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The Impact of Human Activities on Flood Trends in the Semi-Arid Climate of Cheliff Basin, Algeria

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Abstract—Algeria shares similarities with other countries of the world facing destructive floods. The need to understand changes in the intensity, frequency and severity of floods is critical for reducing significant social, economic, and environmental implications. In this study, flood indicators derived from annual maximum series and peak over threshold series were analyzed using Mann–Kendall trend analysis and linear regression analysis. Several studies in northern Algeria found decreasing trends of annual precipitation. However, precipitation could not explain most flood indicator trends found in our study. A general decreasing annual and seasonal trends of flood indicators were detected in the wadi Cheliff Basin. This result is partly due to decreasing precipitation and partly due to the construction of dams which have significantly altered flood processes. Increasing trends were found in the Mina Basin, which could be explained as the result of increases in urban area and decrease in soil moisture content before the occurrence of floods. Conversely, there was no dependency demonstrated between significant changes and spatial scales for these flood indicators. That is to say, human impacts and climate variability likely constitute the main factors causing increasing or decreasing flood trends.

Keywords: flood indicators, trend analysis, Cheliff Basin, human impacts

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INTRODUCTION

Floods affect all countries of the world but with very diverse frequency, severity, and outcomes. Each of these dynamics have major impacts on societies. The Dartmouth Flood Observatory reported 3713 flood events between 1985 and 2010, and relevant statistical data showed that 50.8% of the world's population was affected by flooding [4]. As noted by [11], precipitation-generated local flooding is expected to increase due to projected increases in the frequency of heavy rainfall. Rising economic losses have already been documented for the early 21st century and are expected to rise concomitantly with increased flooding. Given the magnitude and scope of flooding influence, it is therefore important to analyze its impact on the lives and health of the economy, as well as the environment. Policies to address this phenomenon are numerous and continue to multiply as the risk of flooding increases [27].

Large-scale changes in the complexity of river networks, often induced by accelerating urbanization near rivers, have increased the risk of floods [27, 45]. These changes can be effectively understood through time series analysis using non-stationary assumptions, an improvement over traditional flood frequency analysis. This approach is particularly effective when audited by the Mann-Kendall (MK) test [9, 18] and reflects a legitimate means for understanding river hydrology in light of climate change, thus demonstrating capacity as a management tool for avoiding human and economic disasters [27].

A growing number of studies that analyze trends in various hydrological variables, especially in connection with anticipated climate change, have received a great deal of attention [8]. Several examples within Chinese catchments are worth noting [17] found the runoffs of five typical watersheds showed increasing trends, though increasing trends of runoff were not significant for the north slope of the Kunlun Mountains or the south slope of the Altai Mountains. In Alaska, [3] analyzed trends for annual maximum streamflow and found that most systems are experiencing declines, whilst minimum flow trends are largely increasing. Over the 1950–2004 period, [19, 20, 23] found a significant decline in annual rainfall during the mid-1970s in the Macta Basin in northwest

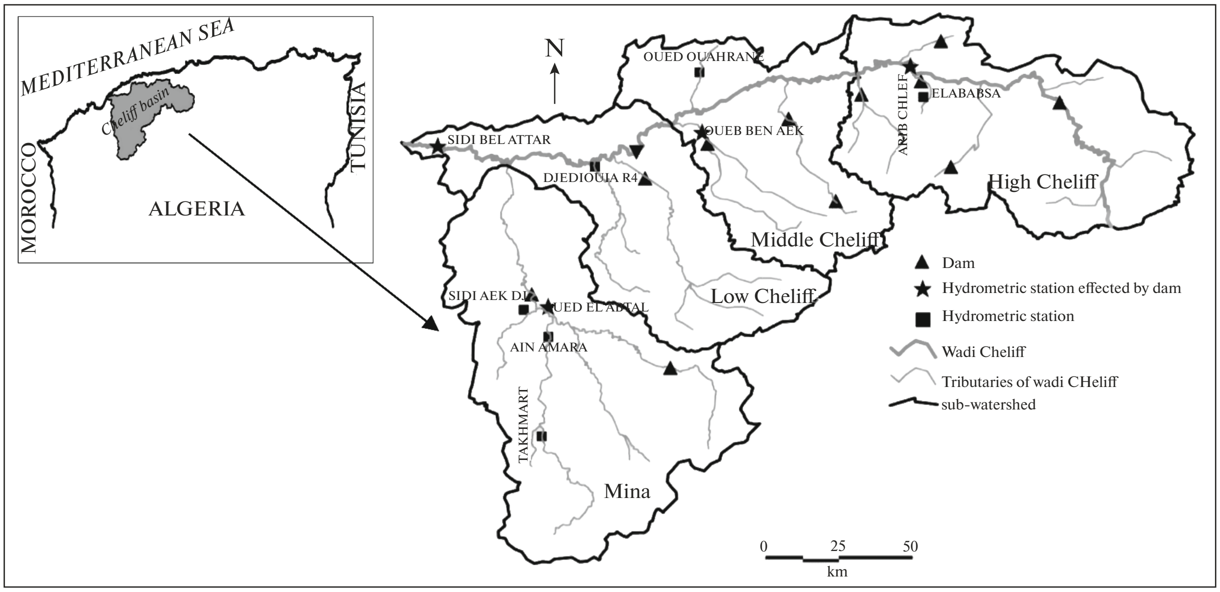

Fig. 1. Location of the analyzed hydrometric stations in the Cheliff basin (Low, Middle, High Cheliff, and Mina).

Algeria [12] found that annual maximum rainfalls over short durations provided important information in determining precipitation trends for long-term planning.

Other noteworthy locations have recently been the recipient of flood trend analyses [27] found a decreasing trend in the magnitude and timing of floods for 22% of alpine catchments. In Germany, [31] found significant flood trends for a large percentage of basins. Often, these trends were upward, while changes for winter compared to summer were spatially clustered. In Spain, [27] found a decreasing trend in magnitude and frequency of floods in the three periods 1942–2009, 1949–2009 and 1959–2009, with the more notable evidence for 1959–2009 even at seasonal scale, the trends are negative in winter, spring and summer. Additionally, an increasing trend in timing of floods was also found in the northwest of Spain.

Despite the proliferation of studies on climate change related trends in hydrological variables, little work has been done on fluctuations of hydrologic phenomena in Algeria. This paper reports on a study carried out in the wadi Cheliff basin (High, Middle, Low, and Mina). The study analyzed trends of fifteen flood indicators using observed daily flow series of ten hydrometric stations obtained from annual maximum, seasonal maximum and peaks-over-threshold (POT) for the period 1969–2009. Presently there are no studies on flood trends in Algeria. The main objective of this study was to addresses the behavior of flood trends in areas of Algeria where drought hazards are increasing in the last few decades. It is mainly interested in determining if there are coherent spatial patterns of flood trends across the study area during the last four decades.

