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Analysis of precipitation and drought trends by a modified Mann–Kendall method: a case study of Lorestan province, Iran

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ABSTRACT

In this study, to evaluate the trend of precipitation change, the Mann–Kendall method has been used. The studied area is Lorestan province located in the western part of Iran. To achieve this goal, time series of annual and monthly rainfall data were collected for different statistical periods. Moreover, in order to analyze the drought, the standard precipitation index and the non-parametric Mann–Kendall test were used. To predict the meteorological drought in this province, the monthly time series of the precipitation parameter was incorporated. The results showed that most parts of Lorestan province are facing an extreme drought and such conditions will happen again in the future. Furthermore, the amount of precipitation was predicted until 2032, and the trend of predicted precipitation data in the entire Lorestan province showed that there is a significant trend in most months. The results of the research on an annual scale showed that all stations have a significant negative trend at the level of 5%, which indicates the existence of a negative trend, or in other words, a decrease in irrigation in the studied stations. Therefore, according to the obtained results, it is necessary to plan water consumption in Lorestan province toward sustainable management.

Key words: drought, hydrological analysis, Mann–Kendall test, non-parametric test

HIGHLIGHTS

- The modified Mann–Kendall method has been implemented to evaluate the trend of precipitation change in Lorestan province, Iran.
- Agricultural lands of the study area are facing an extreme drought in the future.
- The available water is estimated for the next two decades to decrease the effects of drought on water supplements.

1. INTRODUCTION

For the long-term planning of water resources, it will be necessary to study the climate in the future to determine the number of water resources and consumption for evaluating the solutions to the water crisis in a sustainable management system (Sherly *et al.* 2015; Alamanos *et al.* 2018; Hou *et al.* 2021).

Precipitation is one of the most important components in the definition of drought. Drought as a climatic phenomenon cannot be defined only by the lack of rainfall in a region (Schlesinger & Ramankutty 1994; Azaranfar *et al.* 2006). This phenomenon occurs in almost all climatic regions of the world, but its characteristics are different from one region to another. Climatic drought occurs when the annual rainfall is less than its long-term average. If a climatic drought continues, it will lead to the occurrence of hydrological drought (Lalehzari & Kerachian 2020, 2021). A yield degradation phenomenon occurs when the available soil moisture for the crop water requirement decreases below the level of the permanent wilting point (Zhang *et al.* 2019). This disaster occurs after the continuation of climatic, hydrological and agricultural drought (Li & Zhang 2008; Huo *et al.* 2019; G. Wang *et al.* 2022a, 2022b).

In recent years, due to the importance of the topic in the field of evaluating the effects of climate change on water resources management, several studies have been conducted in Iran. Studied areas in Iran were the East Azarbayjan province (Ashofteh & Masahbavani 2007), Urmia Lake (Fakheri *et al.* 2011), Gorganrud watershed (Azari *et al.* 2013), Tuyserkan Basin, Hamedan (Poormohammadi *et al.* 2017) and Zayandehrud River (Sabbaghi *et al.* 2020). Karamouz *et al.* (2018) have used the output of atmospheric circulation models to evaluate the effect of climate change on groundwater resources in Rafsanjan plain and have done microscaling of climate variables by the LARS-WG model. Jamshidzadeh & Mirbagheri (2017) in the evaluation of the quantity and quality of groundwater in Kashan based on the data of 53 wells observed that the average water level has decreased by 7.93 m during the years 1990–2006 and the average decrease in the water level per year is 0.496 m. Azizi *et al.* (2017), by investigating the effects of climate change on the water resources of the Karaj River catchment using the Mann–Kendall method and predicting meteorological data, found that despite the decrease in precipitation in the coming decades, the river discharge will increase, which indicates an increasing temperature and loss of water resources in the mountains. H. Y. Wang *et al.* (2022) used land use and climate change information to investigate the relationship between drought and water resources. The results showed that droughts in groundwater occur 2–3 months later than climatic droughts.

Furthermore, reference can be made to the studies of Elsner *et al.* (2009) in the United States, Daba *et al.* (2013) and Fentaw *et al.* (2018) in the Nile River Basin in Ethiopia, de Pinto *et al.* (2012) in Ghana, Nkomozepi & Chung (2014) in South Korea, Maier & Dietrich (2016) in Germany, Shrestha *et al.* (2017) in the Athabasca River Basin Canada, Tan *et al.* (2017) in the Kelantan in northeastern Malaysia, Brouziyne *et al.* (2018) in the Mediterranean watershed in northwestern Morocco, and Guevara-Ochera *et al.* (2020) in a watershed in Buenos Aires, Argentina. Gebremeskel & Kebede (2018) investigated the impact of climate change on the water resources of the Werii River basin located in northern Ethiopia by using general climate and hydrological models. This research presented the impact of climate change on water resources using SDSM (Statistical Down-Scaling Model) and WetSpa (Water and Energy Transfer between Soil, Plants and Atmosphere) models. A fully distributed model (WetSpa) was used to simulate baseline water resources (2010–2014) and future periods (2015–2050). Digital elevation models (DEMs), land use, soil, water and meteorological characteristics were used as inputs to the WetSpa model.

Jahangir *et al.* (2019) used a Mann–Kendall test method and an artificial neural network to estimate evaporation from the lake surface of Amirkabir Dam. This research was planned with 18-year statistics for neural network training and the best structure was chosen to calculate the evaporation rate. The developed structure had four neurons in the first layer and five neurons in the second layer. Zhu *et al.* (2022) evaluated the changes in precipitation data using the hydrological rank method and by examining the trend of station changes. Examining the trend of minimum and maximum precipitation changes was more heterogeneous than for semi-humid regions.

According to the many studies that have been carried out for identifying the effect of climate change (H. Wang *et al.* 2022), and since the powerful non-parametric Mann–Kendall test has a high ability to determine the presence or absence of the trend and sudden changes in the time series, it is necessary to discuss and examine the results of this test in climatic series. Lorestan province is the second rainiest basin in Iran after the Caspian Sea watershed. This province has very good capacities in the water resources sector, but the lack of proper management and planning in controlling water resources contributes to the occurrence of drought. Therefore, in this research, the impact of climate change has been evaluated by calculating the trend of precipitation changes using the Mann–Kendall method and evaluating annual and monthly precipitation in different stations of Lorestan province.

2. MATERIALS AND METHODS

2.1. Study area

Lorestan province with an area of 28×10^3 km^2 in the west of Iran covers 1.7% of the total area of the country. This province is located between 32°37′ and 36°22′ north latitude and 46°1′ to 50°3′ east longitude. The location of Lorestan province in Iran is shown in Figure 1. The data required in this research include the daily amounts of precipitation at nine synoptic stations of Lorestan province in a 30-year statistical period (1991–2021), which was obtained from the Statistics and Information Center of the Iran National Meteorological Organization. Geographical characteristics and the main synoptic stations are summarized in Table 1.

