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Rainfall and Runoff Trend Analysis in the Wadi Mina Basin (Northern Algeria) Using Non-Parametric Tests and the ITA Method

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Abstract: The aim of this paper is to analyze the temporal tendencies of monthly, seasonal, and annual rainfall and runoff in the Wadi Mina basin (north-western side of Africa) using data from five stations in the period from 1973–2012. With this aim, first, a trend analysis was performed using two non-parametric tests: the Theil–Sen estimator and the Mann–Kendall test. Then, to identify trends in the different rainfall and runoff values of the series, the Innovative Trend Analysis technique was further applied. The results of the application of the non-parametric tests on the rainfall data showed a general negative rainfall trend in the Wadi Mina basin for different timescales. Similarly, the results evidenced a general reduction in the runoff values, in particular in the Sidi Abdelkader Djillali and Oued Abtal stations, even though the results obtained for the Oued Abtal station are influenced by a dam. These results were further analyzed through Sen's method, which enabled the trend identification of the different values (low, medium, and high) of the series.

Keywords: rainfall; runoff; climate change; trend; Wadi Mina basin

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1. Introduction

Climate change is affecting all regions worldwide, and in the few past years extensive and rapid changes in the ocean, atmosphere, biosphere, and cryosphere have occurred. In fact, in the last 10 years, greenhouse gas concentrations have continued to grow in the atmosphere, glaciers have retreated, and the global surface temperature and the global mean sea level have increased [1]. In this context, the Mediterranean basin is particularly important, for which the level of warming in the decades to come has been estimated to be about 20% higher than global averages, and devastating heatwaves, water shortages, losses of biodiversity, and risks to food production are expected. As a result, the Mediterranean region will be a 'hot spot' for global warming [1].

The Mediterranean region is affected by a strong precipitation variability, at both temporal and spatial scales, due to its geographical position between two strongly contrasting masses of water: the Atlantic Ocean and the Mediterranean Sea [2]; thus, numerous analyses of the temporal and spatial precipitation variability in this area have been performed in the last few years [3]. The results of these studies evidenced a diffuse decrease in the precipitation at the annual scale and an increase in both extreme rainfall and prolonged drought events [4]. Anyway, some differences have emerged between the western and the eastern sides of the Mediterranean basin, with the first characterized by an irregular rainfall decrease [5], and the latter affected by both positive and negative trends [6,7].

Considering northwest Africa, several studies have evidenced a marked negative trend in the precipitation value in the last twenty years [8–10]. For example, as evidenced by

Tramblay et al. [11], in this area, a negative trend in the period from 1950–2009 characterized both the yearly rainfall and the number of wet days. In particular, relevant trends have been identified in Morocco and western Algeria with the latter being characterized since the mid-1970s by a marked decrease in mean annual precipitation [12]. This tendency has been projected to continue during the 21st century, particularly in the semi-arid areas [13,14]. Regarding Algeria, Elouissi et al. [15] noticed decreasing trends of monthly precipitations in the northern part of the Macta basin, close to the coastal Mediterranean Sea area, and Achite et al. [16] evidenced a marked negative trend in the annual rainfall in the Wadi Cheliff basin. Furthermore, the seasonal trend behavior of the precipitation in the Wadi Sly basin was detected by Achite and Caloiero [17].

At the same time, several studies have evidenced worldwide changes in the temporal distributions of runoff mainly due to human activity and climate change, such as in the Nile River, the Colorado River, the Yangtze River, and the Yellow River [18]. Specifically, geographically different changes in river runoff have been evidenced, with an increasing trend that mainly characterizes the high latitudes and decreasing trends dominating in regions such as southern Europe, southern Africa, and the Middle East [19,20]. In particular, concerning Europe, increases in mean annual values in Northern Europe and decreases in Southern Europe have been detected in the last few decades [21].

Restricted data and missing values in the records have limited the attempts to detect runoff trends at a regional scale in Africa, where the majority of the studies have been performed at a catchment scale [22]. Nevertheless, a general decrease in runoff was detected in the Sudanian regions for the 1960–2010 period [23] and in West Africa [24] in particular since 1970, while no significant trends have been evidenced in Central Africa [25]. Generally, these trend studies were based on non-parametric tests, such as the Mann–Kendall test or Sen's slope methods that are more appropriate than parametric ones to deal with non-normally distributed data in hydrometeorology [26]. Nevertheless, these tests present some limitations linked with the null hypothesis [27], which assumes the serial correlation of data [28,29]. Serinaldi et al. [30] showed that even if the empirical estimation of trends based on common statistical tests is always feasible from a numerical point of view, it has poor information sources of nonstationarity if it does not assume a priori additional information on the underlying stochastic process. To overcome this problem, the Innovative Trend Analysis (ITA) has been proposed and applied in several studies on precipitation variability worldwide [31]. ITA has been mainly applied in the detection of rainfall trends at different timescales, such as those in New Zealand [32], India [33], Italy [34], Ethiopia [35], Turkey [36], and Algeria [16], but it has been also widely applied in the trend analyses performed on several variables such as temperature, Standardized Precipitation Index, heat waves, water quality parameters, sea wave parameters, evaporations, and streamflow data [37–44].

In this study, to detect possible changes in rainfall and runoff data in the northwestern side of Africa, monthly rainfall and runoff series recorded in the Wadi Mina basin have been analyzed and the temporal changes of the different series have been detected using two non-parametric tests. Moreover, the ITA method has been applied to detect if low, medium, or high values in the data contribute to the trends. Due to the importance of the water resources in the semi-arid region of Algeria, the current study thus endeavors to add further considerations to earlier studies on Algerian basins hydrology. In particular, the study attempts to understand the rainfall trends in the Wadi Mina basin and their impact on runoff. In fact, to the authors' knowledge, this area lacks a detailed analysis of the future tendencies of rainfall and runoff values.

The findings of the study shall provide essential guidance for sustainable water resources.

2. Methodology

In this paper, to analyze the possible trends in rainfall and runoff series, two non-parametric tests for trend detection have been used: the Theil–Sen (TS) estimator [45] for the evaluation of the slopes of the trends and the Mann–Kendall (MK) test [46,47] for the assessment of the statistical significance. In particular, the TS estimator has been selected because it is generally considered more powerful than linear regression methods for trend magnitude evaluation, because it is not subject to the influence of extreme values.

The slope estimates of N pairs of observations are computed based on the equation:

$$Q_k = \frac{P_j - P_i}{t_j - t_i} \quad for\ k = 1, \ldots, N, \tag{1}$$

where P_j and P_i are the observations at time j and i ($j > i$), respectively.

The median of these N values of Q_i is the Sen's estimator of slope, which is evaluated as follows:

$$Q_{med} = \begin{cases} Q_{[(N+1)/2]} & if\ N\ is\ odd \\ \frac{Q_{[N/2]} + Q_{[(N+2)/2]}}{2} & if\ N\ is\ even \end{cases}, \tag{2}$$

The Q_{med} sign reveals the trend behavior, while its value indicates the magnitude of the trend.

Concerning the MK test, the test statistic S is calculated using the following equation:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn\left(P_j - P_k\right) \quad where \quad sgn\left(P_j - P_k\right) = \begin{cases} 1\ \ if\ \left(P_j - P_k\right) > 0 \\ 0\ \ if\ \left(P_j - P_k\right) = 0 \\ -1\ \ if\ \left(P_j - P_k\right) < 0 \end{cases}, \tag{3}$$

in which n is the number of data and P is the observation at times k and j (with $j > k$). The variance of S is computed as:

$$Var(S) = \left[n\ (n-1)\ (2\ n+5) - \sum_{i=1}^{m} t_i\ (t_i - 1)\ (2\ t_i + 5) \right] / 18, \tag{4}$$

where t_i is the number of ties of extent i and m is the number of tied rank groups.

For n larger than 10, the standard normal Z_{MK} test statistics are computed as the Mann–Kendall test statistics as follows:

$$Z_{MK} = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & for\ \ S > 0 \\ 0 & for\ \ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & for\ \ S < 0 \end{cases}, \tag{5}$$

By applying a two-tailed test, for a specified significance level α, the significance of the trend can be evaluated. In particular, in this work, the rainfall and runoff series have been examined for three different significance levels (SL) equal to 90%, 95%, and 99%.

Besides the non-parametric MK and TS tests, the ITA method was also applied. This method can be applied following 3 main steps:

1. Divide the time series into two equal parts;
2. Order each part from the lowest value to the highest one;
3. Locate the two ordered time series in a Cartesian diagram with the first half on the x-axis and the second half on the y-axis.

Considering the data's position in the Cartesian diagram, it is possible to evaluate the trend behavior by detecting data falling above the 1:1 ideal line (45° line), which characterize positive trends, and data located below this line, which identify decreasing trends. Data close to the 1:1 ideal line show no trend in the time series [31,40]. In this paper, before the application of the ITA method, the rainfall and runoff monthly series have been converted into anomalies, and to better match the evidence, the distance of the points from the 1:1 ideal line following [34] two confidence bands (0.25 in blue and 0.5 in red) have been added in the Cartesian diagram (Figure 1).