METHODS AND DATA

Study Area

Located in northwestern Algeria, the Cheliff Basin has an area of 47269 km^2 and is drained by the longest wadi in Algeria, originating in the Tell Atlas and flowing into the Mediterranean (Wadi refers to an intermittent stream). The Cheliff Basin is bounded on the north by the coastal Dahra mountains, on the south by the High Plains, on the west by the Oranais basin, and on the east by the Algiers basin. It encompasses the four sub-basins of High Cheliff, Middle Cheliff, Lower Cheliff, and the Mina catchment (Fig. 1). Despite its proximity to the Mediterranean Sea, the climate of the Cheliff Basin is regulated by the barrier of the Dahra Mountins and is characterized by very hot summers and cold winters. Long summer drought periods range from three to four months in the north and five to six months in the High Plains. The hydrological regime of our watershed, the Chléff Basin, is similar to other Algerian basins in that it is characterized by pronounced low streamflow, in contrast to the important, yet turbulent, contribution of wadis during flood periods.

Daily discharge series were provided freely by the National Agency of Water Resources (NAWR) of Algiers, Blida, and Oran for the time series September 1969 to August 2009. Monthly rainfall shows great annual variability, increasing from west to east (300 to 500 mm/year) and south to north (100 to 900 mm/year) [22].

The Cheliff furrow is composed of numerous permeable geological formations containing groundwater, the oldest correspond to Jurassic age alluvium, while the most recent correspond to Quaternary allu-

Table 1. Characteristics of hydrometric stations included in the study

Station	Longitude, km	Latitude, km	Altitude, m	Surface, km^2
Arib Chlef	245	230	230	2.452
El Ababssa	444	318	320	102
Ouled Fares	368	327	140	262
O.B.AEK	373	302	95	1.225
Djediouia R	333	294	58	835
Takhmart	313	203	606	1.550
Ain Amara	316	335	288	2.480
Sidi AEK Dj	308	244	225	470
O. Elabtal	317	246	252	5.400
S. Belattar	279	301	43	43.700

Table 2. Flood indicators studied for 10 hydrometric stations

	Annual maximum daily mean streamflow (Maximum discharge for each hydrological year)	Peaks-Over-Threshold (Discharge peaks over threshold on average µ events per year)	Peaks-over-threshold frequency (Annual number of discharge peaks above threshold; on average µ events per year)
Annual (01.10–30.09)	$Q_{\max}$	$Q_{\mathrm{POT}\mu}$	$N\mu$
Autumn (01.10–31.12)	$AQ_{\max}$	$AQ_{\mathrm{POT}\mu}$	$AN\mu$
Winter (01.01–31.03)	$WQ_{\max}$	$WQ_{\mathrm{POT}\mu}$	$WN\mu$
Spring (01.04–31.06)	$PQ_{\max}$	$PQ_{\mathrm{POT}\mu}$	$PN\mu$
Summer (01.07–30.09)	$SQ_{\max}$	$SQ_{\mathrm{POT}\mu}$	$SN\mu$

vium. In the northern zone of the study, two Tellian chains exhibit mediocre resources and are largely unexploited due to accessibility and encasing by low permeability formations [22]. The Cheliff enters the Tellian chain where its meanderings are encased by steep slopes. The average altitude of our region of study varies between less than 300 m (under Cheliff Ouarizane and Mina downstream basins) to more than 900 m (under Oued Deurdeur and Oued Abd amont basins).The areas below 400 m in the Aval Boughzoul Basin correspond exclusively to the valleys drained by Middle and Lower Cheliff (the main tributary of Chliff Oued Mina) [28].

DATA

The catchment of the study area has a total of 19 hydrometric stations distributed more or less evenly, though this study is concerned with only ten for which representative and reliable data were available. It should be noted that four stations (Arib Chelif, O.B. AEK, Oued Elabtal, and Sidi Belattar) are affected by dams (Fig. 1; Table 1). The Sidi Belattar station is located at the mouth of the Chéliff Zahrez, the main river of the Wadi Chléff Basin, in order to understand its maximum flow rate with respect to the evolution of flow in its tributaries.

In the last 80 years, more than 17 large and small dams have been constructed within the Cheliff Basin, 12 of these dams were influential in this study.

Fifteen flood indicators, indicated in Table 2, are obtained for annual maximum ($Q_{\max}$), seasonal maximums (autumn, winter, spring, and summer), as well as Peaks-Over-Threshold series (Q_{POT}) for annual and seasonal number of discharge peaks above threshold. On average two events per year were noted (N_2). The largest independent flood events (Q_{POT1}) were retained, as were an additional series with on average two events per year for the POT time series (Q_{POT2}).

For the period 1969–2009 we selected the 82 largest independent flood events (POT_2). POT time series were obtained from daily flow series by checking the quality of the sample data and verifying satisfaction of conditions of independence, homogeneity, and stationarity [13]. Seasonal time series were derived from annual flood time series, thus annual spring maximum streamflow time series ($PQ_{\max}$) represents the largest daily mean discharge of the spring period of each year. POT time series was separated into four seasonal events. For example, the autumn time series (AQ_{POT2}) reflects discharge peaks above threshold on average two events per year. In addition, the series seasonal N_2, (e.g. WN_2) indicates the number of floods within the winter period. Subsequently, two events were selected per year.

METHODS

Mann–Kendall Test

In this study, we used the Mann–Kendall test, a robust non-parametric test commonly used to assess the significance of monotonic trends in climatological, meteorological and hydrological data time series [7, 10, 30, 39, 44, 43].