One of the climatic characteristics of Lorestan is the climate diversity that three distinct climate zones can be recognized in it:

1. Cold mountainous area, including regions that are more than 1,400 m above sea level. The regions of Boroujerd, Durood, Azna, Aligodarz, Aleshtar and Noorabad are located in this climate zone.
2. The moderate temperate zone includes the stations that are relatively low above sea level. Khoramabad and Kohdasht stations have this type of climate.
3. The warm area includes regions with a very low altitude above sea level. High temperature and low amounts of rainfall are the specialties of this area. Poledokhtar station is located in this area.

Since precipitation has always been a variable factor and a fundamental component in water budget, climatologists have always been interested to investigate the trend of changes in the average annual precipitation for evaluating long-term water

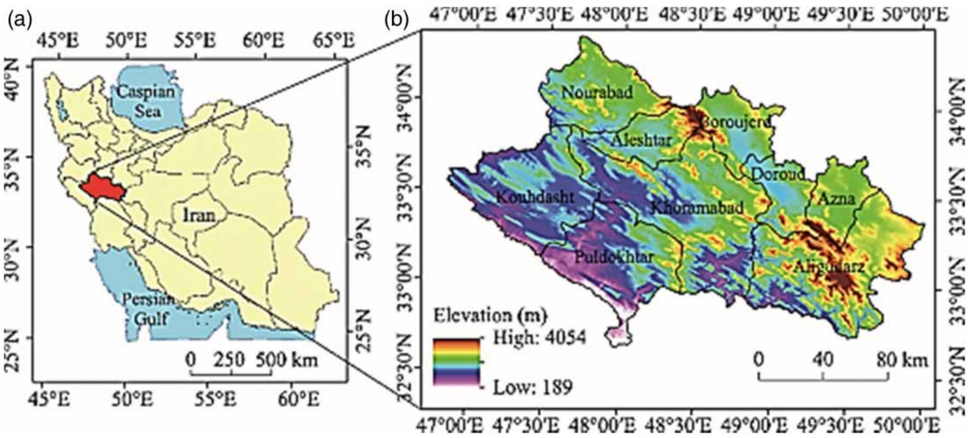

Figure 1 | Location of the study area in Lorestan province, Iran.

Table 1 | Synoptic stations of the study area

Station	Longitude	Latitude	Height above sea level (m)
Aleshtar	48° 15′	33° 49′	1,567
Aligodarz	49° 42′	33° 24′	2,022
Azna	49° 25′	33° 27′	1,872
Boroujerd	48° 45′	33° 55′	1,629
Durood	49° 00′	33° 31′	1,522
Khoramabad	48° 17′	33° 26′	1,155
Kohdasht	47° 39′	33° 31′	1,198
Noorabad	48° 00′	34° 03′	1,859
Poledokhtar	47° 43′	33° 09′	714

resources to achieve sustainable development. Therefore, the long-term hydrological information of the study area was collected and analyzed on a daily time-step and was used as the basis of the simulation model. The amount of rainfall based on the available statistical periods and the amount of annual water consumption in each of the stations are summarized in Table 2. In addition, based on the annual amount of agricultural consumption in each area and the amount of annual precipitation, a correlation coefficient was extracted between long-term statistics, which shows the correlation between precipitation and water consumption. Pearson correlation coefficient (*PCC*) was used for different study periods (n) and is expressed in Table 2. *PCC* can be written as follows:

$$PCC = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{\left[n(\sum x^2) - (\sum x)^2\right]\left[n(\sum y^2) - (\sum y)^2\right]}} \quad (1)$$

where x and y are the precipitation and agricultural water consumption, respectively.

2.2. Simulation of climatic parameters

The LARS-WG is one of the random meteorological data generation models that is used to provide daily rainfall data (Li *et al.* 2022), maximum radiation and minimum temperature of a station under current and future climate conditions. In this model, the output of general circulation models is microscaled by statistical methods in such a way that it is very close to the real value. This model includes three main parts: calibration, verification and creating meteorological data for the future

Table 2 | Precipitation and allocated water in agriculture

Station	Study period year	Annual precipitation (mm) Max	Average	Min	Allocated water MCM	Correlation%
Aleshtar	21	619	448	254	50	76
Aligodarz	32	631	384	205	138	69
Azna	18	569	400	252	184	82
Boroujerd	29	728	461	279	156	58
Durood	19	884	613	372	149	75
Khoramabad	66	814	495	220	130	86
Kohdasht	21	485	377	220	113	91
Noorabad	18	614	460	294	248	72
Poledokhtar	19	493	368	185	119	66

period. In the model calibration section, after collecting precipitation data and the average temperature of the nine mentioned stations for the base period (1991–2021) and preparing the input files, the model was run for the base period.

After ensuring the correctness of the evaluation results of the model and its capability in simulating meteorological data, this model was used for microscaling the data of general atmospheric circulation models (HADCM–INCM–IPCM–NCCCSM) and producing or simulating climate data for the period of 2011–2031 was implemented using scenarios (B1, A2, AIB) approved by *PCC* and daily values of climate parameters were produced. In the next step, the weight of these models was determined for each station in Lorestan province based on the data and scenarios received from the Climate Information Center.

$$w_i = \frac{1/\Delta T_i}{\sum_{i=1}^{n} 1/\Delta T_i} \qquad (2)$$

where W_i is the weight obtained in the predetermined month, and ΔT_i is the long-term average deviation of the climate parameter simulated by the General Circulation Model (GCM) in the base period from the average observational data. After generating the data for the next two decades and weighting the obtained values, the monthly precipitation values were calculated to obtain the standard precipitation index (*SPI*).

In 1993, the Colorado Climate Center and the US National Drought Mitigation Center used the SPI to define and monitor drought conditions. The variability of the SPI allows it to be used on short-term scales for agricultural purposes and on long-term scales for hydrological purposes such as groundwater resources, river flows, lake levels and surface resources. To determine the SPI, the monthly rainfall values of each station are calculated for each of the desired time-scales, and then the cumulative rainfall values in each month are fitted to the gamma distribution. Finally, this distribution becomes a normal distribution.