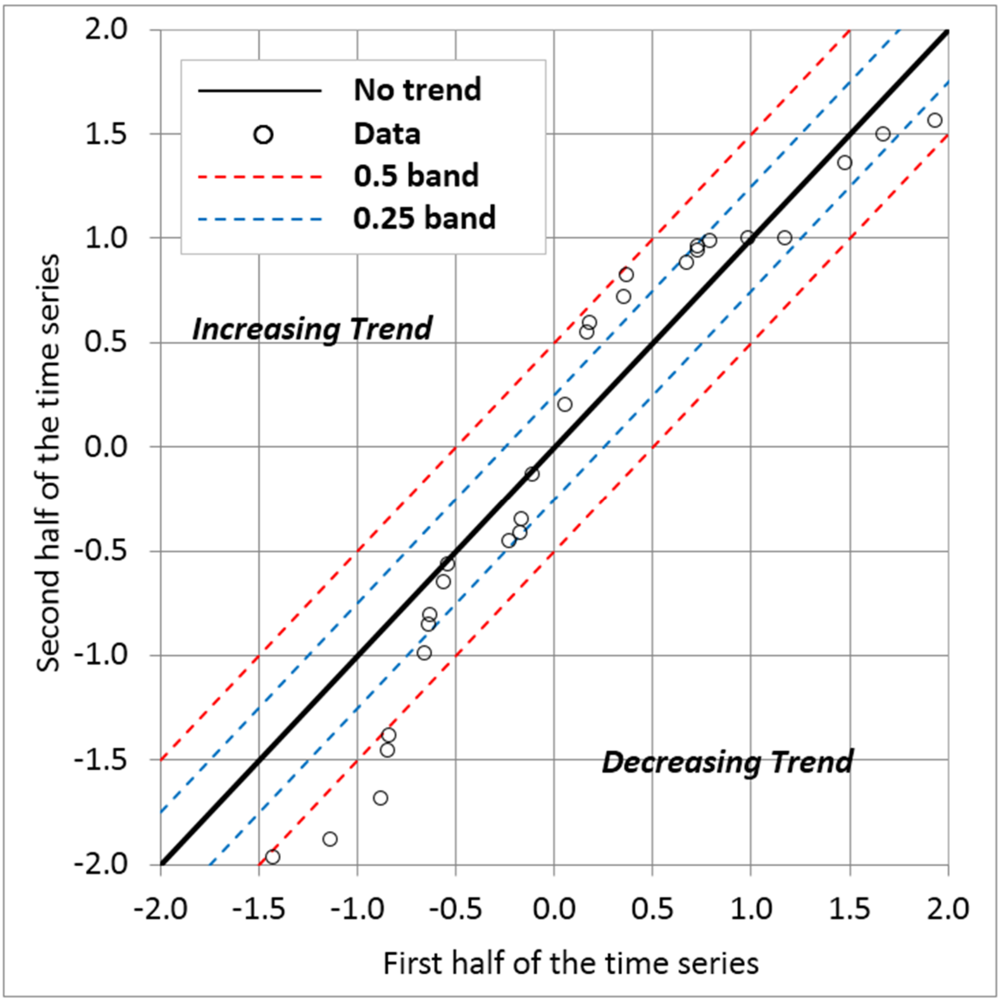

Figure 1. Example of the ITA method.

3. Study Area and Data

The study area comprises the Wadi Mina basin in northwestern Algeria, which covers an area of 4900 km^2 and lies between 00° 22′ 59′′ E to 01° 09′ 02′′ E and between 34°41′57′′ N and 35°35′27′′ N (Figure 2). The Wadi Mina involves four major tributaries: Wadi Mina, Wadi Haddad, Wadi Abd, and Wadi that. The topography of the basin is complex and rugged. The altitude varies from 164 m to 1327 m. The climate of the study area is continental, with cold winters and hot summers with large temperature differences. The average annual precipitation ranges from 500 mm to 250 mm in the basin and most precipitation occurs between November and March. The mean annual temperature ranges from 16 °C to 19.5 °C. Almost half of the basin is covered by a varying density of vegetation, with 32% of this vegetation consisting of scrubs, 35.8% of forests, and cereal crops [48].

Monthly rainfall and runoff records for a 40-year observation period (1973–2012) were compiled for five rainfall and hydrometric stations from the National Agency of the Water Resources (Figure 2 and Tables 1 and 2).

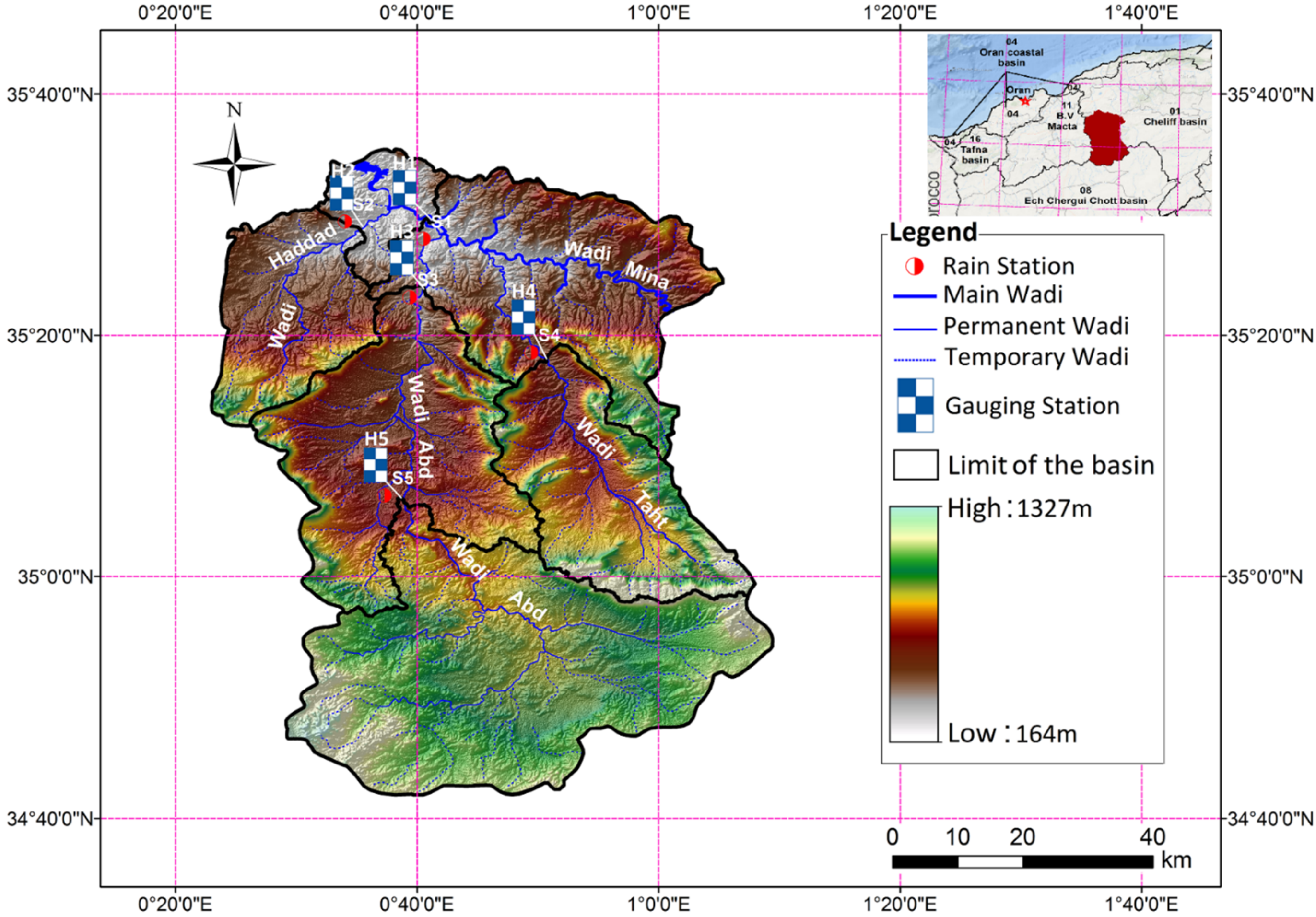

Figure 2. Spatial distribution of the stations in the Wadi Mina basin.

Table 1. Rainfall stations characteristics.

ID	Code	Name	Longitude	Latitude	Elevation (m)
S1	013306	Oued Abtal	0°40′33.97″ E	35°28′03.59″ N	354
S2	013401	Sidi Abdelkader Djillali	0°34′08.35″ E	35°29′20.71″ N	225
S3	013302	Ain Hammara	0°39′16.85″ E	35°23′15.39″ N	288
S4	013001	Kef Mehboula	0°49′34.20″ E	35°18′40.72″ N	475
S5	013304	Takhmaret	0°37′27.25″ E	35°06′49.01″ N	655

Table 2. Gauging stations characteristics.

ID	Code	Name	Basin Area (km^2)	Longitude	Latitude
H1	013402	Oued Abtal	4126	0°41′00.49″ E	35°29′26.28″ N
H2	013401	Sidi Abdelkader Djillali	480	0°35′19.99″ E	35°28′46.05″ N
H3	013302	Ain Hammara	2480	0°40′33.19″ E	35°23′50.09″ N
H4	013001	Kef Mehboula	680	0°50′47.89″ E	35°18′05.21″ N
H5	013301	Takhmaret	1553	0°38′46.54″ E	35°06′20.08″ N

4. Results and Discussion

4.1. Rainfall Data

The results of the application of the non-parametric tests on the rainfall data enabled the identification of a general negative rainfall trend in the Wadi Mina basin (Table 3).

Table 3. Results of the trend analysis on rainfall data at different timescales.

Period	Oued Abtal	Sidi Abdelkader Djillali	Ain Hamara	Kef Mehboula	Takhmaret
September			2.323 **		4.833 *
October					
November		3.625 **			
December	−2.294 *				
January					
February					
March	−7.455 **	−5.800 **		−11.211 **	
April				−8.250 **	
May			−1.000 *		
June		−1.627 *	−0.526 *	−1.115 *	
July	0.435 ***	−0.774 **			
August		0.943 *			
Year	−27.400 **			−34.048 ***	
Autumn				−6.900 *	
Winter	−12.000 ***				
Spring	−9.917 *	−9.000 **	−7.385 **	−17.759 ***	
Summer					

* SL = 90%, ** SL = 95%, *** SL = 99%.