The test statistic *S*, can be calculated using Eqs. (1) and (2):

$$\operatorname{sgn}(xj - xi) = \begin{cases} 1, & \text{if } xj > xi \\ 0, & \text{if } xj = xi \\ -1, & \text{if } xj < xi, \end{cases} \qquad (1)$$

$$s = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\operatorname{sgn}(xj - xi). \qquad (2)$$

The variance is computed as:

$$\operatorname{var}(s) = \left[n(n-1)(2n+5) - \sum_{i=1}^{p} t_i(t_i - 1)(2t_i + 5)\right] \Big/ 18, \qquad (3)$$

where *p* is the number of the tied groups in the data set and t_i is the number of data points in the *i*th tied group. In cases where the sample size $n > 10$, the standard normal test statistic *Z* is computed as follows:

$$Zs = \begin{cases} \dfrac{s-1}{\sqrt{Var(s)}} & \text{if } s > 0 \\ 0 & \text{if } s = 0 \\ \dfrac{s+1}{\sqrt{Var(s)}} & \text{if } s < 0. \end{cases} \qquad (4)$$

Besides identifying the existence of a trend, it is also vital to determine trend magnitude. Trend magnitude β can be defined as follows [34]:

$$\beta = \operatorname{median}\left(\frac{X_j - X_i}{j - i}\right) \forall\ i < j, \qquad (5)$$

where β is the slope, denoting the magnitude of trends; $1 < i < j < n$, a positive value of β means an "upward trend"; a negative value of β denotes a "downward trend", MK test is as follows:

Null hypothesis H_0: $\beta = 0$.

The calculated standard *Z* value is compared with the standard normal distribution table with three-tailed confidence levels ($\alpha = 10\%$, $\alpha = 5\%$ and $\alpha = 1\%$).

Sampling Technique for POT

Several studies have been done in the past using long term annual maximum flood series ($Q_{\max}$) for mitigation and reduction of any kind of disasters. Recent studies have begun to consider Q_{POT} as an indicator of floods, while the maximum annual flow ($Q_{\max}$) is used as a flood indicator in almost all studies [31]. A Peaks-Over-Threshold (POT) series consists of all the peaks above a certain threshold level, whereas an annual maximum flood series contains only the maximum [1, 6, 29]. Given that POT method uses more information about floods, such as magnitude and frequency of events ($N\mu$), it has been argued that POT better reveals the temporal pattern of flood occurrence [15, 32, 36]. However, the technique of POT is more difficult to implement [13–16, 32, 33]. Although POT series improves an annual maximum series with a minimum of two events per year on average, (POT_2) [13].

Recent studies have begun to consider (Q_{POT}) as an indicator of floods while the maximum annual flow ($Q_{\max}$) is used as a flood indicator in almost all studies [31]. The Water Resources Council [42] imposes that successive flood events be separated by using Eqs. (6), while the intermediate flows between two consecutive peaks given by Eqs. (7) must drop below 75% of the lowest of these two flood events [13].

$$\theta > 5 \text{ days} + \log(A), \qquad (6)$$

$$Q_{\min} < \frac{3}{4}(Q_1, Q_2), \qquad (7)$$

where θ is the lag time between two consecutive peaks in days, *A* is the catchment area in km^2, and $Q_{\min}$ the minimum discharge between two successive peaks Q_1 and Q_2.

RESULTS

Spatial distribution of trends are indicated on maps using similar markers, where upward triangles indicate significant trends upward and downward triangles show significant decreasing trends. Dark colors match on all maps of important significance. Spatial results and trend analysis are discussed exemplarily for the stations Arib Chlef (impacted station) in the Middle Cheliff catchment and TAKHMART (natural station) in the Mina catchment (Fig. 1). Observed values and linear regression trends in the fifteen flood indicators given in Table 2 are illustrated in Fig. 2. Two general, opposite results were found—a downward trend in the Arib Chlef station and upward trend in the Takhmart station.

Consistency between the spatial distribution of flood trends throughout the catchment was examined for the last four decades. However, the trend analyzes for the four seasonal maximums and the annual maxima showed the same pace of results. The significance and magnitude of winter maximum in ARIB CHLEF station are very similar to annual maximum, while the increasing trend of TAKHMART station is not significant and the magnitude of their values are sometimes less important than summer maximum. A similar magnitude and significant trend comparing with annual maxima were showed in the spring maxima of TAKHMART station; however, spring maxima indicate the same level of significance than annual maximum though the magnitude is 10 times less than annual maximum in ARIB CHLEF station. In both stations, the significance level of spring maxima is stronger than autumn maxima, while the magnitude of spring maxima of ARIB CHLEF station is less important than autumn (unlike TAKHMART station).

Comparison of Results between Dam Affected Station (Arib Chlef) and Unaffected Station (Takhmart)

In the case of ARIB CHLEF station, summer maxima exhibited a decreasing, though not significant, trend. However, magnitudes are very comparable with autumn maxima. The Takhmart station showed an increasing trend of $SQ_{\max}$, significant at the 5% significance level, and having low magnitudes. Contrary to Q_{POT2}, the trends in Q_{POT1} are less significant than $Q_{\max}$ identified for both stations. Thus, a decrease in the threshold can be identified in the trend. The seasonal variation of discharge peaks-above-threshold, on average two events per year, indicates that in the Arib Chlef station no significant trend was recorded, with the exception of WQ_{POT2}, where the significance level equaled 1%. In Takhmart station, only SQ_{POT2} was not significant.

The N_2 time series of both stations show a different behavior where the trends of N_2 are upward and significant in Takhmart station; however, Arib Chlef station showed small decreases with no significant trend (Fig. 2). In both stations, we have found that the four seasonal separations of N_2 are not significant.

Spatial Distribution of Trends

Trends in Q_{max} and Q_{POT} at the Annual Scale

Analysis results showed at least one significant trend in the fifteen flood indicators.

The annual indicators floods Q_{POT2} and $Q_{\max}$ are more significant than Q_{POT1} among the ten stations studied, where 50% have significant trends, 40–60% of these significant trends are increasing (Fig. 3). A general downward trend in $Q_{\max}$ series was found for the three stations in the north Cheliff (Low, Middle and High) catchments. However, two increasing trends were detected in both stations, TAKHMART and Ain Amara, of the Mina catchment (Fig. 4).

A downward trend of Q_{POT2} showed in the north of Cheliff (Low, Middle, and High) catchments for the both stations Arib Chlef, Sidi Belattar. Three stations in the Mina catchment indicate a clear increasing trend (Fig. 4). Only one significant increasing trend was found for Q_{POT1} at station SIDI AEK DJ in the Mina catchments, in addition two downward tendencies were detected in ARIB CHLEF and O.B. AEK stations in the north Cheliff catchment (Fig. 4).