2.3. Modified Kendall test

One of the common methods to analyze time series of meteorological and hydrological data is to check for the presence or absence of trends in them caused by gradual natural changes and climate change due to human activities (Liu *et al.* 2020). Trend determination tests are divided into two types, which are parametric and non-parametric tests. The advantage of a non-parametric test over a parametric test such as the *t*-test is that the non-parametric test is suitable for time series that do not have a normal statistical distribution and also for data some of which are missing or omitted. The Mann–Kendall test is a non-parametric test that is a suitable statistical method to prove the existence of a trend in hydrological series. In recent years, many researchers have used this test as the best option to check the existence of seasonal and annual changes in the flow of rivers, streams and rainfall in watersheds. The Mann–Kendall method was first presented by Mann (1945) and then expanded and developed by Kendall (1970). The zero hypothesis of the Mann–Kendall test indicates randomness and the absence of a trend in the data series, and the acceptance of the one hypothesis (rejection of the null hypothesis) indicates the existence of a trend in the data series (Sen 1968). In this method, first, the difference between each observation and all the observations is calculated and the parameter S is obtained. For a random sample containing n observations, the estimator S can be calculated with the following equation:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sgn}(x_i - x_j) \tag{3}$$

$$\mathrm{sgn}[\psi] = \begin{Bmatrix} 1 & \text{if} & \psi > 0 \\ 0 & \text{if} & \psi = 0 \\ -1 & \text{if} & \psi = 0 \end{Bmatrix} \tag{4}$$

where sgn[ψ] refers to the sign function and $n = i$, $j = 1, 2, 3, \ldots, n$.

Mann (1945) and Kendall (1975) showed that when the number of observations is more than eight, S almost follows the normal distribution and its mean and standard deviation are determined by the following relations:

$$E(S) = 0 \tag{5}$$

$$V(S) = n(n-1)(2n+5) - \frac{\sum_{i=1}^{n} t_i(t_i - 1)(2t_i + 5)}{18} \tag{6}$$

where t_i is the number of identical data in the ith category. Kendall's standardized Z statistic is written as follows:

$$Z = \begin{cases} S - 1/\sqrt{V(S)} & S > 0 \\ 0 & S = 0 \\ S + 1/\sqrt{V(S)} & S < 0 \end{cases} \tag{7}$$

The Z statistic is a standardized Mann–Kendall test that follows a normal distribution and has a mean of 0 and a variance of 1. Kumar *et al.* (2009) improved the Mann–Kendall test by removing the effect of first-order autocorrelation. For this purpose, the autocorrelation coefficient of order k was obtained from the following relationship:

$$r_k = \frac{(1/(n-k)) \sum_{i=1}^{n-k} (x_i - \bar{x})(x_{i+k} - \bar{x})}{(1/n) \sum_{i=1}^{n} (x_i - \bar{x})^2} \tag{8}$$

By specifying the value of $k = 0$, the first-order autocorrelation coefficient was calculated. The significance test of the obtained function is that if the value of r_1 is between c_1 and c_2, it is assumed that the data are independent of each other at the 10% significance level. Otherwise, it is assumed that the data have autocorrelation and their effect should be removed from the time series before performing the Mann–Kendall test.

$$c_1 = \frac{-1 + 1/65\sqrt{n-2}}{n-2} \tag{9}$$

$$c_2 = \frac{-1 - 1/65\sqrt{n-2}}{n-2} \tag{10}$$

In the present study, this test is used for 95% confidence levels. If the Z statistic is positive, the trend of the data series is considered to be upward, and if it is negative, the trend is considered to be downward. In order to improve the test for monthly series that have autocorrelation, modifications to the Mann–Kendall test have been made (Yue *et al.* 2002). In this method, at first, the values of the S statistic are calculated for each year, and finally, the results of different years are added together:

$$S' = \sum_{j=1}^{p} S_j \tag{11}$$

where S_j is the value of S for season j ($j = 1, 2, \ldots, p$). In the case that the time series has no autocorrelation, the variance of S' is determined using the following relationship:

$$\sigma^2_{S'} = \sum_{j=1}^{p} \text{Var}\ (S'_j) \tag{12}$$

2.4. Precipitation trends

In the first stage, the data are arranged in the order of occurrence, and the time order of the data is indicated by n. Then, the data are ranked, and for this purpose, the T statistic is used, which is defined as the ratio of rank i to the previous rank. Then, the values of mathematical expectation (E_i), variance V_i and Kendall's index u_i can be calculated using the following numerical relations:

$$E_i = \frac{n_i(n_i - 1)}{4} \tag{13}$$

$$V_i = \frac{n_i(n_i - 1)(2n_i - 5)}{72} \tag{14}$$

$$u_i = \frac{(\sum t_i - E_i)}{\sqrt{V_i}} \tag{15}$$

To identify partial and short-term trends, break points and the beginning of the time series trend, the time series graph has been used in terms of u and u' values. The time series graph of consecutive values of u and u' statistics will be obtained using the above relationship for u. To calculate u', the steps below can be followed. First, the data are ranked by the T' statistic and the mathematical expectation values E_i', variance V_i' are calculated as follow:

$$E'_j = \frac{(N - (n_i - 1))((N - n_i))}{4} \tag{16}$$

$$V_i = \frac{((N - n_i)(N - (n_i - 1))(2(N - (n_i - 1)(N - n_i)))) + 5}{72} \tag{17}$$

$$u'_i = -\frac{(\sum t'_i - E'_i)}{\sqrt{V'_i}} \tag{18}$$

where N is the number of statistical years. The intersection point of the u and u' index with a 95% confidence factor indicates changes in the time series and the behavior of u after the point of intersection shows the state of the trend (decrease or increase) of the series. The non-crossing of two indicators indicates the absence of a series trend.

2.5. Monthly evaluation

For monthly evaluation, in the case that the monthly data have autocorrelation, the variance of S' is determined using the following relationship:

$$\sigma^2_{S'} = \sum_{j=1}^{p} \text{Var}\ (S_j) + \sum_{g=1}^{p-1} \sum_{h=g+1}^{p} \sigma_{gh} \tag{19}$$

where σ_{gh} is the covariance between Kendall statistics for years g and h. Covariance is also determined using the following relations:

$$\sigma_{gh} = \frac{1}{3}\left[K_{gh} + 4\sum_{i=1}^{n} R_{ig}R_{ih} - n(n+1)^2\right] \tag{20}$$

$$K_{gh} = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sgn}[(X_{jg} - X_{ig})(X_{jh} - X_{ih})] \quad (21)$$

$$R_{ig} = \frac{1}{2}\left[n + \sum_{k=1}^{n} \text{sgn}(X_{ij} - X_{kj})\right] \quad (22)$$

where R_{ig} is the rank of each of the data and n is the number of data of each month, and finally, the value of the modified Mann–Kendall statistic is obtained.

This method is recommended for data series whose first-order autocorrelation value is less than 0.6. If the data have no autocorrelation, the normal method performs better. To eliminate the effect of autocorrelation in annual series, the following method was used:

$$Y_t = X_t - r_1 X_{t-1} \quad (23)$$

where r_1 is the autocorrelation value in the first delay and X_t is the observation data at time t. After obtaining the values of the residuals (Y_t), the Mann–Kendall test is performed on the values of the residuals. Hamed & Rao (1998) removed the effect of autocorrelation by determining the optimal size and correcting the Mann–Kendall computational variance. The optimal size of the corrected variance sample is determined using the following equations:

$$\frac{n}{n'} = 1 + \frac{2}{n(n-1)(n-2)} \sum_{i=1}^{n-1} (n-k)(n-k-1)(n-k-2) r_k^{\mathrm{R}} \quad (24)$$

$$V'(S) = \frac{n}{n'} \times V(S) \quad (25)$$

where r_k^{R} is the autocorrelation value of the ranks. In this research, the proposed algorithm (Yu *et al.* 2002) was used to identify the trend in a time series with autocorrelation. The steps of this algorithm programmed in MATLAB are as follows.