In fact, at an annual scale, a marked negative trend was identified in the Oued Abtal and the Kef Mehboula stations, with a reduction of about 27 mm/10 years (SL = 95%) and about 34 mm/years (SL = 99%), respectively. From a seasonal point of view, a negative trend was detected in spring in four out of the five stations, with a maximum reduction of 17.8 mm/10 years identified in the Kef Mehboula station, for an SL = 99%. Negative trends at seasonal scale have also been observed in winter for the Oued Abtal station (−12 mm/10 years, for an SL = 99%) and in autumn for the Kef Mehboula station (about −7 mm/10 years, for an SL = 90%). Regarding the monthly rainfall, the Takhmaret station only showed a significant trend (SL = 90%) in September when an increase in rainfall of 4.8 mm/10 years was detected. The Ain Hamara station evidenced different monthly trend signs, with a positive trend in September (2.3 mm/10 years, for an SL = 95%) and slightly negative trends detected in May and June, with a reduction of about 1 mm/10 years and about 0.5 mm/10 years, respectively (SL = 90%). In the Sidi Abdelkader Djillali station, positive rainfall trends were detected in November (3.6 mm/10 years, for an SL = 95%) and in August (about 1 mm/10 years, for an SL = 90%), while decreases of −5.8 mm/10 years, −1.6 mm/10 years, and −0.7 mm/10 years were documented in March (SL = 95%), June (SL = 90%), and July (SL = 95%), respectively. A slightly positive trend in June (0.4 mm/10 years, for an SL = 99%) and negative trends in December (−2.3 mm/10 years for an SL = 90%), and March (−7.5 mm/10 years, for an SL = 95%) were found for the Oued Abtal station. Finally, for the Kef Mehboula station, monthly negative trends were identified in March, April, and June with reductions of about 11.2 mm/10 years (SL = 95%), 8.2 mm/10 years (SL = 95%), and 1.1 mm/10 years (SL = 90%), respectively.

These trend results were confirmed through the application of the ITA method, which also enabled an identification of which values highly contributed to the trend behavior. In fact, the results of the ITA applied to the annual rainfall evidenced a non-monotonic decrease for the Oued Abtal and Kef Mehboula stations (Figure 3d,e) and an opposite trend for the Takhmaret, Ain Hamara, and Sidi Abdelkader Djillali stations (Figure 3a–c), especially for the highest values.

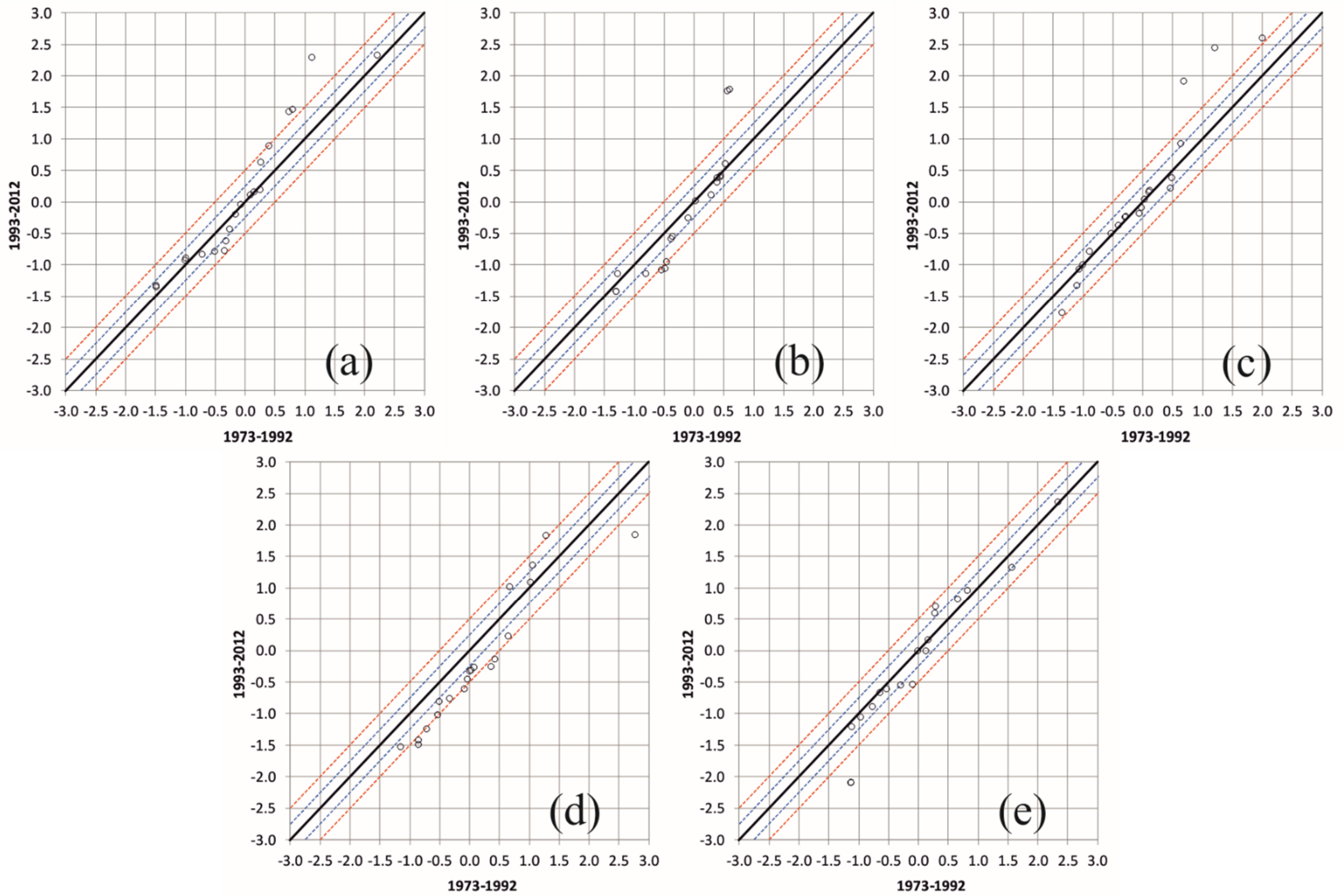

Figure 3. Results of the ITA applied to the annual rainfall measured at the (**a**) Takhmaret, (**b**) Ain Hamara, (**c**) Sidi Abdelkader Djillali, (**d**) Oued Abtal, and (**e**) Kef Mehboula stations.

Figures 4–8 show the results of the ITA method on the monthly and seasonal scales. Regarding the Takhmaret station (Figure 4), a marked positive trend was identified in September, in particular for the highest values, which significantly differ from the 1:1 ideal line. Remarkable results were also obtained for March, when a negative trend was detected, and in the autumn, when a positive trend was identified especially for the highest values. This latter trend behavior was influenced by the monthly trend detected in September.

In the Ain Hamara station (Figure 5), the ITA method showed increasing trends in September and November, which were particularly evident for the medium and the highest values, and decreasing trends in March and June involving the medium values. Due to the monthly trends, non-monotonic increases and decreases were detected in autumn and spring, respectively, for almost all the values, while a positive trend of the highest values was detected in winter.

Concerning the Sidi Abdelkader Djillali station (Figure 6), monotonic increases were identified in September and in August, especially for the highest values, while an opposite behavior characterized March and June, particularly for the medium values. On a seasonal timescale, remarkable results were detected only in autumn (positive trend) and in summer (negative trend) for the medium and the highest values, respectively.

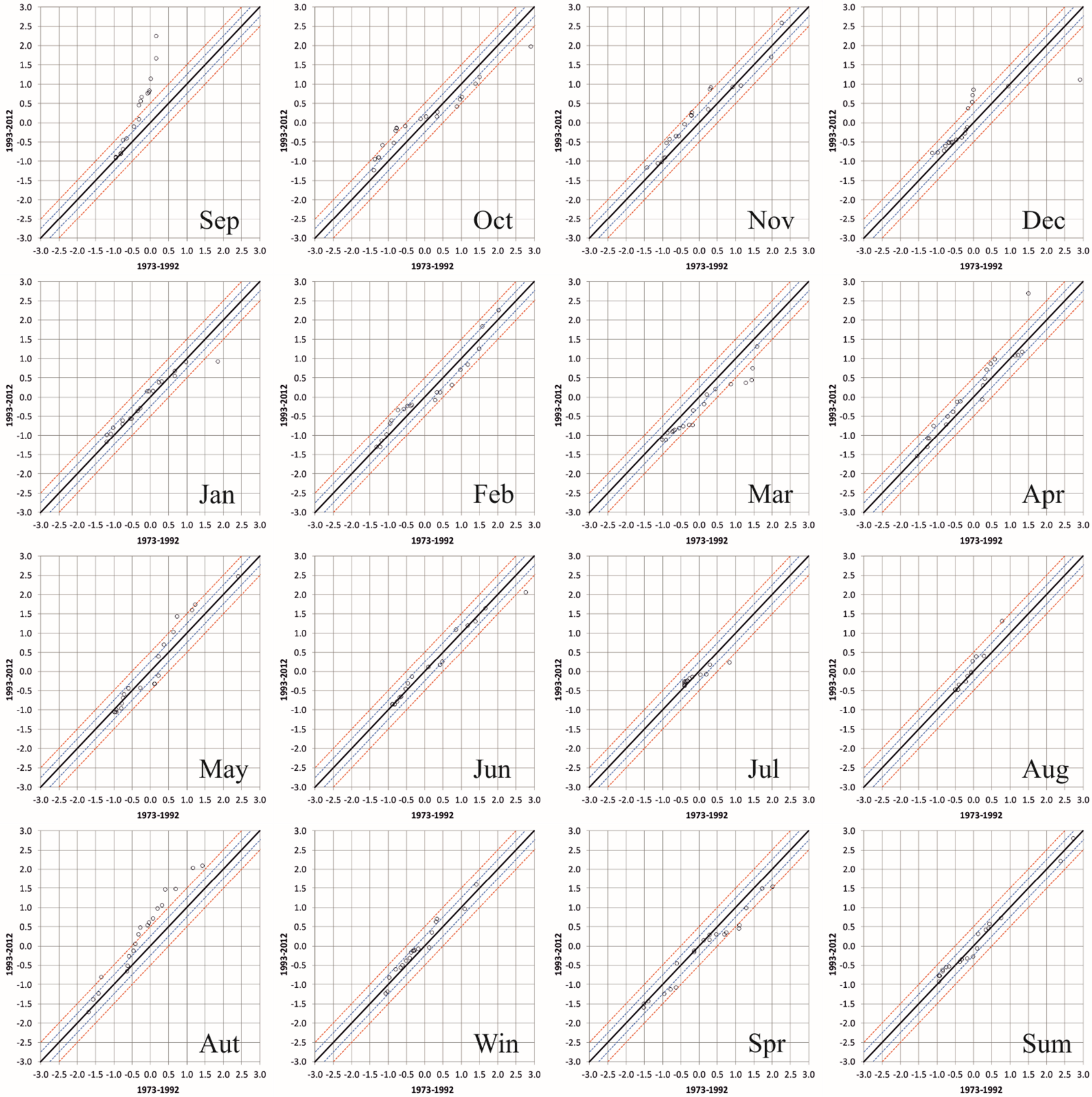

Figure 4. Results of the ITA applied to the monthly and seasonal rainfall measured at the Takhmaret station.