Trends in Q_{max} and Q_{POT} at the Seasonal Scale

Trends of flood indicators in each season were analyzed (Fig. 4). We found in autumn two decreasing tendencies were detected in the Cheliff catchments and only one increasing in Mina catchment of the $AQ_{\max}$ series (Fig. 4). However, a clearer pattern of increasing trends was found in the Mina catchment for AQ_{POT2}, while in Cheliff catchment no trend was recorded (Fig. 4). In winter, only two upward tendencies for WQ_{POT2} were found in Mina catchments with three stations downward in the Cheliff catchment (Fig. 4). This pattern becomes clearer for $WQ_{\max}$, where six of ten stations exhibited significant decreasing trends (Fig. 4). In spring, decreasing trends were found for the $PQ_{\max}$ series, mainly in the northwestern of Cheliff and north of Mina catchment, with only increase in the south of Mina catchment (Fig. 4). The PQ_{POT2} series showed only decreasing trend in the north-western of Cheliff catchment and one upward trend in the southern Mina catchment (Fig. 4). In summer (Fig. 4) no evidence of trends was found in the Cheliff catchment for SQ_{POT2}, only AIN AMARA station indicated increasing trend within the Mina catchment. However, for $SQ_{\max}$ two upward trends were found in Mina catchment and a stronger decreasing trend of Ouled Fares station in Cheliff catchment (Fig. 4).

Trends in Number of Floods N_2 Annual and Seasonal

A trend analysis of the N_2 series was performed using the POT2 series. Figure 4 indicates that no significance of trends was found as only one up trend was detected in Mina catchment at Takhmart station, and two down trends in the north of Cheliff catchment. A general no trend pattern was detected in seasonal frequency of flood events exactly in autumn. However, in spring two decreasing trends for PN_2 was found in the

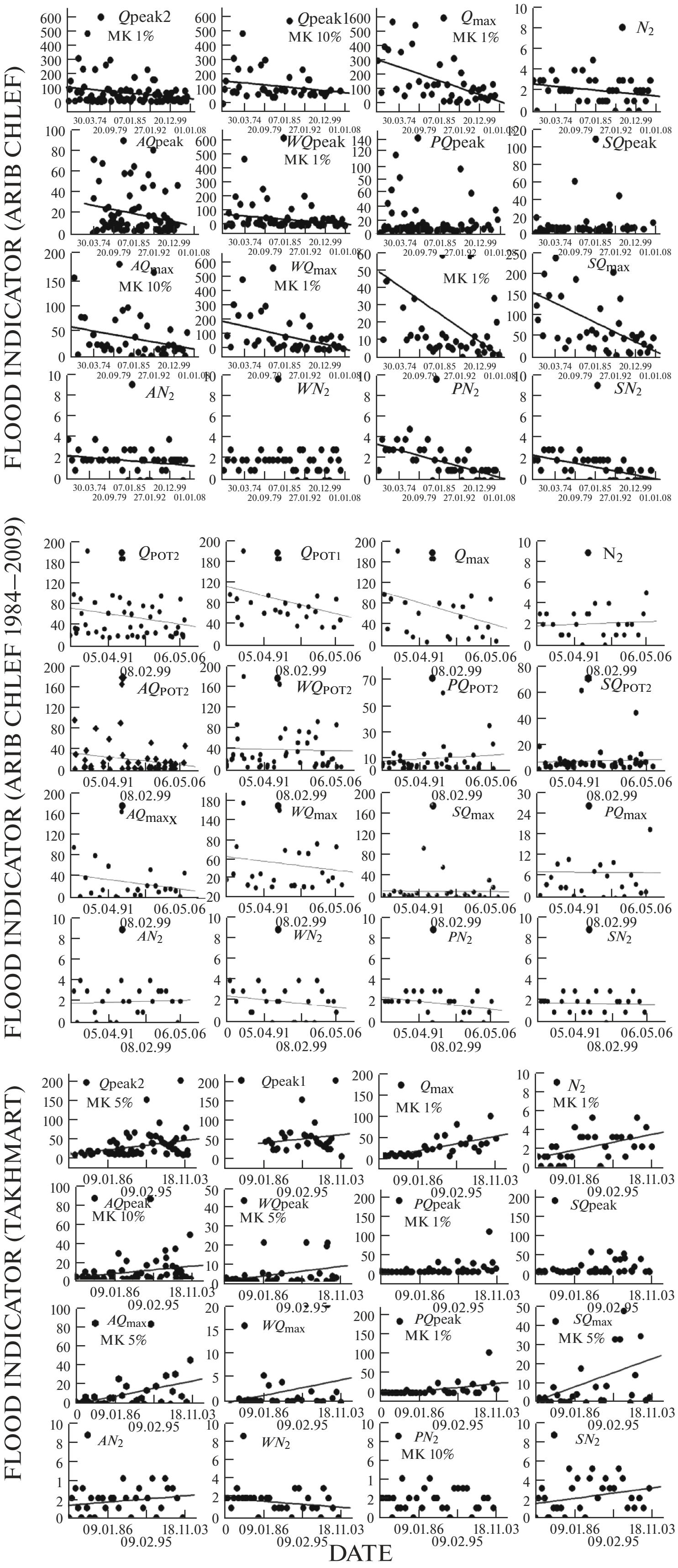

Fig. 2. Linear regression trends in the flood indicators (Table 2) of TAKHMART and ARIB CHLEF station (before and after the realization of the two dams at the upstream).

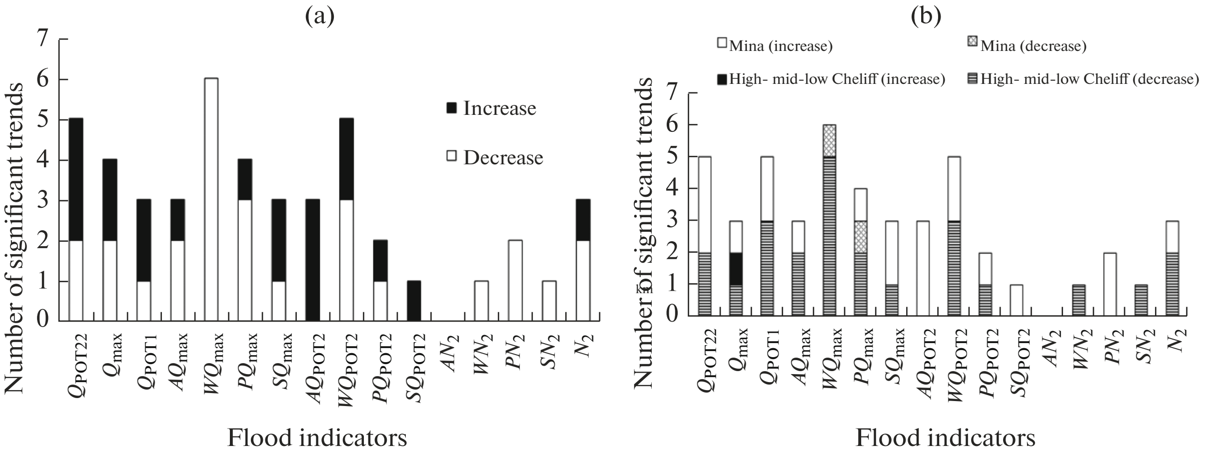

Fig. 3. Number of significant trends in (a) the both basins together, (b) the both basins separated.

south of Mina catchment, while in winter and in summer only decreasing trends were shown in the north of Cheliff catchment (Fig. 4).