1. Using the TSA method, the slope of the data trend (b) is estimated:

$$b = \text{median}\left(\frac{X_j - X_l}{j - l}\right) \quad (26)$$

where X_l is the lth observation.

2. If the slope is equal to zero, there is no need to continue analyzing the trend, and if it is not zero, it is assumed that the trend is linear and the trend is eliminated using the following relationship:

$$X_t' = X_t - T_t = X_t - b_t \quad (27)$$

3. The first-order autocorrelation value of the trendless series (X_t') is calculated and then the value of the first-order autocorrelation coefficient AR(1) is removed from the data:

$$Y_t' = X_t' - r_1 X_{t-1}' \quad (28)$$

The residuals after removing the trend should form an independent series.

4. In this step, the trend values removed in the first step are added with the remaining values:

$$Y_t = Y_t' + T_t \quad (29)$$

5. The Mann–Kendall test is applied to the series (Y_t).

3. RESULTS AND DISCUSSION

3.1. Precipitation trend analysis

The analysis of the trend was carried out by the Mann–Kendall method using the u and u' graphs for the maximum rainfall of the Aleshtar station, and is shown in Figure 2. The results showed that the graphs intersected each other in years 5, 9 and 21, which indicated a sudden change, but it was in the critical range of ± 1.96 and did not show any particular trend. The changes of Mann–Kendall coefficients at the Aligodarz station have varied between -1.6 and 0.8, which indicates the absence of an increasing or decreasing trend in precipitation (Figure 2). However, there were sudden changes in the fourth, tenth, 18th and 25th years. According to the fact that the beginning of statistics collection in the Aligodarz station was in 1986, the years that encountered jumps were 1990, 1996, 2004 and 2010.

For the Azna region, all the fluctuations were in the critical range and sudden fluctuations were observed at four times. Between the fifth and seventh years, or in other words, between the years 2003 and 2007, there were three sudden jumps, but they did not change the precipitation trend. The range of changes in Boroujerd was between -1 and 1.6. The stability of precipitation is observed in this station more than in other parts of the province. Therefore, no clear trend of increase or decrease was observed in the Boroujerd area either.

According to the calculations, there is no clear trend in precipitation changes in the Durood station. Only in the 11th and 18th years, sudden changes and jumps occurred, which were in the range of ± 1.96. The data recorded at the Khoramabad station reaches back more than 66 years and can indicate the changes of precipitation in the entire province. The fluctuation range of the Mann–Kendall method at this station does not indicate an increasing or decreasing trend in precipitation. The time points that caused sudden changes in rainfall are the 16th year, the 46th year and the 64th year from 1954.

Kohdasht has the most influence in agriculture and water consumption in Lorestan province. The results showed that there was no clear trend during the statistical period. However, sudden changes have happened at different times. As in other parts of the province, there has not been a proven trend in the Kendall method in this area. There was a sudden jump in rainfall only in the eighth year (2007) and the 13th year (2012).

Despite the occurrence of a sudden jump in the Poledokhtar station where the intersection points of the graphs are observed, collisions have occurred within the critical limit. Therefore, by examining all the curves obtained by the Mann–Kendall method at different stations of Lorestan province, it can be concluded that no detectable increase or decrease in rainfall has been observed in the time range of the statistics.

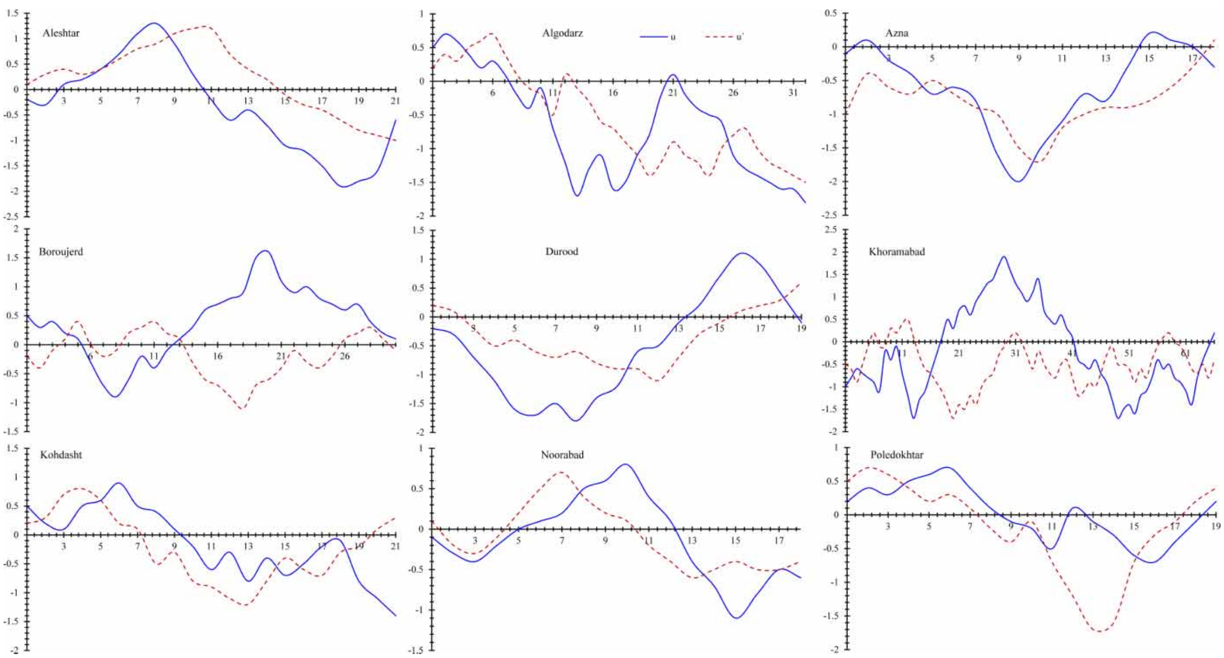

Figure 2 | Precipitation trend graphs using a Mann–Kendall test.

3.2. LARSE-WG validation

Validation of the LARSE-WG model was done by comparing the data of the statistical period and the data generated by the model for all the synoptic stations of the province. Figure 3 shows the observed and simulated rainfall values in the three stations of Khoramabad, Aleshtar and Boroujerd. A good match between the simulated and observed values is observed, and therefore it was ensured that the LARSE-WG model has the ability to simulate precipitation and climatic parameters for the next two decades for stations in Lorestan province.

