Climate change effect on decline groundwater level using Entropy wavelet (case study of Khorramabad city)

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ABSTRACT

Changing global climate predicts a warmer future which may alter the hydrological cycle, surface water as well as groundwater resource. The Entropy wavelet criterion is a new indicator to analyze the time series fluctuations. In this study, the effective factors of decreasing the groundwater level in Khorramabad city during the years 2005–2018 have been evaluated by the use of Entropy wavelet criterion. In general, it can be said that the decreasing of Entropy wavelet criterion or time series complexity of a phenomenon shows the time series decrease of fluctuations natural amounts, which it leads to an unfavorable trend. In this regard, in order to identify the affecting factors of the groundwater level decrease in Khorramabad, the groundwater level has been divided into 4 time periods, and after being investigated, the monthly time series of runoff, temperature, and precipitation of this city were divided into 4 periods. Each of these subset were decomposed into other several subsets at different time scales under the wavelet transform, and finally, after calculation of the normalized wavelet energy for this subset, its Entropy wavelet criterion was calculated for each period. Investigation of Entropy wavelet complexity shows a 21.3% decrease in groundwater level in the second period, but in the third and fourth periods, it has increased by 145 and 272%, respectively. Also, according to the results of Entropy wavelet changes analyzing for the precipitation time series, 35.2, 32.8, and 10.06% decrease in the second, third, and fourth periods were shown. The air temperature time series complexity decreased of 26.8% only in the third time period and in the second and fourth period, it shows an increase of 29.65 and 34.7%, respectively. However, the runoff time series did not show any reduction complexity according to the entropy wavelet criterion. These results indicate that the impact of climatic factors has been more effective than human factors in reducing the groundwater level of Khorramabad.

Key words: air temperature, complexity, Entropy wavelet, groundwater level, Khorramabad

HIGHLIGHTS

• Temperature and precipitation parameters are considered as climatic factors.
• Runoff parameter are considered as human factor.
• Used the Entropy wavelet criterion to investigate the cause of groundwater level decrease.