Localization Patterns and the Change in Their Magnitude, as Function the Catchment Area

Figure 3 includes the results for the fifteen series of studies. Changes in flood behavior was detected for different levels of significance (10, 5, 1%) for $Q_{\max}$, $WQ_{\max}$, Q_{POT2} and WQ_{POT2}. In all three cases of $Q_{\max}$, Q_{POT2}, and WQ_{POT2}, upward trends are located in the Mina catchment and downward trends in Cheliff (Low, Middle, and High) catchment. However, in both catchments, $WQ_{\max}$ showed decreasing trends. No trend significance could be found of increasing trends for the seasonal flood indicators (AN_2, WN_2, PN_2, SN_2).

At last, we examined the dependency of change in trends of each flood indicators using the slope (β), according to the size of catchment areas. To this end, slope magnitude of significant and not significant trends in each indicator flood were performed according to the basin area (Fig. 5).

DISCUSSION

Analysis of trends in fifteen flood indicators for 10 stations across the Cheliff Basin (High, Middle, Low, and Mina) give a number of interesting results. First, a relatively noticeable trend has been observed in most of the flood indicators in all the stations selected in this work of the last four decades. The spatial and seasonal patterns for different flood indicators showing emerging trend differences was affirmed after looking relationship with a field. Second, the distributions of stations with increasing and decreasing trends of flood indicators are spatially grouped. Relative flood behaviors are a downward change in north of Cheliff catchment (Low, Middle, and High), while the most changes of increasing trends appeared in the Mina catchment. Third, large shares of significant trends in $Q_{\max}$, $WQ_{\max}$, Q_{POT2}, and WQ_{POT2} were found for about 50% of the surveyed station in our basin. Only decreasing trends were showed to be field-significant in $WQ_{\max}$ for 60% of examined hydrometric stations (Fig. 4).

In general, the results of annual flood indicators agree with seasonal flood indicators carried out previously where a clear increasing trend was found in Q_{POT2} in Mina catchment, which is consistent with the results of AQ_{POT2} shown in the same basin. A stronger proportion of significant down trends were showed in $WQ_{\max}$ in the northwestern of Cheliff basin. these latter are suitable with obtained for $Q_{\max}$ in the north of Cheliff catchment (shown in Fig. 4), while increasing trends found in $Q_{\max}$ of the Mina catchment can be attributed to trends in the autumn, spring, and summer season (Fig. 4). Further, the frequency of floods (N_2) is not significant at many stations, especially along the main wadi Chlef. Only two significant decreasing trends were shown for Cheliff catchment (Low, Middle, and High), and only one increasing trend in TAKHMART station of Mina catchment, which is visible in seasonal N_2. Only decreasing frequency in both seasons of winter and summer were shown in Cheliff catchment, and two decreasing in the Mina catchment. No significant trend was found in autumn (Fig. 4).

At the Arib Chlef station, located in the upstream region of the wadi Cheliff, flood indicators demonstrated a decreasing trend over the past 40 years (Fig. 2). These can be understood through the presence of three dams, one constructed in 1939 on the wadi Cheliff, and two constructed in 1984 on tributaries of wadi Cheliff near the upstream Arib Chlef station (Fig. 1). The average annual runoff volume of the