3.3. Drought

One of the important and fundamental components in drought studies in each region is determining indicators to measure the severity and duration of the drought period. The standardized precipitation index is based on the probability of rainfall in time (month, season and year) and is used in drought planning. To determine the SPI, the long-term rainfall statistics are drawn according to a normal distribution curve and the amount. SPI numbers indicate drought conditions. Positive numbers indicate no drought and negative numbers indicate drought.

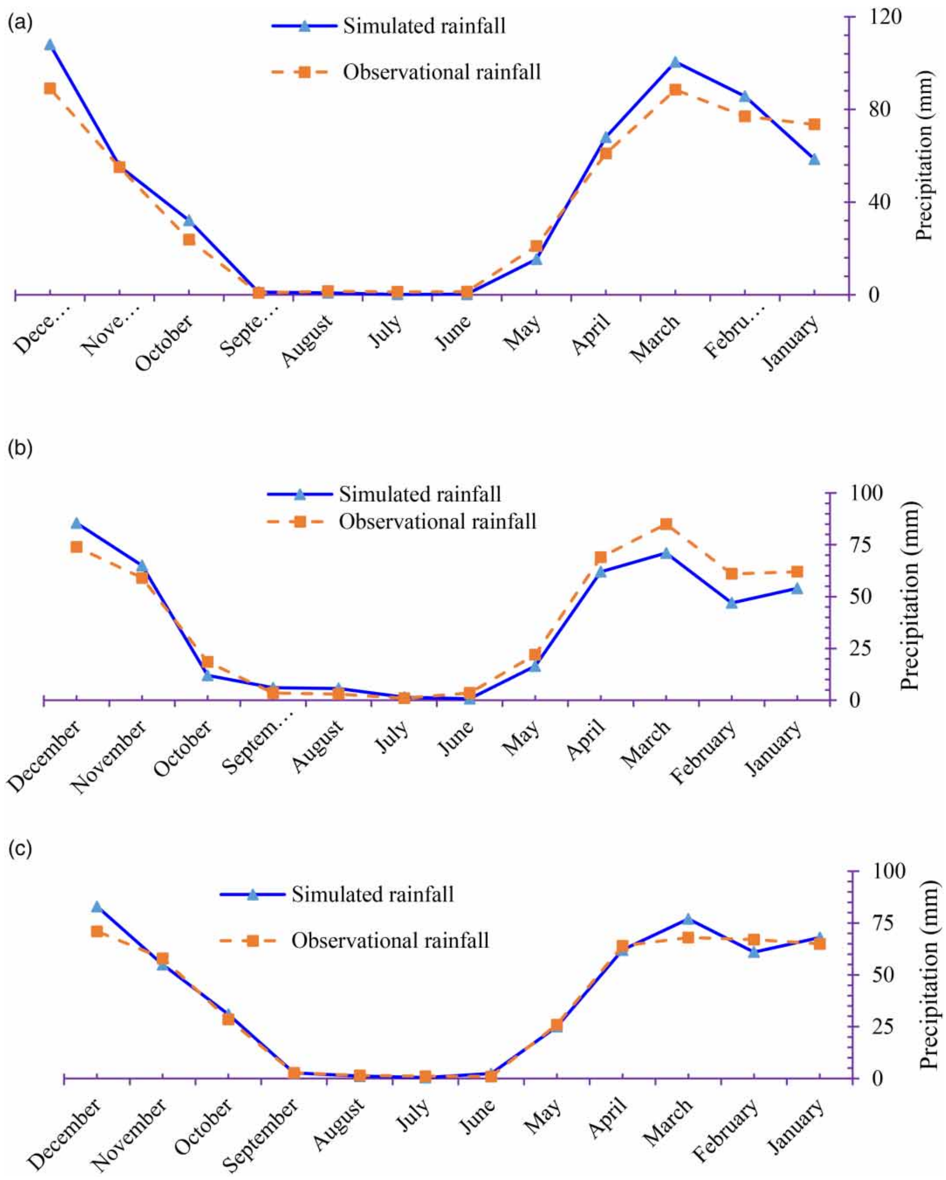

Figure 3 | Comparison of simulated and observed precipitation: (a) Khoramabad, (b) Boroujerd and (c) Aleshtar.

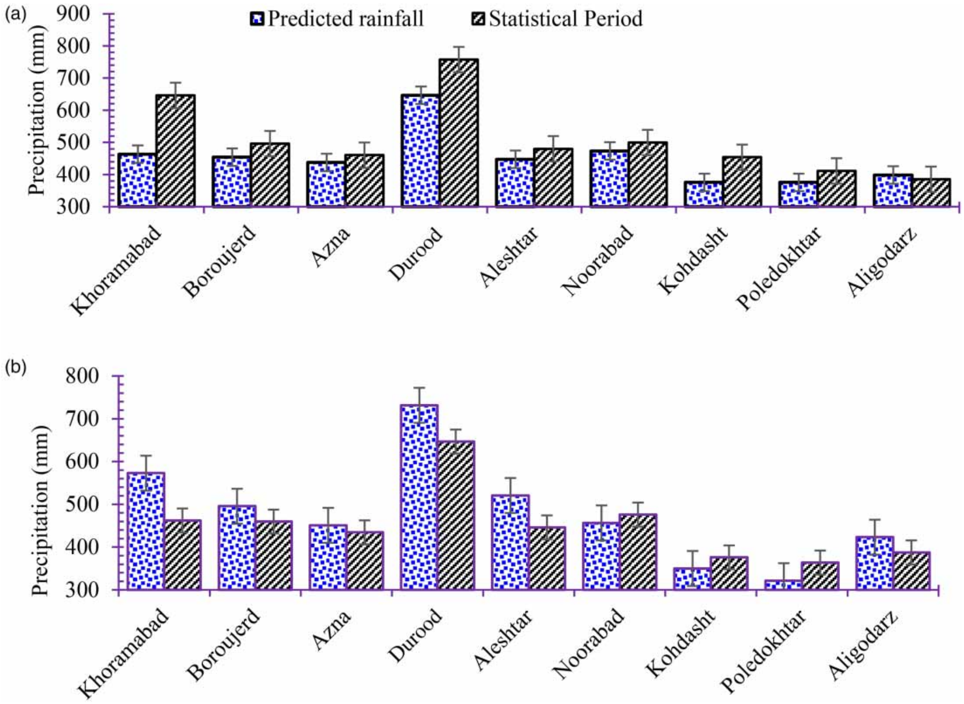

Figure 4 | Comparison of annual precipitation in a statistical period and predicted precipitation: (a) 2022–2032 and (b) 2032–2042.