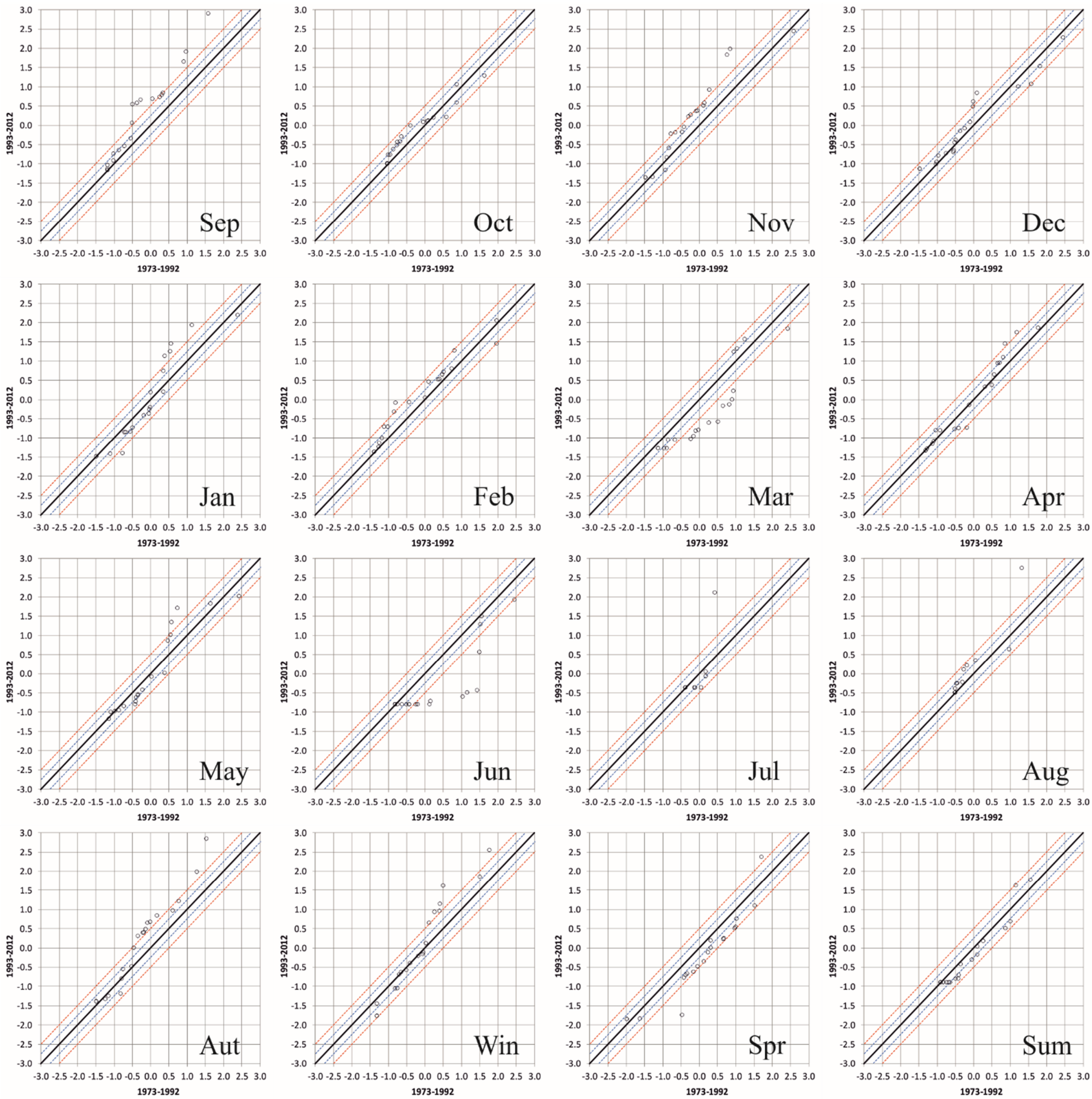

Figure 5. Results of the ITA applied to the monthly and seasonal rainfall measured at the Ain Hamara station.

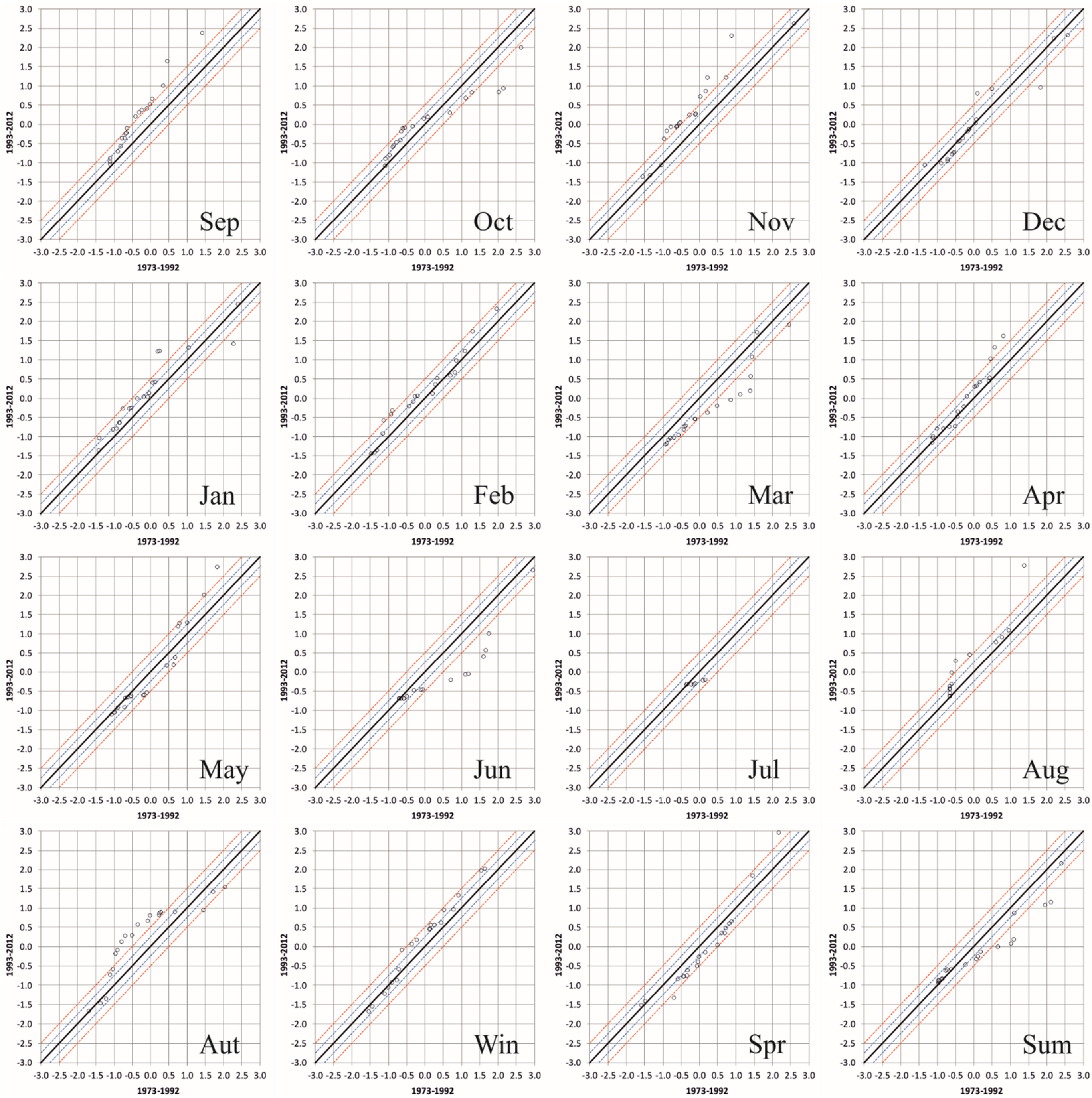

Figure 6. Results of the ITA applied to the monthly and seasonal rainfall measured at the Sidi Abdelkader Djillali station.

A monotonic increase in September and a monotonic decrease in March were detected in the Oued Abtal station (Figure 7). Negative trends, involving almost all the values, were also identified in December and in January while in February this trend behavior characterized only the highest values. On a seasonal scale, a negative trend was detected in winter and spring, a divergent trend was identified in autumn (positive for the medium values and negative for the highest ones), and summer's results were trendless.