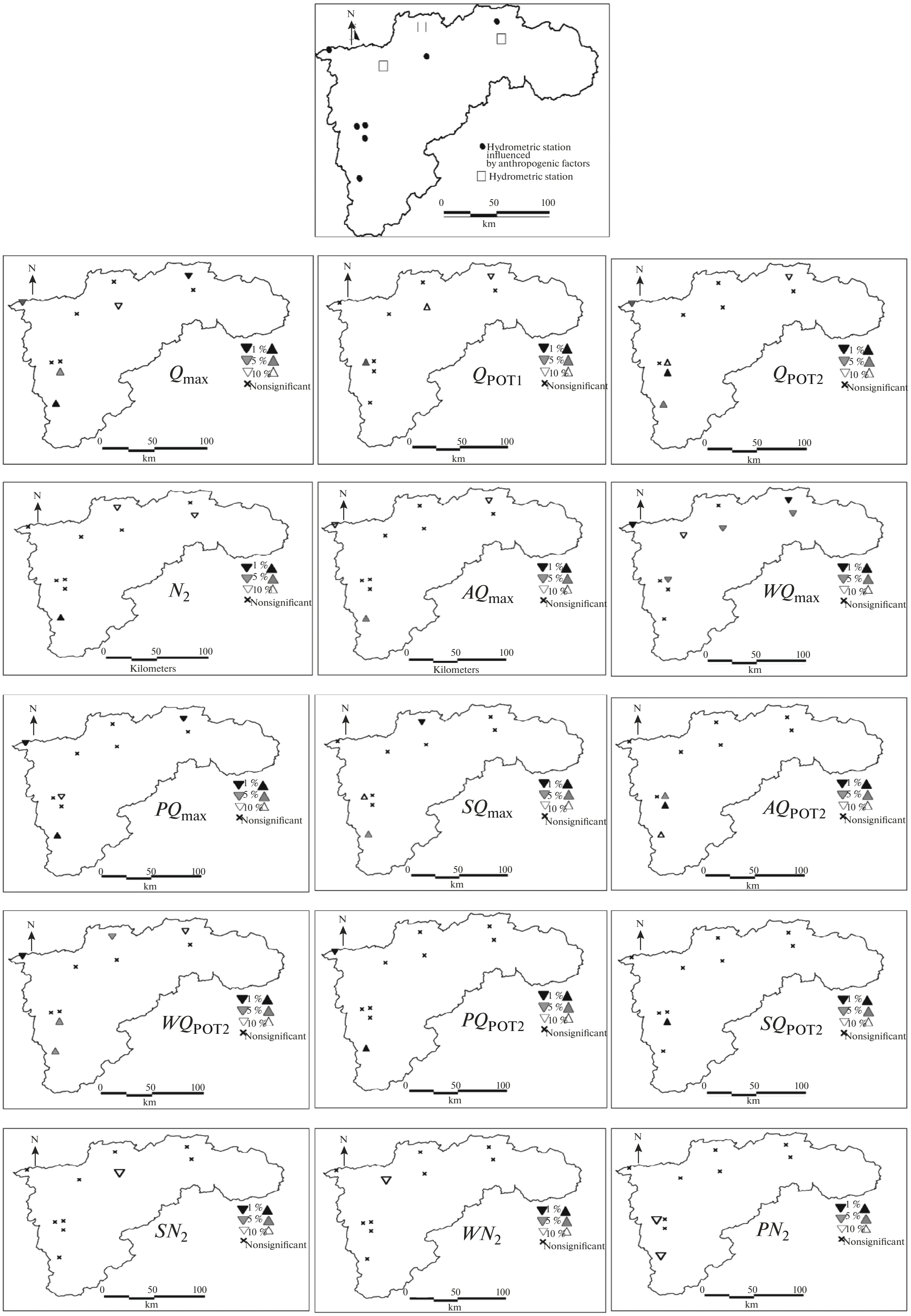

Fig. 4. Trends in annual and the seasonal of maximum and peak-over-threshold and peak-over-threshold frequency of discharge series with Mann–Kendall test (affected or not affected by anthropogenic factors) in the Cheliff basin.

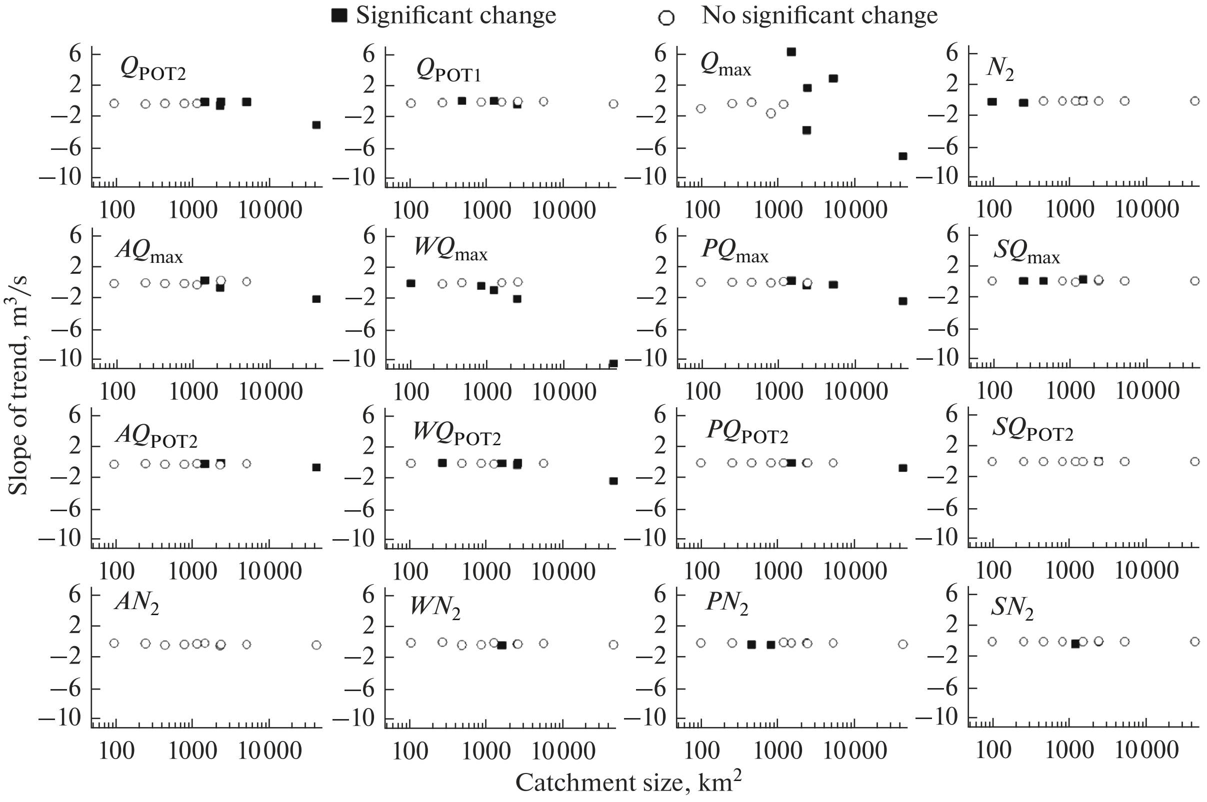

Fig. 5. Change in trends as function of basin area using the slope (β, m^3/s).

latter two dams is 21.84 × 10^6 m^3, representing only 2.5% of the Cheliff average annual runoff volume.

In contrast, over the second period (1984–2009), these indicators showed slight decreasing trends that are not significant at the 10% significance level (Fig. 2). The flood indicators of Sidi Belattar station show a strong decreasing trend (Fig. 2). This trend is significant at the 99% confidence level. This result is due to the presence of 12 reservoirs (Fig. 1), which represents 69.27% of the annual runoff recorded in Cheliff basin. It should be noted that further dams are under construction, but were not counted in this study. Also, there are gaps in the record for the O.B. AEK station for the observation period 1986–2009, and the Sidi Yakoub dam was completed in 1986.

For the Mina catchment, the observation period of Oued Elabtal station is 1969 to 2009, while the downstream reach is influenced by a dam constructed in 1936. Generally, the trends in all flood indicators of these stations are not significant. The northwestern and central plains of Algeria were particularly affected by drought during the period 1930–2007, resulting in significant decrease of precipitation and water resources with severe damages to crops recorded in 1981 and 1989 in the Cheliff plain [21–25].

Thus, our results of decreasing trends, especially in the north of Cheliff catchment, is in part due to decreasing precipitation and partially, directly or indirectly, caused by the addition of reservoirs. These issues cannot be ignored when considering variations in indicators floods. As noted by [2], the construction of dams leads to reduced sediment discharge and increased vegetation coverage and farmland area that result in increased interception and soil moisture capacity.

These conditions ultimately result in a decrease in the direct runoff and peak discharge and, for our study, all flood indicators in the north of Cheliff catchment. Studies on the temporal variability of daily and extreme rain in Algeria show that application of the Mann–Kendall test indicates a general downward trend that is significant for total rains. The frequency of heavy rainfall shows no significant change in its temporal evolution for the majority of the studied stations, although the root cause of most flooding is the arrival of heavy rainfall [38].