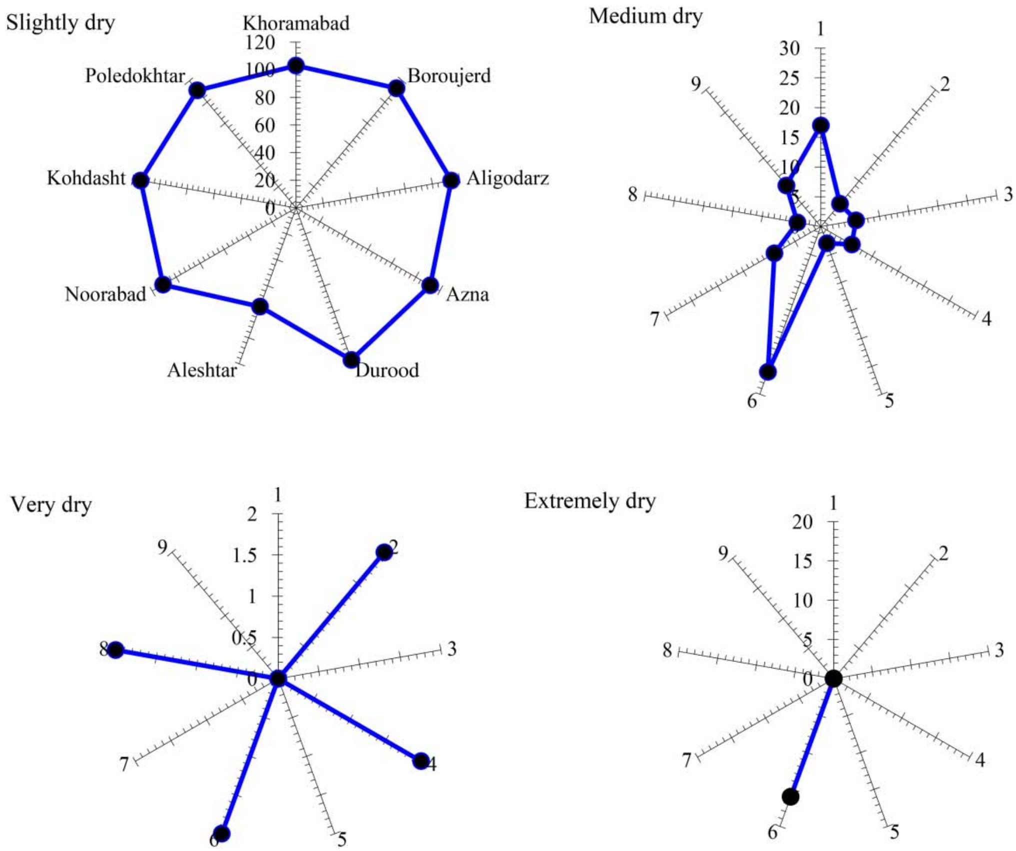

Figure 5 | Comparing the frequency of monthly SPI classes in the first decade of forecasting.

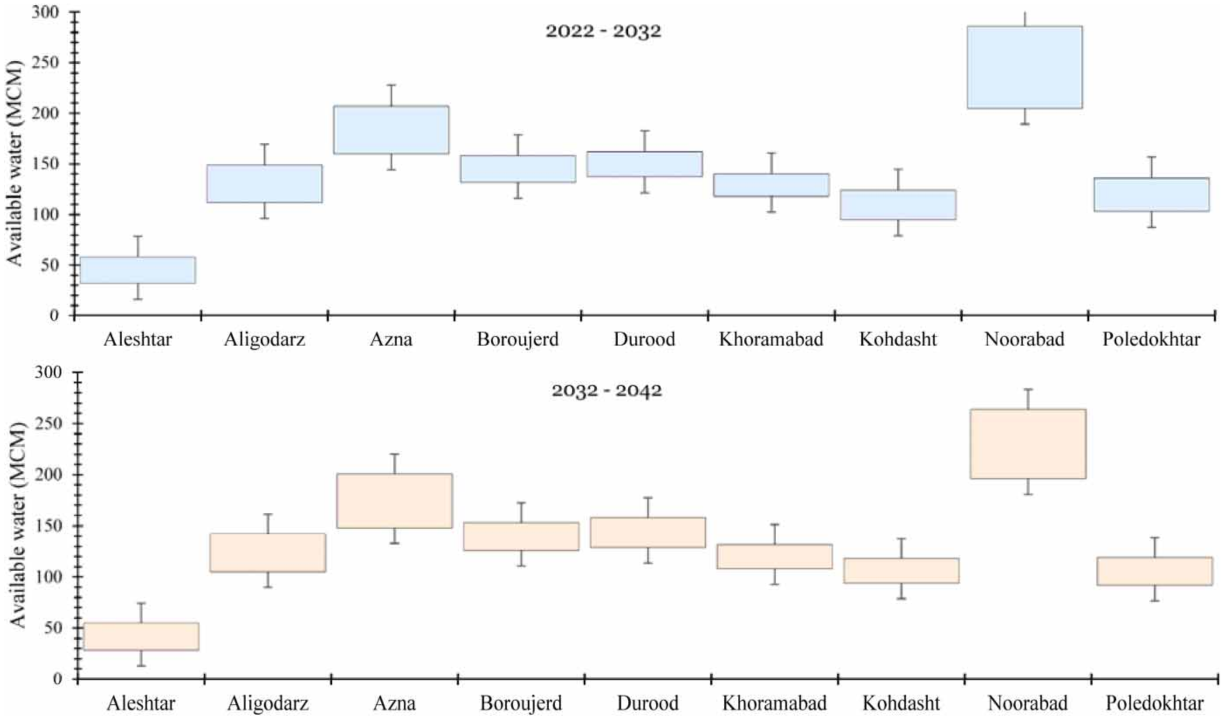

Figure 6 | Available water for yield production based on the predicted precipitation and SPI.

Next, the prediction of rainfall and drought in the stations of Lorestan province during the next decade (2022–2042) was carried out. Figure 4 shows an increase in the average rainfall in the stations of the province in the first decade of the forecast compared with the statistical period. In this decade, we have a decrease in rainfall compared with the statistical period only in Aligodarz, Durood and Azna stations. Also, in the second decade, the forecast shows a decrease in rainfall in the four stations of Azna, Poledokhtar, Noorabad and Aligodarz compared with the statistical period and an increase in rainfall in the rest of the stations.

The frequency table of different classes of monthly SPI in the next decade (2022–2032) for the synoptic stations of Lorestan province was examined (Figure 5). As can be seen in all stations, the number of months with slightly dry conditions showed an increase compared with other classes of drought, so that in the first decade of Durood, with 117 months of slightly dry conditions, it has the highest amount. Also, Aleshtar shows special conditions with 26 months of medium dryness and 16 months of extreme dryness.

In the second future decade (2032–2042) of the Durood forecast, with 120 months, the most months with slight drought have been allocated. In this decade, Poledokhtar with four months of very dry and Aleshtar with 25 months of medium dry and 18 months of extremely dry conditions have the highest SPI classes.