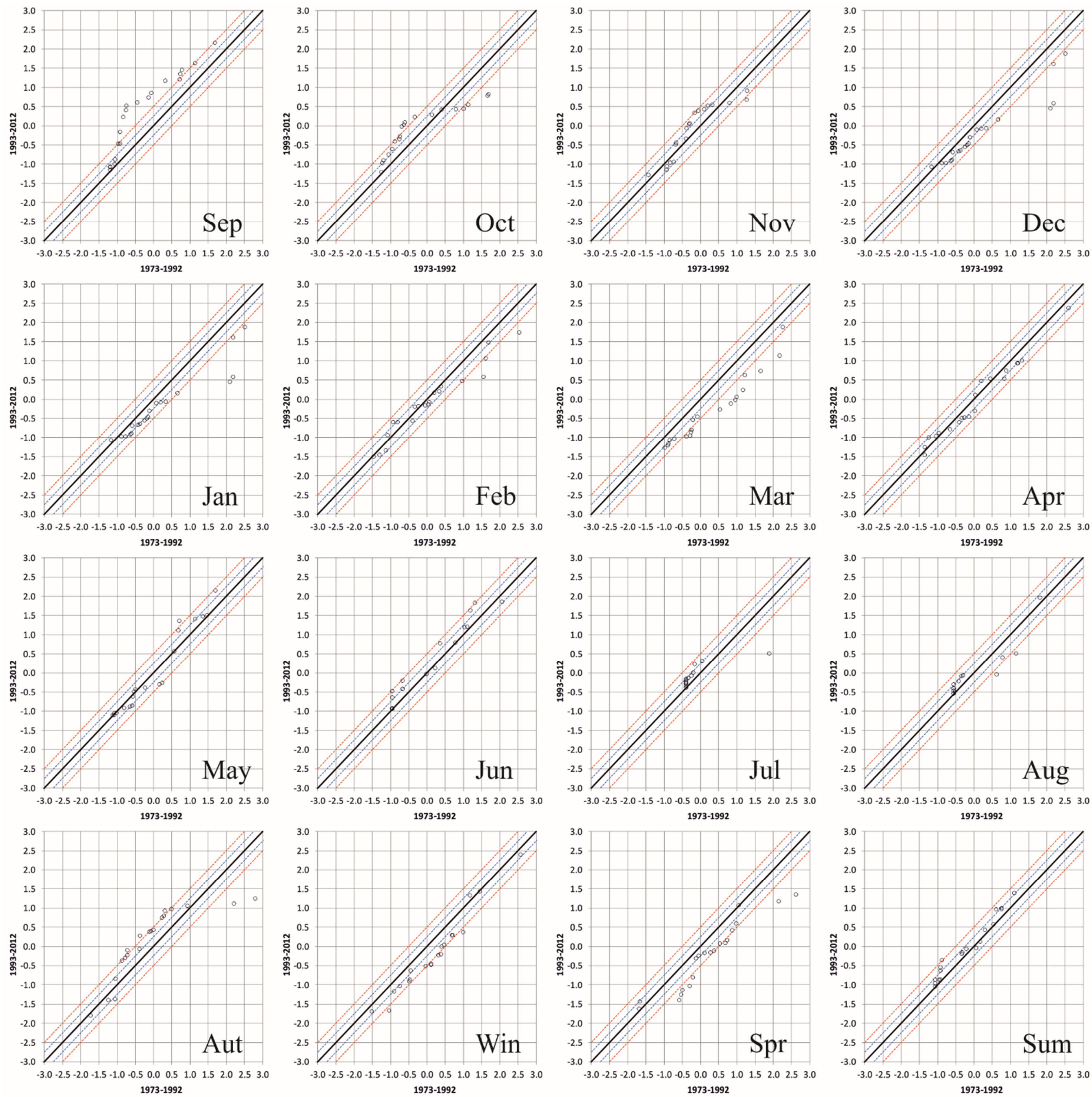

Figure 7. Results of the ITA applied to the monthly and seasonal rainfall measured at the Oued Abtal station.

Finally, considering the Kef Mehboula station (Figure 8), only in September (positive), November (negative), December (positive), and March (negative) was a relevant tendency observed, while the other months and seasons seemed to show a trendless behavior.

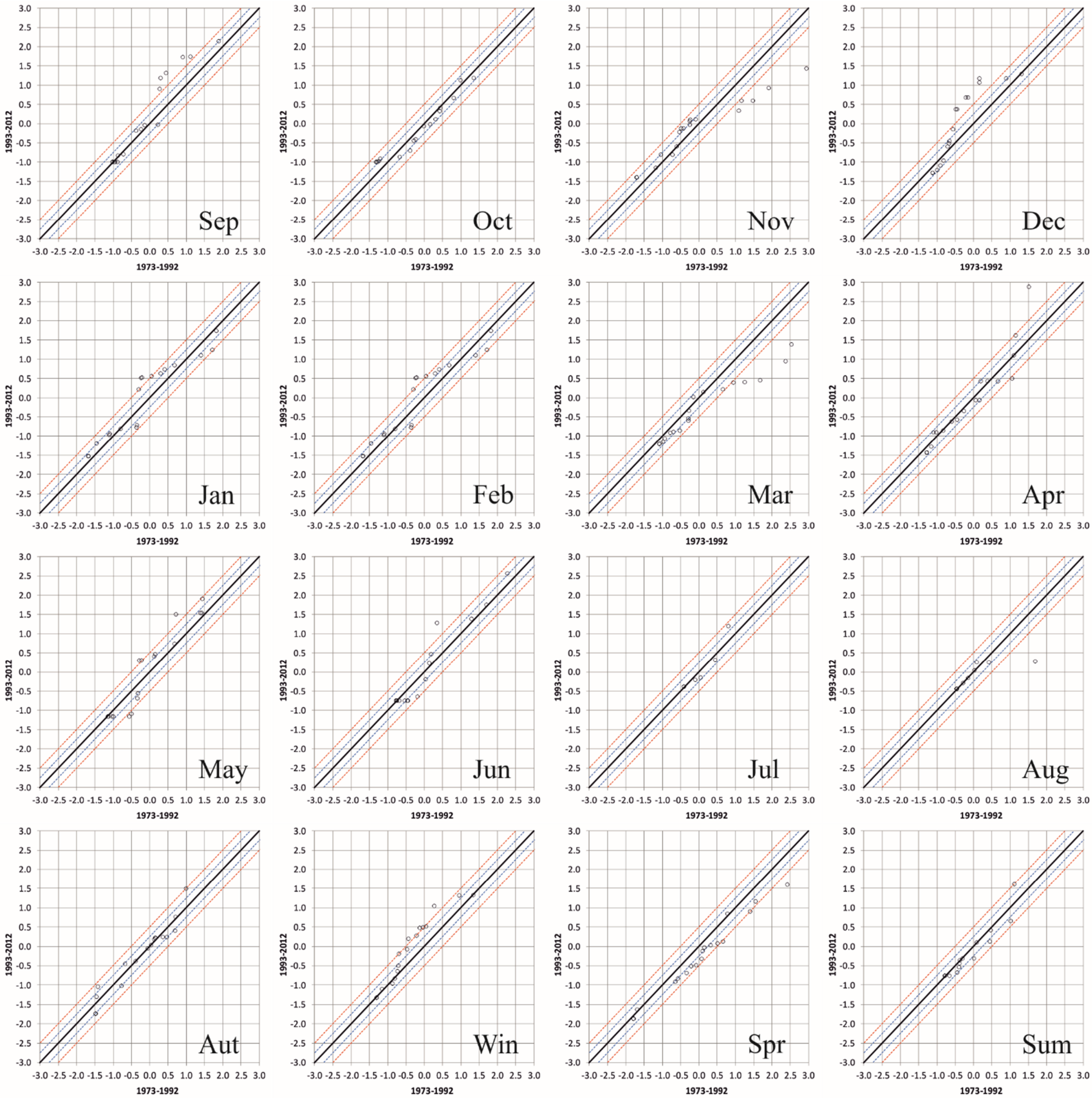

Figure 8. Results of the ITA applied to the monthly and seasonal rainfall measured at the Kef Mehboula station.

4.2. Runoff Data

In the analysis of the runoff data, it must be considered that the results obtained for the Oued Abtal station are influenced by a dam, which—especially during summer—releases water for irrigation.

Through the application of the non-parametric tests on the runoff data, a general reduction in the runoff values in the Wadi Mina basin was identified, particularly in the Sidi Abdelkader Djillali and Oued Abtal stations (Table 4). In fact, at the annual scale, a marked negative trend was found for these stations, with a reduction of 0.06 $m^3/s/10$ years (SL = 99%) and about 0.5 $m^3/s/10$ years (SL = 99%), respectively. On the contrary, an increasing trend with a magnitude of 0.13 $m^3/s/10$ years was detected for the Takhmaret station with an SL = 95%. On a seasonal scale, a negative trend was detected in all the seasons in the Sidi Abdelkader Djillali and Oued Abtal stations and for three out of four seasons for the Ain Hamara station. Specifically, maximum reductions of 0.113 $m^3/s/10$ years (SL = 99%), 0.752 $m^3/s/10$ years (SL = 99%), and 0.127 $m^3/s/10$ years (SL = 95%) were found for the Sidi Abdelkader Djillali (in winter), the Oued Abtal (in spring), and the Ain Hamara (in spring) station, respectively.

Table 4. Results of the trend analysis on runoff data at different timescales.

Period	Oued Abtal	Sidi Abdelkader Djillali	Ain Hamara	Kef Mehboula	Takhmaret
September	−0.185 ***	−0.005 ***		−0.018 *	
October	−0.191 *	−0.016 ***			
November	−0.392 ***	−0.060 ***			
December	−0.372 ***	−0.080 ***	−0.076 **		
January	−0.309 **	−0.091 ***	−0.121 ***	−0.019 *	
February	−0.468 **	−0.111 ***	−0.225 **	−0.046 *	
March	−0.615 ***	−0.061 ***	−0.240 ***	−0.050 **	
April	−0.482 ***	−0.034 ***	−0.150 **	−0.040 **	
May	−0.666 ***	−0.027 ***	−0.116 ***		
June	−0.133 ***	−0.006 ***	−0.073 ***		
July	−0.111 ***	−0.003 ***	−0.069 ***		−0.026 **
August	−0.108 ***	−0.001 **	−0.051 ***		
Year	−0.495 ***	−0.060 ***			0.130 **
Autumn	−0.188 **	−0.033 ***			0.306 **
Winter	−0.497 ***	−0.113 ***	−0.094 **		
Spring	−0.752 ***	−0.062 ***	−0.127 **	−0.038 *	
Summer	−0.210 ***	−0.003 ***	−0.072 ***		

* SL = 90%, ** SL = 95%, *** SL = 99%.

The Takhmaret and Kef Mehboula stations showed significant trends only in autumn (positive) and in spring (negative), respectively, with an increase of 0.306 $m^3/s/10$ years (SL = 95%) and a decrease of 0.038 $m^3/s/10$ years (SL = 90%). Considering the monthly rainfall, the Takhmaret station showed a significant trend (SL = 95%) only in July, when a decrease in runoff of 0.026 $m^3/s/10$ years was detected. The Ain Hamara station evidenced only negative trends from December to August, with a runoff reduction ranging from 0.051 $m^3/s/10$ years in August (SL = 99%) to 0.240 $m^3/s/10$ years in March (SL = 99%). In the Sidi Abdelkader Djillali and the Oued Abtal stations, negative runoff trends were detected in all the months. In particular, the runoff reduction ranged from 0.001 $m^3/s/10$ years in August (SL = 95%) to 0.340 $m^3/s/10$ years in April (SL = 99%), and from 0.108 $m^3/s/10$ years in August (SL = 99%) to 0.666 $m^3/s/10$ years in May (SL = 99%), for the Sidi Abdelkader Djillali and the Oued Abtal station, respectively. Finally, for the Kef Mehboula station, monthly negative trends were identified for September and from January to April, with a maximum reduction of 0.05 $m^3/s/10$ years for March with an SL = 95%.