The significant increasing trend of flood indicators, and decreasing trends of annual precipitation found in the Mina catchment, may be a response to population increases and subsequent increase in urban area. Indeed, land degradation attributed to a decrease in surface cover and increased erosion was shown in the Mina basin [40, 41]. According to ABHCZ (Chlef Zarhrez river basin agency), there were 340 373 inhabitants in 2000. This population has grown to 427 287 inhabitants in 2010 and is projected to reach 895 271 inhabitants by 2020. Specifically, population growth rate reached 4.9%, resulting in land degradation evidenced by decreased vegetation cover of 856 km^2 between 1987 and 2009.

Results indicate that no scale-dependency can be observed, where the magnitude (slopes) and significant trends are not concentrated with a spatial scale. The observed changes in flood behavior are climate-driven and human activities have become more and more extensive in the Cheliff basin during the last four decades. In general, these results agree with the findings of similar studies conducted in Europe, where a mixture of flood generating mechanisms was demonstrated [26]. In this case, five geographically distinct, large-scale homogeneous regions across the Mediterranean region were examined. In Spain, [27] found a clear decreasing trend in the annual winter maximum streamflow ($WQ_{\max}$). Similar to our findings on significant increasing trends in the indicators flood for the Mina catchment, their results were attributed to urban land development. These results are also in agreement with those obtained by [5] in Italy, especially in coastal locations in the Mediterranean during the period 1833–2013. As noted, the construction of dams leads to reduced sediment discharge and an increase in vegetation coverage and farmland area, resulting in a decrease in direct runoff and peak discharge and all flood indicators. [35] found evidence of this for dammed catchments constructed in floodplains in Morocco and the lower Senegal River in West Africa [37], [31] found that significant changes are not concentrated within spatial scales in Germany.

CONCLUSIONS

An examination of trends in amplitude and frequency of floods was carried out for 10 hydrometric stations of the Cheliff basin (low, middle, high, Mina) for fifteen flood indicators for the period 1969–2009. These trends are spatially clustered, where decreasing flood trends are located in the north of Cheliff catchment, and increasing trends found in the Mina catchment. Analysis of the results showed the highest seasonal changes occurred more in the winter than other seasons, followed in succession by autumn, spring, then summer. generally speaking downward trend in annual winter maximum series ($WQ_{\max}$) was obtained in the Cheliff catchment, especially in the north of the basin where the stations are affected by existents dams. Decreasing flood trends were rarely found and were not field-significant in the frequency (N_2) of flood events found at the annual and seasonal scale. The hydrometric stations exhibited different patterns of change in their values of annual and seasonal flood indicators. During the last decade, several studies found decreasing trends of annual precipitation in northern Algeria. In addition, slightly decreasing trends for flood indicators were shown in the north of the Cheliff catchment, particularly for stations affected by dams where the beginning of the flood series is after the dam construction. This result is partly due to decreasing precipitation and partly due to the presence of several dams in the north of the Cheliff basin (Low, Middle, and High Cheliff).

These led to increased interception and soil moisture capacity due to increasing vegetation coverage and farmland area, resulting in decreased streamflow and related flood indicators. Additionally, this study showed significant positive trends in flood indicators for the Mina catchment, which may be a response to increases in urban area and subsequent increased erosion due to loss in vegetation surface cover. This study indicates that precipitation alone could not explain most flood indicators trends. That is to say, climate variability and human activities were the main driving factor for changing (increasing or decreasing) flood trends.

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REFERENCES

1. Assani, A.A., Recherche d'impacts d'une retenue sur le comportement d'une rivière ardennaise (Hydrologie sédimentologie morphologie et végétation); cas du barrage de Butchenbach sur la Warche (Belgique), *PhD Thesis*, Liège, Belgium: Univ. Liège., 1997.
2. Bao, Z., Zhang, J., and Wang G., Attribution for decreasing streamflow of the Haihe River basin northern China: Climate variability or human activities?, *J. Hydrol.*, 2012, vol. 460–461, pp. 117–129.
3. Bennett, K.E., Cannon, A.J., and Hinzman, L., Historical trends and extremes in boreal Alaska river basin, *J. Hydrol.*, 2015, vol. 527, pp. 590–607.
4. *Community Surface Dynamics Modeling System*. http://csdms.colorado.edu.
5. Faccini, F., Luino, F., and Sacchini, A., Flash flood events and urban development in Genoa (Italy): Lost in translation, *Engineering Geol. Soc. Territory*, 2015, vol. 5, pp. 797–802.
6. Guru, N. and Jha, R., Flood frequency analysis of Tel Basin of Mahanadi River System, India using annual maximum and POT flood data, *Aquatic Procedia*, 2015, vol. 4, pp. 427–434.