3.4. Climatic effect on water consumption in agriculture

Changes in precipitation and drought are the most important components in yield production. According to the rainfall in the next two decades and its relation to water consumption in agriculture, the correlation of which is presented according to the Pearson coefficient in Table 2, the results in Figure 6 are obtained. A confidence factor of 95% is considered to estimate the available water at each station for agriculture. Estimating the volume of available water for each station can play a significant role in sustainable planning. The results showed that in order to achieve sustainable planning, Noorabad must reduce the cultivated area by about 8%. But in Aligodarz, agriculture can be more reliably considered for food security.

4. CONCLUSION

The climatic condition of Lorestan province is in a critical state; therefore, for long-term planning of water resources, it will be necessary to check the rainfall situation in the future so that solutions to deal with the crisis can be identified and used with sustainable management. The approach of this research can be summarized as follows. The phenomenon of precipitation can be considered a major challenge in the future in this province. The results of drought analysis showed that in all stations, the number of months with slightly dry conditions compared with other classes of drought shows an increase, so that in the first decade Durood with 117 months of slightly dry conditions has the highest amount. Also, Aleshtar showed special conditions with 26 months of medium dry and 16 months of extremely dry conditions. In general, the study conducted in Lorestan province and its results indicated that this area is moving toward a climate with lower humidity and higher temperature. Therefore, under the conditions of predicted climate change and due to the expected changes in temperature and precipitation, we will probably face water shortage in the future. For this reason, sustainable management measures should be taken in this area, taking into account the effects of climate change, and appropriate solutions should be provided in order to deal with water shortage.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

Alamanos, A., Mylopoulos, N., Vasiliades, L. & Loukas, A. 2018 Climate change effects on the availability of water resources of Lake Karla watershed for irrigation and Volos city urban water use. In: *Proceedings of the 14th Protection and Restoration of the Environment (PRE) Conference*, Thessaloniki, Greece, pp. 3–12.

Ashofteh, P. & Masahbavani, A. 2007 Impact of climate change on the intensity and frequency of flooding in future periods, case study: Aidoghmoush Basin, East Azarbaijan. In: *Technical Workshop on the Impacts of Climate Change on Water Resources Management*, Tehran, Iran (in Persian).

Azaranfar, A., Abrishamchi, A. & Tagrishi, M. 2006 Evaluation of precipitation and temperature changes due to climate change using the output of general circulation models. In: *Second National Conference on Water Resources*, Esfahan, Iran.

Azari, M., Moradi, H. R., Saghafian, B. & Faramarzi, M. 2013 Assessment of hydrological effects of climate change in Geourganroud River basin. *Journal of Water and Soil* **27** (3), 537–547.

Azizi, H. R., Hassan Pourdarvishi, H. & Ebrahimi, H. 2017 Investigating the trend of changes in precipitation and discharge parameters of the Karaj River catchment under climate change conditions. In: *Second International Conference on Management, Demand and Efficiency of Water Consumption*, Hamedan, Iran.

Brouziyne, Y., Abouabdillah, A., Hirich, A., Bouabid, R., Zaaboul, R. & Benaabidate, L. 2018 Modeling sustainable adaptation strategies toward a climate-smart agriculture in a Mediterranean watershed under projected climate change scenarios. *Agricultural Systems* **162**, 154–163.

Daba, M., Mamo, G. & Rao, G. N. 2013 Evaluating potential impact of climate change on hydro-meteorological variables in upper Blue Nile Basin. In: *Second International Conference on Hydrology and Groundwater Expo*, 26–27 August, Rayleigh, NC, USA.

De Pinto, A., Demirag, U., Haruna, A., Koo, J. & Asamoah, M. 2012 *Climate Change, Agriculture and Food Crop Production in Ghana*. Policy Note #3, International Food Policy Research Institute, Washington, DC, USA. Available from: http://www.ifpri.org/sites/default/files/publications/gssppn3.pdf (accessed on 13 June 2013).

Elsner, M. M., Cuo, L., Voisin, N., Hamlet, A. F., Deems, J. S., Vano, J. A., Mickelson, K. E. B., Lee, S. Y. & Lettenmaier, D. P. 2009 Implications of 21st century climate change for the hydrology of Washington State. In: *The Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate* (M. M. Elsner, J. Littell & L. W. Binder, eds), Center for Science in the Earth System, Joint Institute for the Study of the Atmosphere and Oceans, University of Washington, Seattle, WA, USA.

Fakheri, A., Romiynfar, S., Aboali, H. & Khaki Torabi, A. 2011 Investigation effects of climate change on water inflow into Lake Orumiyeh using SDSM micro-scale model. In: *Fourth Conference on Water Resources Management*, Amirkabir Technology University, Tehran, Iran (in Persian).

Fentaw, F., Mekuria, B. & Arega, A. 2018 Impacts of climate change on the water resources of Guder Catchment, Upper Blue Nile, Ethiopia. *Waters* **1** (1), 16–29.

Gebremeskel, G. & Kebede, A. 2018 Estimating the effect of climate change on water resources: integrated use of climate and hydrological models in the Werii watershed of the Tekeze river basin, Northern Ethiopia. *Agriculture and Natural Resources* **52**, 195–207.

Guevara-Ochera, C., Medina-Sierra, A. & Vives, L. 2020 Spatio-temporal effect of climate change on water balance and interactions between groundwater and surface water in plains. *Science of the Total Enviroment* **722**, 137886.

Hamed, K. H. & Rao, A. R. 1998 A modified Mann-Kendall trend test for autocorrelated data. *Journal of Hydrology* **204** (1–4), 182–196.

Hou, R., Li, S., Wu, M., Ren, G., Gao, W., Khayatnezhad, M. & Gholinia, F. 2021 Assessing of impact climate parameters on the gap between hydropower supply and electricity demand by RCPs scenarios and optimized ANN by the improved Pathfinder (IPF) algorithm. *Energy* **237**, 121621.

Huo, W., Li, Z., Wang, J., Yao, C., Zhang, K., Huang, Y. 2019 Multiple hydrological models comparison and an improved Bayesian model averaging approach for ensemble prediction over semi-humid regions. *Stochastic Environmental Research and Risk Assessment* **33**, 217–238. https://doi.org/10.1007/s00477-018-1600-7.

Jamshidzadeh, Z. & Mirbagheri, A. 2017 The effect of fault on salt water intrusion and groundwater quality around a hypothetical salt dome. In: *First National Conference of Drinking Water Demand and Supply: Challenges and Solutions*, Isfahan University of Technology, Isfahan, Iran.

Jahangir, M. H., Soltani, K., Nohagar, A. & Sadatinejad, S. J. 2019 Modeling and routing of surface evaporation from the Amir Kabir reservoir using the Mann-Kendall and neural network technology. *Journal of Watershed Engineering and Management* **10** (4), 635–644.