The results of the ITA method applied to the annual runoff evidenced a monotonic increase for the Takhmaret and Kef Mehboula stations and an opposite trend for the Sidi Abdelkader Djillali station (Figure 9a,c,e). These trend behaviors involved all the values, and especially the medium and the highest ones. A non-monotonic increase and decrease have also been identified for the Ain Hamara and the Oued Abtal stations, respectively (Figure 9b,d), mainly due to the highest values.

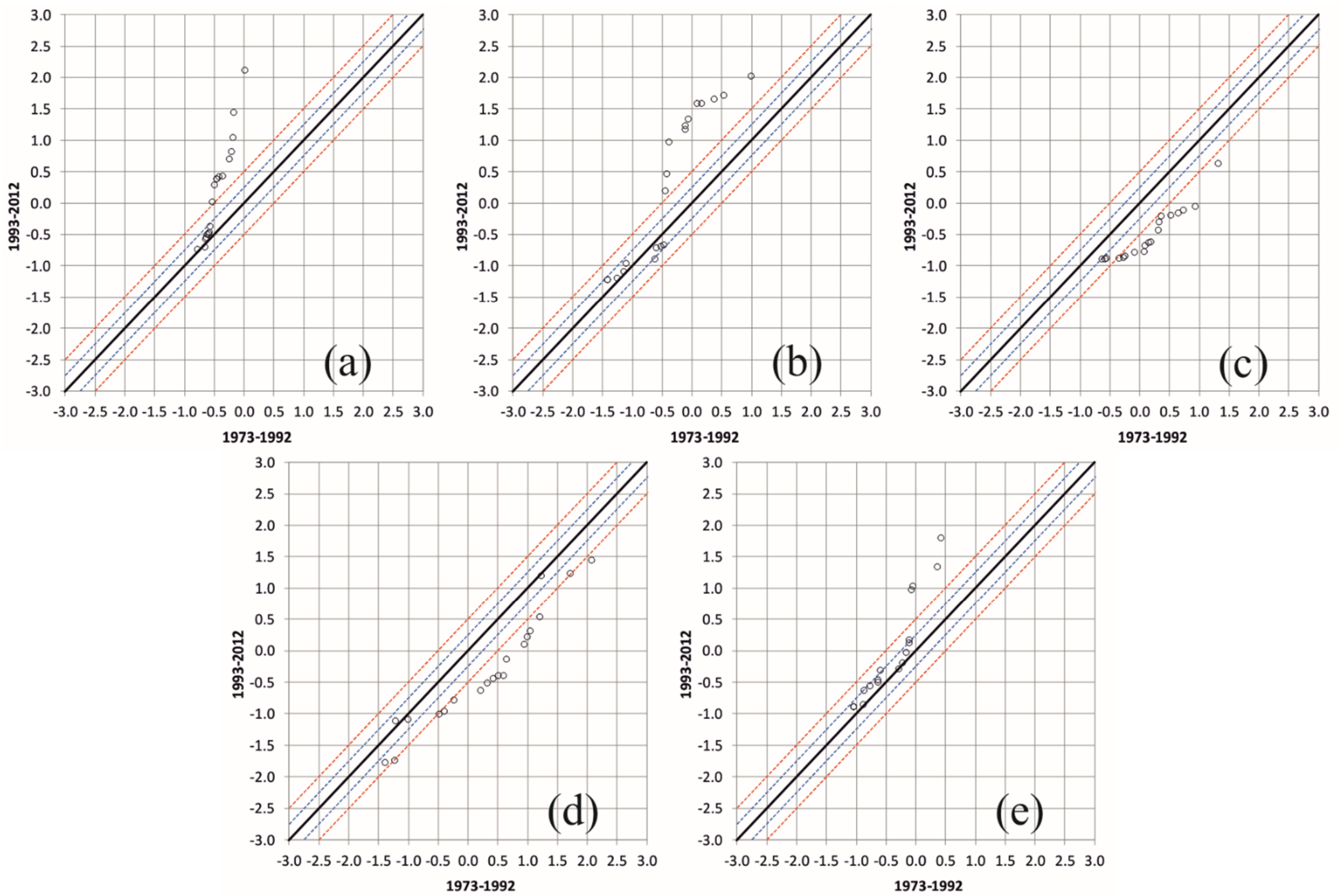

Figure 9. Results of the ITA applied to the annual runoff measured at the (**a**) Takhmaret, (**b**) Ain Hamara, (**c**) Sidi Abdelkader Djillali, (**d**) Oued Abtal, and (**e**) Kef Mehboula stations.

Figures 10–14 show the results of the ITA method on the monthly and seasonal scales. Regarding the Takhmaret station (Figure 10), a marked positive trend was identified from September to February but also in April and in May. This trend behavior was also identified at a seasonal scale, particularly in autumn and in winter and for the highest values, which significantly differ from the 1:1 ideal line.

Considering the Ain Hamara station (Figure 11), the application of the ITA method enabled the identification of monotonic increasing trends in September, October, and in November, which were particularly evident for the medium and highest values. Non-monotonic increases were found in December, January, and April while the opposite behavior was detected in March, June, and July. The seasonal trend behavior reflects the monthly one, with a monotonic increase and decrease in autumn and spring, respectively.

Regarding the Sidi Abdelkader Djillali station (Figure 12), monotonic increases were identified in September, November, and in August, especially for the highest values, while an opposite behavior characterized March and June, particularly in the medium values. At a seasonal timescale, negative trends were detected in spring (lowest values) and summer (highest values), a positive trend was detected in autumn for the medium values, and winter showed a trendless behavior.

For the Oued Abtal station, a monotonic decrease in the runoff values was evaluated from March to August (Figure 13). This trend is mainly due to the medium values. Regarding the other months, no relevant tendencies were observed, except for the highest values in September and in November that showed a positive trend. On a seasonal scale, a negative trend was detected in spring and summer, while a positive trend was identified in autumn.

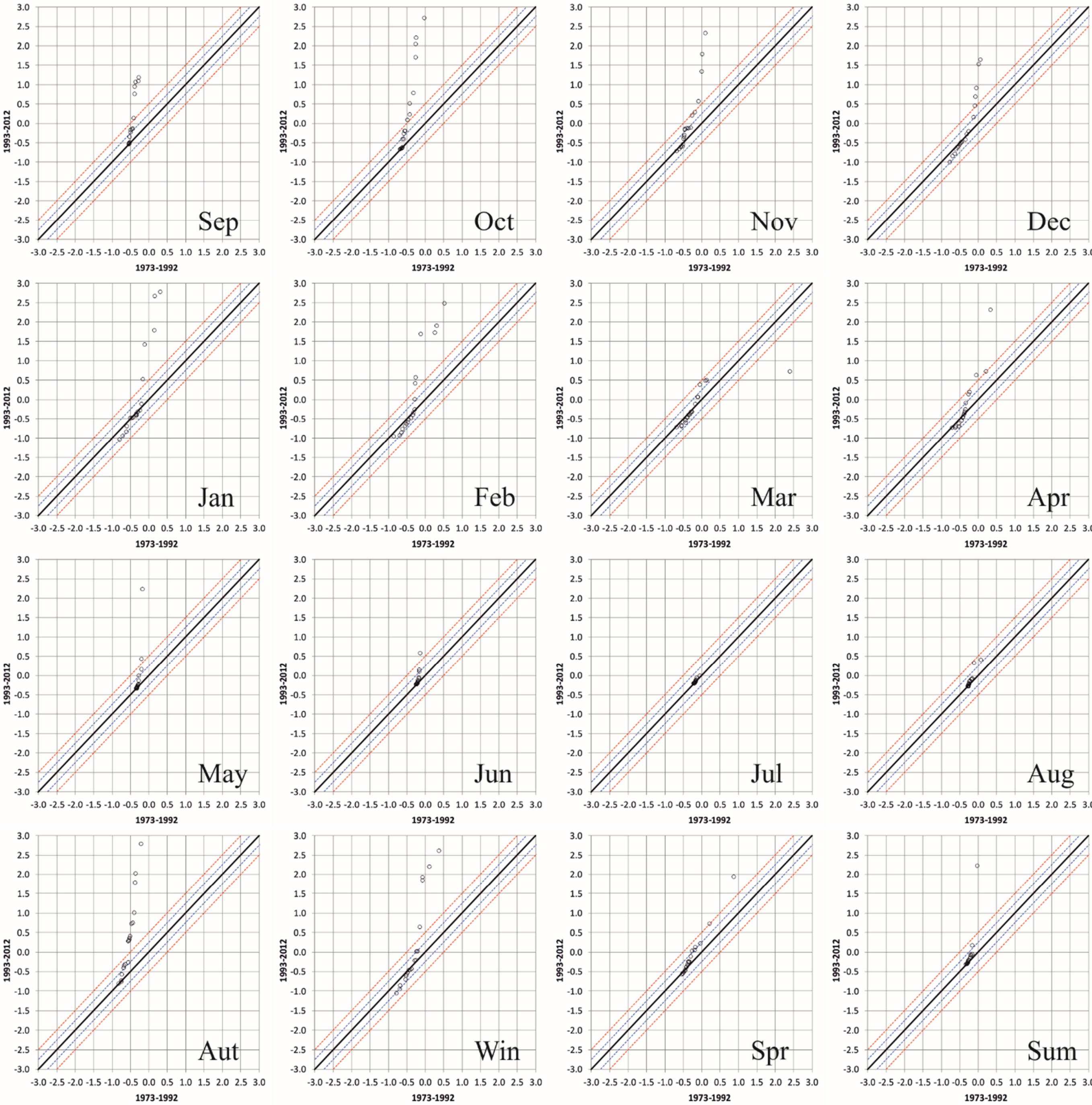

Figure 10. Results of the ITA applied to the monthly and seasonal runoff measured at the Takhmaret station.