7. Haktanir, T., Bajabaa, S., and Masoud, M., Stochastic analyses of maximum daily rainfall series recorded at two stations across the Mediterranean Sea, *Arabian J. Geosci.,* 2012. https://doi.org/10.1007/s12517-012-0652-0
8. Hamed, K.H., Trend detection in hydrologic data: The Mann–Kendall trend test under the scaling hypothesis, *J. Hydrol.*, 2008, vol. 349, pp. 350–363.
9. Kendall, M.G., *Rank Correlation Methods*, Griffin: London, 1975.
10. Kisi, O. and Ay, M., Comparison of Mann–Kendall and innovative trend method for water quality parameters of the Kizilirmak River, Turkey, *J. Hydrol.*, 2014, vol. 513, pp. 362–375.
11. Kundzewicz, Z.W., Kanae, S., Seneviratne, S.I, et al., Flood risk and climate change: global and regional perspectives, *Hydrol. Sci. J.*, 2014, vol. 59, pp. 1–28.
12. Kuoa, Y.M., Chub, H.J., Panc, T.Y., and Yud, H.L., Investigating common trends of annual maximum rainfalls during heavy rainfall events in southern Taiwan, *J. Hydrol.*, 2011, vol. 409, pp. 749–758.
13. Lang, M., Ouarda, T.B.M.J., Band obee, B., Towards operational guidelines for over-threshold modeling, *J. Hydrol.*, 1999, vol. 225, pp. 103–117.
14. Lang, M., Analyse probabiliste des crues pour la prévention du risque d'inondation. Habilitation à diriger des recherches, *Institut polytechnique de Grenoble*, 2000.
15. Lang, M., *Les chroniques en hydrologie: Modélisation comparée par un système de gestion de bases de données relationnel et orienté-objet. Traitements de base et intervalles de confiance des quantiles de crues. Techniques d'échantillonnage par la méthode du renouvellement [Mémoire de thèse]*, Grenoble, France: Univ. Joseph Fourier, 1995.
16. Lang, M. and Renard, B., Analyse régionale sur les extrêmes hydrométriques en France: détection de changements cohérents et recherche de causalité hydrologique. *La Houille Blanche*, 2007, vol. 06, pp. 83–100.
17. Li, B., Chen, Y., Chen, Z., and Li, W., Trends in runoff versus climate change in typical rivers in the arid region of northwest China, *Qua. Int.*, 2012, vol. 282, pp. 87–95.
18. Mann, H.B., Nonparametric tests against trend, *Econometrica*,1945, vol. 13, pp. 245–259.
19. Meddi, M. and Talia, A., Runoff evolution in Macta basin (Northwest of Algeria), *Arab. J. Geosci.,* 2013, vol. 6, pp. 35–41.
20. Meddi, M. and Hubert, P., Impact de la modification du régime pluviométrique sur les ressources en eau du nord-ouest de l'Algérie, Hydrology of the Mediterranean and semiarid Regions, *IAHS*, 2003, vol. 278, pp. 1–7.
21. Meddi, H., Meddi, M.A., and Assani, A., Study of Drought in Seven Algerian Plains, *Arab. J. Sci. Eng.,* 2014, vol. 39, pp. 339–359.
22. Meddi, H. and Meddi, M., Variabilité des précipitations annuelles du Nord-Ouest de l'Algérie, *Sécheresse*, 2009, vol. 20, no. 1, pp. 57–65.
23. Meddi, M., Arkamose Assani, A., and Meddi, H., Temporal Variability of Annual Rainfall in the Macta and Tafna Catchments, Northwestern Algeria, *Water Resour. Manage.*, 2010, vol. 24, pp. 3817–3833.
24. Meddi, M. and Boucefiane, A., Impacte des changements climatique sur le renouvellement des ressources en eau souterraines: Cas du Bassin Hydrographique Cheliff-Zahrez, *IAHS-AISH publication*, 2009, pp. 135–142.
25. Meddi, M., Toumi, S., and Assani, A.A., Application of the L-moments approach to the analysis of regional flood frequency in Northern Algeria, *Int. J. Hydrol. Sci. Techn.*, 2017, vol. 7, no. 1, pp. 77–102.
26. Mediero, L., Kjeldsen, T.R., Macdonald, N., et al., Identification of coherent flood regions across Europe by using the longest streamflow records, *J. Hydrol.*, 2015, vol. 528, pp. 341–360.
27. Mediero, L., Santillán, D., Garrote, L., and Granados, A., Detection and attribution of trends in magnitude frequency and timing of floods in Spain, *J. Hydrol.*, 2014, vol. 517, pp. 1072–1088.
28. Mehaiguene, M., Bilan hydrologique et ressources en eau de surface du bassin Cheliff-Zahrez, *Mémoire de thèse*, Chlef, Algerie, Université Hassiba Ben Bouali., 2005.
29. Önöz, B. and Bayazit, M., Effect of the occurrence process of the peaks over threshold on the flood estimates, *J. Hydrol.,* 2001, vol. 244, pp. 86–96.
30. Onoz, B. and Bayazit, M., The power of statistical tests for trend detection, *Turk. J. Eng. Environ. Sci.,* 2003, vol. 27, pp. 247–251.
31. Petrow, T. and Merz, B., Trends in flood magnitude frequency and seasonality in Germany in the period 1951–2002, *J. Hydrol.*, 2009, vol. 371, pp. 129–141.
32. Renard, B., Lang, M., Bois, P., et al., Évolution des extrêmes hydrométriques en France à partir de données observées, *La Houille Blanche*, 2006, vol. 6, pp. 48–54.
33. Rosbjerg, D. and Madsen, H., Advanced approaches in PDS/POT modelling of extreme hydrological events, in *Hydrology, Sci. Practice for the 21st Century*, Proceedings British Hydrological Society, 2004.
34. Sen, P.K., Estimates of the regression coefficient based on Kendall's Tau, *J. Am. Stat. Assoc.*, 1968, vol. 63, no. 324, pp. 1379–1389.
35. Snoussi, M., Kitheka, J., Shaghude, Y., et al., Downstream and Coastal Impacts of Damming and Water Abstraction in Africa, *Environ. Manage.*, 2007, vol. 39, pp. 587–600.
36. Svensson, C., Hannaford, J., Kundzewicz, Z., et al., Trends in river flows: why is there no clear signal in observations? in Frontiers in Flood Research, *IAHS Pub.*, 2006, vol. 305, pp. 1–18.
37. Svensson, C., Kundzewicz, Z.W., and Maurer, Th., Trend detection in river flow series: 2 flood and lowflow index series, *Hydrol. Sci. J.*, 2005, vol. 50, no. 5, pp. 811–824.
38. Taibi, S., Meddi, M., and Mahé, G., Evolution des pluies extrêmes dans le bassin du Cheliff (Algérie) au cours des 40 dernières années 1971–2010, *Proc. Int. Association of Hydrol. Sci.*, 2015, vol. 369, pp. 175–180.
39. Topaloglu, F., Irvem, A., and Ozfidaner, M., Re-evaluation of trends in annual streamflows of Turkish rivers for the period 1968–2007, *Fresenius Environ. Bull.*, 2012, vol. 21, no. 8, pp. 2043–2050.

40. Touaibia, B. and Achite, M., Contribution à la cartographie de l'érosion spécifique du bassin versant de l'Oued Mina en zone semi-aride de l'Algérie septentrionale, *J. des Sci. Hydrol.*, 2003, vol. 48, no. 2, pp. 235–242.
41. Toumi, S., Meddi, M., Mahé, G. et al., Cartographie de l'érosion dans le bassin versant de l'Oued Mina en Algérie par télédétection et SIG, *Hydro. Sci. J.*, 2013, vol. 58, no. 7, pp. 1–17.
42. USWRC, *Guidelines for determining flood flow frequency*, United States Water Resources Council Bull., 17 Hydrol. Comm., Washington DC., 1976.
43. Yue, S., Pilon, P., and Caradias, G., Power of the Mann–Kendall and Spearman's rho tests for detecting monotonic trends in hydrological series, *J. Hydrol.*, 2002, vol. 259, nos. 1–4, pp. 254–271.
44. Yue, S. and Pilon, P., A comparison of the power of the *t* test, Mann–Kendall and bootstrap tests for trend detection, *Hydrol. Sci. J.,* 2004, vol. 49, no. 1, pp. 21–37.
45. Zhang, S., Guoc, Y., and Wangd, Z., Correlation between flood frequency and geomorphologic complexity of rivers network—A case study of Hangzhou China, *J. Hydrol.,* 2015, vol. 527, pp. 113–118.