, the interest of the study of rainfall variability which would allow the improvement of the management of the risks induced by the latter. This will allow better integrated management of water resources based on cartographic management tools and statistical studies, which highlight the general nature of the climate. In this context, the water resource managers will use the results of the research to define an optimal strategy for a better management of the watersheds, in particular the Isser watershed, within the framework of the sustainable development of the country. In the light of the results obtained in the Isser watershed and taking into account the bibliographical research, we can draw up an observation, which stipulates that the precipitation in the study area, Isser watershed, is characterized by a behavior similar to that identified at the scale of North Africa or even the southern shore of the Mediterranean basin.

Conclusion

The present study shows that, over the last 40 years, the Wadi Isser watershed has experienced a strong climatic variability that has had a significant influence on the changes of the rainfall regime. From the analysis of the evolution of this rainfall at the Bni Slimane (1920–2014) and Djebahia (1923–2014) stations, we deduced a climatic variability marked by a dry period between 1970 and 2001. A succession of humid periods and other less humid periods has been highlighted. This evolution is remarkable at the level of the stations of Bni Slimane and Djebahia which present the longest series of measurements. We thus note a period of low rainfall from 1974 at Djebahia and 1976 at Bni Slimane until 2001.

The application of the Pettitt, Buishand, and Lee and Heghinian tests revealed breaks in the series of measurements without determining precisely the characteristic periods of the rainfall evolution in the study area, due to unavailability of more data. The decrease in precipitation, which the watershed experienced starting 1970, resulted in significant deficits of the order from 14 to 43%. The end of the severe drought is pronounced from 2001 marked by an increased rainfall evaluated 35.8% at the Khabouzia station. This observation has already been established by various research studies which indicate a marked return of rainfall (Nouaceur 2011; Nouaceur and Murărescu 2016; Regad and Tatar 2019).

The analysis of the kriged maps elaborated with low variance supported and corroborated the results of Buishand, Pettitt, and Lee and Heghinian statistical tests reinforced by geostatistical modeling.

The spatial interpolation performed on the decadal averages of precipitation illustrates a well-contrasted spatial variability for the four distinguished decades. From the point of the research, the findings and the results obtained allowed to highlight the behavior of rainfall in the Isser watershed. The study will enable us to predict its impact on the groundwater resource in order to better manage and preserve it in a difficult context of climate change that is negatively impacting the world and particularly our study area, in order to define strategic policies for sustainable adaptation and rational management of this precious resource.

At the term of this modest research work, we can finally conclude that the study of annual rainfall variability in the Isser watershed, a semi-arid region, is important to define and identify the evolution of climatic zones and will allow updating this study of the future rainfall behavior in the Isser as well as in other watersheds based on new data.

The mapping done constitutes therefore a tool for decision making by the managers of water resources and the environment. thus optimizing decision-making for hydraulic developments, dimensioning of hydraulic structures, and/or civil engineering (dams, infiltration and artificial retention basins, development of wadis against flooding), and agricultural and industrial development.

Declarations

Conflict of interest The authors declare that they have no competing interests.

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