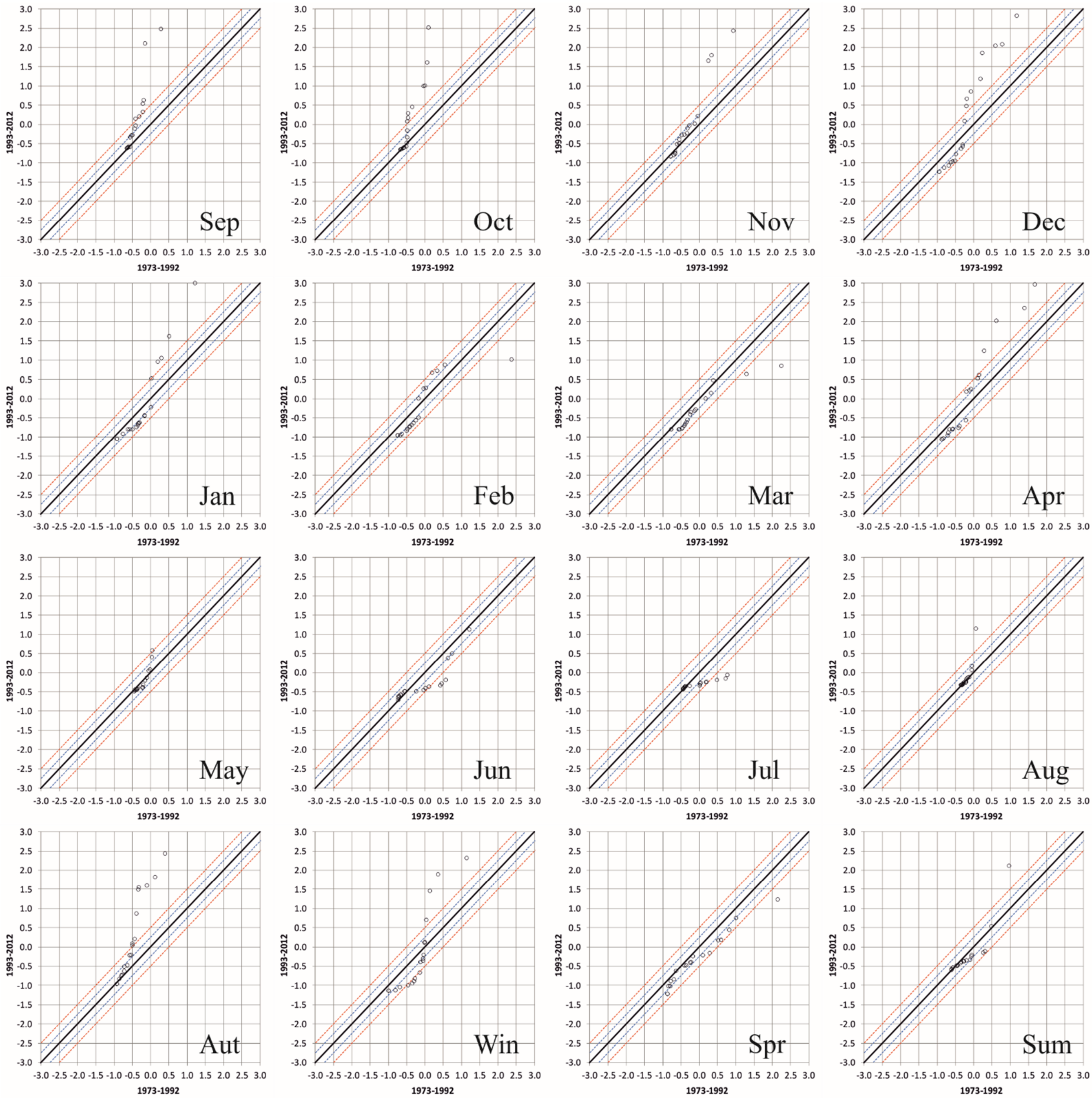

Figure 11. Results of the ITA applied to the monthly and seasonal runoff measured at the Ain Hamara station.

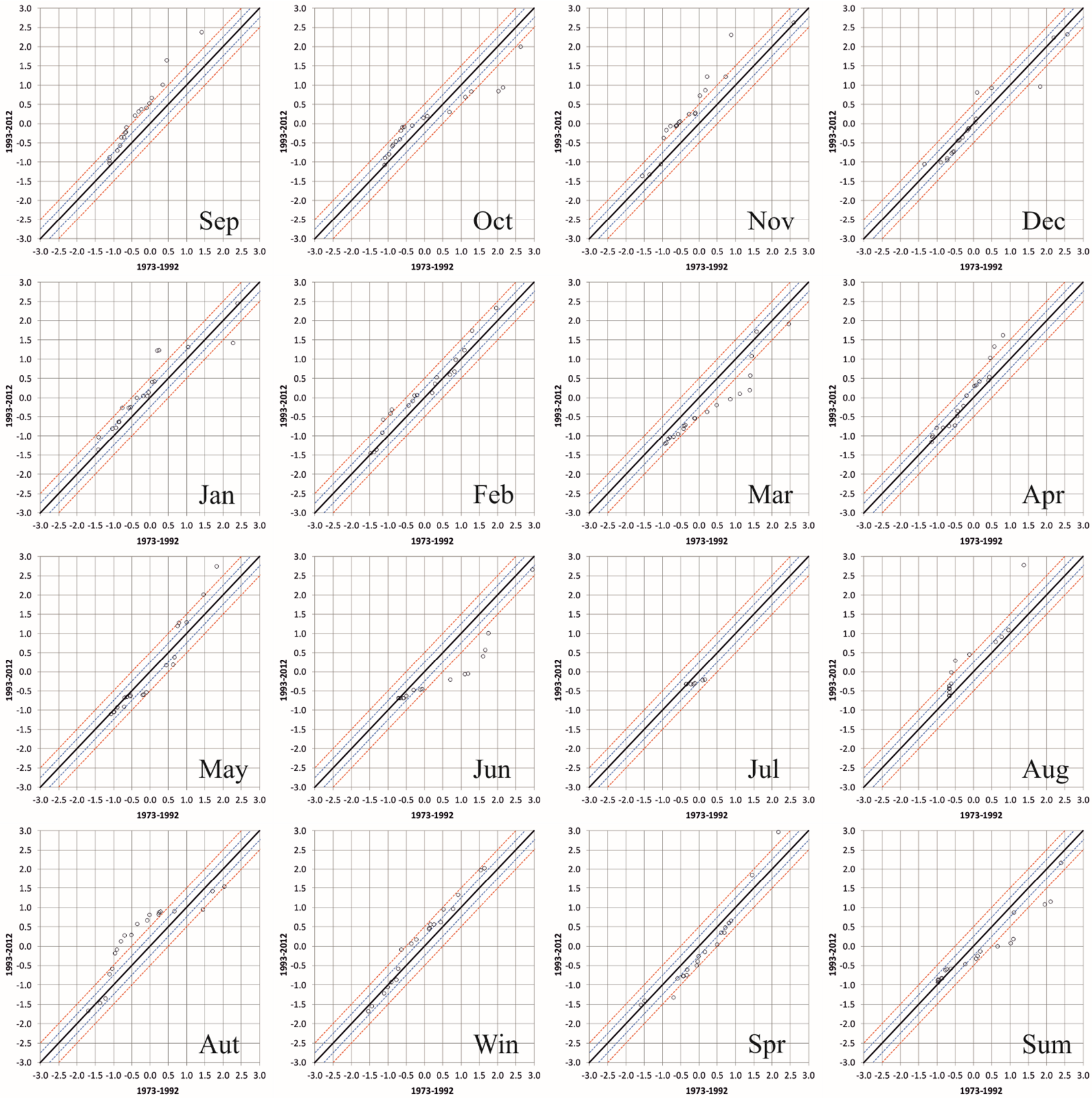

Figure 12. Results of the ITA applied to the monthly and seasonal runoff measured at the Sidi Abdelkader Djillali station.