Karamouz, M., Doroudi, S. & Moridi, A. 2018 Developing a model for optimizing the geometric characteristics of water diversion systems. *Journal of Irrigation and Drainage Engineering* **144** (2), 04017062.

Kendall, M. G. 1970 *Rank Correlation Methods*, 2nd edn. Hafner, New York, USA.

Kendall, M. G. 1975 *Rank Correlation Methods*, 4th edn Charles Griffin, London, UK.

Khayatnezhad, M. & Gholinia, F.

Kumar, S., Merwade, V., Kam, J. & Thurner, K. 2009 Streamflow trends in Indiana: effects of long term persistence, precipitation and subsurface drains. *Journal of Hydrology* **374** (1–2), 171–183.

Lalehzari, R. & Kerachian, R. 2020 Developing a framework for daily common pool groundwater allocation to demands in agricultural regions. *Agricultural Water Management* **241**, 106278.

Lalehzari, R. & Kerachian, R. 2021 An integrated framework for optimal irrigation planning under uncertainty: application of soil, water, atmosphere and plant modeling. *Iranian Journal of Science and Technology, Transactions of Civil Engineering* **45**, 429–442. https://doi.org/10.1007/s40996-020-00442-5.

Li, Z. & Zhang, K. 2008 Comparison of three GIS-based hydrological models. *Journal of Hydrologic Engineering* **13** (5), 364–370. doi:10.1061/(ASCE)1084-0699(2008)13:5(364).

Li, Q., Song, D., Yuan, C. & Nie, W. 2022 An image recognition method for the deformation area of open-pit rock slopes under variable rainfall. *Measurement* **188**, 110544. https://doi.org/10.1016/j.measurement.2021.110544.

Liu, Y., Zhang, K., Li, Z., Liu, Z., Wang, J. & Huang, P. 2020 A hybrid runoff generation modelling framework based on spatial combination of three runoff generation schemes for semi-humid and semi-arid watersheds. *Journal of Hydrology* **590**, 125440. doi:10.1016/j.jhydrol.2020.125440.

Maier, N. & Dietrich, J. 2016 Using SWAT for strategic planning of basin scale irrigation control policies: a case study from a humid region in northern Germany. *Water Resources Management* **30** (9), 3285–3298.

Mann, H. B. 1945 Nonparametric tests against trend. *Econometrica* **13**, 245–259.

Nkomozepi, T. & Chung, O. K. 2014 The effects of climate change on the water resources of the Geumho River Basin, Republic of Korea. *Hydro-environment Research* **8** (4), 358–366.

Poormohammadi, S., Dastorani, M. T., Massah Bavani, A. R., Gudarzi, M., Jafari, H. & Rahimian, M. H. 2017 Effects of climate change on river runoff and compatible solutions, case study: Tuyserkan Basin, Hamedan. *Iranian Journal of Watershed Management Science and Engineering* **11** (37), 1–12.

Sabbaghi, M. A., Nazari, M., Araghinejad, S. & Soufizadeh, S. 2020 Economic impacts of climate change on water resources and agriculture in Zayandehroud river basin in Iran. *Agricultural Water Management* **241**, 106323.

Schlesinger, M. E. & Ramankutty, N. 1994 An oscillation in the global climate system of period 65–70 years. *Nature* **367**, 723–726.

Sen, P. K. 1968 Estimates of the regression coefficient based on Kendall's tau. *Journal of the American Statistical Associate* **63**, 1379–1389.

Sherly, M. A., Karmakar, S., Chan, T. & Rau, C. 2015 Design rainfall framework using multivariate parametric-nonparametric approach. *Journal of Hydrologic Engineering* **21** (1), 04015049. doi:10.1061/(ASCE)HE.1943-5584.0001256.

Shrestha, N. K., Du, X. & Wang, J. 2017 Assessing climate change impacts on fresh water resources of the Athabasca River Basin Canada. *Science of the Total Environment* **601–602**, 425–440.

Tan, M. L., Ibrahim, A. L. Yusop, Z., Chua, V. P. & Chan, N. W. 2017 Climate change impacts under CMIP5 RCP scenarios on water resources of the Kelantan River Basin Malaysia. *Atmospheric Research* **189**, 1–10.

Wang, G., Zhao, B., Lan, R., Liu, D., Wu, B., Li, Y., Li, Q., Zhou, H., Liu, M., Liu, W. & Liu, X. 2022a Experimental study on failure model of tailing dam overtopping under heavy rainfall. *Lithosphere* **2022** (Special 10), 5922501. doi:10.2113/2022/5922501.

Wang, G., Zhao, B., Wu, B., Wang, M., Liu, W., Zhou, H., Zhang, C., Wang, Y. & Han, Y. 2022b Research on the macro-mesoscopic response mechanism of multisphere approximated heteromorphic tailing particles. *Lithosphere* **2022** (Special 10), 1977890. doi:10.2113/2022/1977890.

Wang, H., Khayatnezhad, M. & Yousefi, N. 2022 Using an optimized soil and water assessment tool by deep belief networks to evaluate the impact of land use and climate change on water resources. *Concurrency and Computation: Practice and Experience* **34** (10), e6807. https://doi.org/10.1002/cpe.6807.

Wang, H. Y., Chen, B., Pan, D., Lv, Z. A., Huang, S. Q., Khayatnezhad, M. & Jimenez, G. 2022 Optimal wind energy generation considering climatic variables by Deep Belief network (DBN) model based on modified coot optimization algorithm (MCOA). *Sustainable Energy Technologies and Assessments* **53** (Part C), 102744.

Yu, P. S., Yang, T. C. & Wu, C. K. 2002 Impact of climate change on water resources in southern Taiwan. *Journal of Hydrology* **260** (1–4), 161–175.

Yue, S., Pilon, P., Phinney, B. & Cavadias, G. 2002 The influence of autocorrelation on the ability to detect trend in hydrological series. *Hydrological Processes* **16**, 1807–1829.

Zhang, K., Ali, A., Antonarakis, A., Moghaddam, M., Saatchi, S., Tabatabaeenejad, A., Chen, R., Jaruwatanadilok, S., Cuenca, R., Crow, W. T. & Moorcroft, P. 2019 The sensitivity of North American terrestrial carbon fluxes to spatial and temporal variation in soil moisture: an analysis using radar-derived estimates of root-zone soil moisture. *Journal of Geophysical Research Biogeosciences* **124** (11), 3208–3231. doi:10.1029/2018JG004589.

Zhu, X., Xu, Z., Liu, Z., Liu, M., Yin, Z., Yin, L. & Zheng, W. 2022 Impact of dam construction on precipitation: a regional perspective. *Marine and Freshwater Research*, MF22135. https://doi.org/10.1071/MF22135.

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