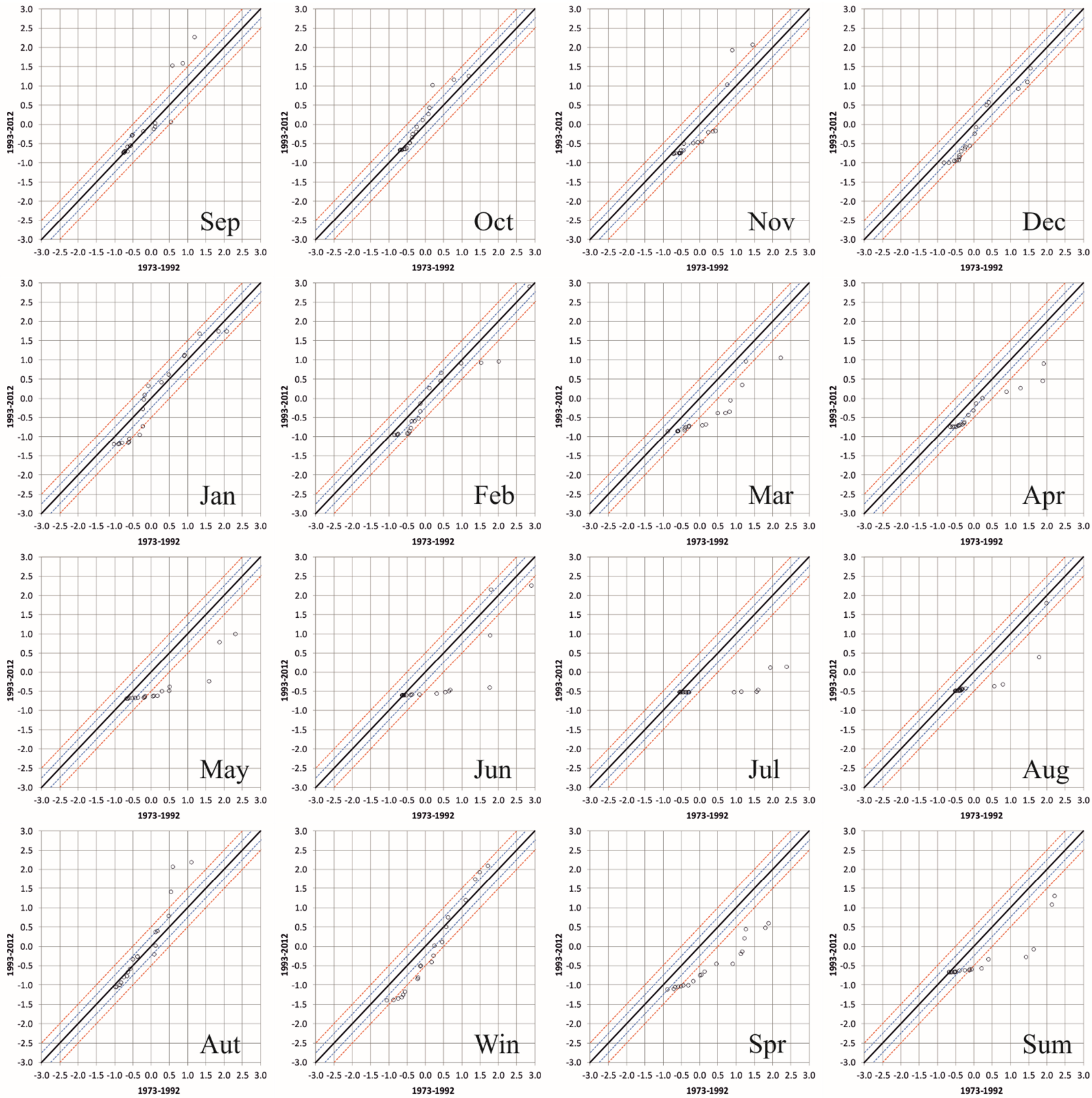

Figure 13. Results of the ITA applied to the monthly and seasonal runoff measured at the Oued Abtal station.

Finally, for the Kef Mehboula station (Figure 14) from September to December, in May, June, and during autumn and summer, a relevant positive tendency was observed and an opposite trend was detected in March, while the other periods seemed to show a trendless behavior.

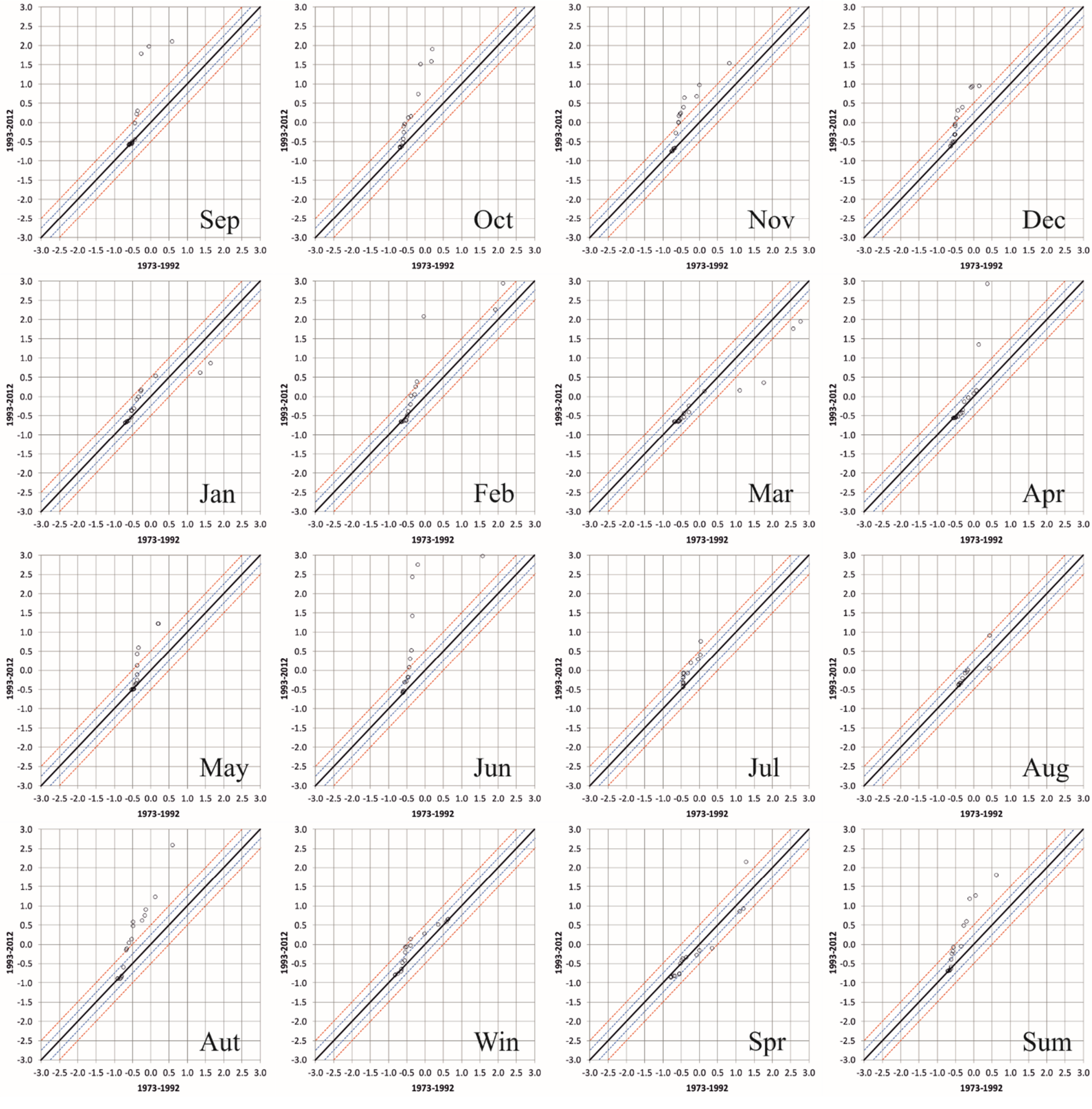

Figure 14. Results of the ITA applied to the monthly and seasonal runoff measured at the Kef Mehboula station.

4.3. Discussion

A large percentage of North Africa's agriculture depends on rainfall (i.e., rain-fed agriculture) and runoff (i.e., small reservoirs); thus, increasing or decreasing trends of these variables can either assist climate resilience and adaptation or badly affect it. The information on rainfall and runoff tendencies can be crucial for decision-makers concerned with effective crop planning and water resource management. Unfortunately, the main obstacle to a detailed rainfall and runoff trend analysis is the unavailability of an adequate long-term and spatially represented database [49]. In North Africa's semi-arid areas, measurements for large areas are unavailable at high intensities with spatial frequencies, a situation that renders low-quality data. Unlike the majority of the North African basins, in the Wadi Mina basin's monthly rainfall and runoff records, over a 40-year observation period (1973–2012), are available for five rainfall and hydrometric stations; thus, it was possible to detect the rainfall trend in the basin, and its impact on the runoff.

The rainfall reduction evidenced at the annual scale confirms some of the results obtained across the Mediterranean basin [2]. Nevertheless, to better understand this rainfall behavior, it could be useful to consider some of the climatic factors influencing rainfall in the Mediterranean area, such as the El Niño Southern Oscillation (ENSO) [50], the Mediterranean Oscillation (MO) [51], and the Western Mediterranean Oscillation (WeMO) [52]. For example, in Algeria, Meddi et al. [53] showed that the temporal variability of the annual precipitation in the west of the country is influenced by ENSO, while Tramblay et al. [11] demonstrated that the rainfall in North African countries such as Morocco, Algeria, and Tunisia is mainly affected by the North Atlantic Oscillation (NAO). In particular, a predominant negative phase of the NAO occurred between 1940 and 1980, corresponding to a period when precipitation was above normal; it was followed by a predominant positive phase, which significantly contributed to the rainfall reduction observed from the beginning of the 1980s in the Mediterranean basin and in Algeria as well. Moreover, some studies have forecasted a further increase in the positive phase of the NAO occurrence in the future [54,55].

The results of the trend analysis on the runoff data confirm past ones obtained in the Mediterranean basin and particularly in North Africa. Based on large-scale hydrological models, future decreases in water resources have been detected [56], as a consequence of a rainfall decrease forecasted for the southern Mediterranean region [57]. Recently, the impact of climate change on water resources in 46 basins of North Africa has been analyzed by Tramblay et al. [58], who evidenced a future decline in surface water resources given a combination of precipitation decreases and evapotranspiration increases.

The results obtained with the non-parametric tests have been compared with the ones obtained with the ITA method, which allowed for a more detailed analysis of the rainfall trends in terms of an evaluation of different values (low, medium, and high values). The results of the ITA method were slightly different from the previous ones, evidencing some positive trends in the runoff despite the decreasing rainfall, with a trend behavior described by some authors as the "Sahelian paradox" [22].

5. Conclusions

To evaluate the climatic trends in a semi-arid area, in this paper, five rainfall and runoff series of the Wadi Mina basin (Algeria) were analyzed. With this aim, first, a trend analysis was performed using the Theil–Sen estimator and the Mann–Kendall test. Then, the Innovative Trend Analysis technique was further applied. The following main results were obtained:

1. A marked negative trend at the annual scale in the Oued Abtal and the Kef Mehboula stations;
2. From a seasonal point of view, a negative trend was detected in spring (in four out of five stations), in winter for the Oued Abtal station, and in autumn for the Kef Mehboula station;
3. A general reduction in the annual runoff values in the Wadi Mina basin was identified, particularly in the Sidi Abdelkader Djillali and Oued Abtal stations;
4. On a seasonal scale, a negative trend was detected in all the seasons in the Sidi Abdelkader Djillali and Oued Abtal stations and in three out of four seasons for the Ain Hamara station.

The results of this study are particularly relevant because the evaluated trends showed a future reduction of the surface water resources in an area that is already facing water stress, thus evidencing that a strong strategy for adaptation is required together with reliable monitoring and forecasting systems for droughts.

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