1. INTRODUCTION

Sustainable management and the use of water resources is very important for all-around human development and without water, sustainable development is not possible. Groundwater resources as one of the most sensitive water resources are directly related to human life and the sustainable development of a community. In recent decades, many changes in the groundwater level have been occurred due to climate change and human activity. In many parts of the country, declining groundwater levels have not only limited the exploitation of waters resource but also led to land subsidence environmental disaster, financial losses, and decrease quality water. Anomalies and changes in groundwater resources that are influenced by climatic and human factors can be deduced in various ways, including the concept of complexity. In this regard, the Entropy criterion is one of the methods which can be used in this field. The theory of Entropy, which was proposed quantitatively and mathematically by Shannon (1948), is defined as a comparison of irregularity and uncertainty in a system. The entropy...
wavelet criterion can provide a suitable indicator in predicting future conditions to make better use of water resources using correct water resources management. Combining the concepts of wavelet and entropy a new tool called wavelet-entropy is obtained to developed the complexity calculate. Using this method, it is possible to discernment at what time scale the main signal is examined. In this research, the Entropy wavelet method has been used to measure the complexity of hydrological processes. In investigating the complexity of hydrological series due to the seasonal nature of hydrological processes, using the wavelet method is considering to have favorable Entropy results. Many research has been done to identify factors that decrease groundwater levels. For example, Salem et al. (2018) studied the impacts of climate change on groundwater level and irrigation cost in a groundwater dependent irrigated region. The results showed that the impact of climate change-induced fluctuations in groundwater level on crop production cost is much less compared to other costs, but it may be significant in locations where groundwater level is declining fast. Also, Faramarzi et al. (2014), studied the effect of land-use changes on the drop in groundwater level in the Dehloran plain (Iran). The results showed that there is a high correlation between increasing dry and irrigated lands with decreasing water table. Zhang et al. (2019) studied the prediction of groundwater level in seashore reclaimed land using wavelet and artificial neural network-based hybrid model. The results showed that the WA-NARX hybrid model provides better prediction performance, especially for short-term periods. Ghimire et al. (2021) in Bangkok area, Thailand investigated climate and land-use change impacts on spatiotemporal variations in groundwater recharge. The findings showed that groundwater decrease in high and medium urbanization areas, ranging from 5.84 to 20.91 mm/yr for the RCP 4.5 scenario and 4.07 to 18.72 mm/yr for RCP 8.5. Komasi et al. (2016) investigated the routing and classification of factors affecting the reduction of groundwater level by using cross and coherence wavelet transformation in the Silakhor plain. The results showed that runoff time series caused by human harvesting with a caused by average wavelet coherence coefficient of 0.83 of the precipitation and air temperature time series that are of caused by climate change, with an average wavelet coherence coefficient of 0.52 respectively and 0.58, have a more impact on reducing the aquifer level of Silakhor plain. In general, results of researches on drought and water scarcity in Iran has been contradictory and have not yet achieved any comprehensive and clear goal. Rising population and rising living standards in many countries have led to increasing demand for groundwater due to various uses such as drinking, agriculture, and industry (Nakhaei et al. 2009). Rezvankhah et al. (2018) examined the drop in groundwater level in the Birjand plain. The groundwater level of this plain has been decreased for 2.6 during the 30 years, since around 10% of surface water resources and around 90% of groundwater resources are harvested, therefore the highest amount of water harvested from the groundwater in the study area used in irrigation of agriculture lands. Razzaq et al. (2018) using the Entropy wavelet criterion, identified the effective factors in the fluctuation of groundwater resources in Tasuj plain. the results showed that pumping had more effect on groundwater level than changes in air temperature and precipitation. Some researchers believe that the water shortage crisis is due to climate changes (Rabani & Alikhani 2010; Vahidi 2011), and others believe that the uncontrolled perception of humans of water resources and the lack of proper management of these waters have reduced water resources (Fashkodi & Mirzaei 2013; Nourani et al. 2015). In recent years, identifying the factors affecting groundwater decrease is one of the most important points that politicians should pay attention to preserve this vital resource for the future. Entropy wavelets can be used to rank the factors and the percentage of the impact of different factors on groundwater changes. Shannon first used the entropy method to measure the content of signal information (1948). After Shannon, other researchers in different fields used the entropy method to analyze the signal and time series. (Chen & Li 2014; Varanis & Pederiva 2015). In this regard, Mishra et al. (2009), used the concept of Entropy to study the local and temporal changes of the rainfall time series in the US state of Texas. Using this criterion, they extracted several characteristics from the rainfall time series, including the number of rainy days. In another study, Komasi et al. (2016) used Entropy to identify the factors that reduce the groundwater level of Silakhor plain. Their results showed that 71% reduction in the complexity of runoff of rivers flowing out of this region more than the changes in precipitation and temperature with a decrease in complexity respectively of 15 and 10.5% has affected the reduction of groundwater level complexity, and this indicates the precedence of the impact of human factors on climate change factors in reducing the groundwater level in this plain. Anine & Madan (2017) the studied comparison of analytic hierarchy process, catastrophe and Entropy techniques for evaluating groundwater prospect of hard-rock aquifer systems. he validation results revealed that the groundwater potential predicted by the AHP technique has a pronounced accuracy of 87% compared to the Catastrophe (46% accuracy) and Entropy techniques (51% accuracy). It is concluded that the AHP technique is the most reliable for the assessment of groundwater resources followed by the Entropy method. The developed groundwater potential maps can serve as a scientific guideline for the cost-effective siting of wells and the effective planning of groundwater development at a catchment or basin scale. Mohammadrezapour & Kabiri (2016)
Khorramabad city is located in the west of Iran and it is one of the cities of Lorestan province (Figure 1). This study area is located between latitudes 47° 55' to 48° 50' east and latitudes 32° 40' to 34° 20' north. The study area is 2501 square kilometers and the average height of the area is 1903 meters. Khorramabad study area is one of the study areas of Karkheh watershed. The city has a Mediterranean climate with favorable precipitation, especially in spring. The most important studies conducted in this area are water resources census operations in the study areas of the Lorestan province in 2003 and 2009 and semi-detailed studies of water resources. According to the year 2009 census, Khorramabad study area has 611 wells, 7 aqueducts, 230 springs spring, 23 creeks, 115 mobile motor pump and a fixed pumping station which are used to supply water in different sectors (drinking, agriculture, and industry). Also, this plain has rivers such as Khorram river, Karganeh, Bahramjoo, Naveh-kesh, and Changaei. Table 1 shows the average statistical characteristics of the study area during 2005–2018. According to the available information from Lorestan province regional water company, the volume of discharge from the groundwater resources is 25.24 million cubic meters per year. Figure 2 shows the average groundwater level and precipitation in the study area. It should be noted that in Table 1 and Figure 2, the groundwater level is the average of the total groundwater in Khorramabad. Also, Figures 3 and 4 show the changes air temperature and runoff.

1.1. Case study
Khorramabad city is located in the west of Iran and it is one of the cities of Lorestan province (Figure 1). This study area is located between latitudes 47° 55' to 48° 50' east and latitudes 32° 40' to 34° 20' north. The study area is 2501 square kilometers and the average height of the area is 1903 meters. Khorramabad study area is one of the study areas of Karkheh watershed. The city has a Mediterranean climate with favorable precipitation, especially in spring. The most important studies conducted in this area are water resources census operations in the study areas of the Lorestan province in 2003 and 2009 and semi-detailed studies of water resources. According to the year 2009 census, Khorramabad study area has 611 wells, 7 aqueducts, 230 springs spring, 23 creeks, 115 mobile motor pump and a fixed pumping station which are used to supply water in different sectors (drinking, agriculture, and industry). Also, this plain has rivers such as Khorram river, Karganeh, Bahramjoo, Navehkesh, and Changaei. Table 1 shows the average statistical characteristics of the study area during 2005–2018. According to the available information from Lorestan province regional water company, the volume of discharge from the groundwater resources is 25.24 million cubic meters per year. Figure 2 shows the average groundwater level and precipitation in the study area. It should be noted that in Table 1 and Figure 2, the groundwater level is the average of the total groundwater in Khorramabad. Also, Figures 3 and 4 show the changes air temperature and runoff.

2. MATERIALS AND METHODS
Complex systems are phenomena that are highly complex due to the relationship between their components as well as communication with other phenomena and show different collective behavior. This means that by studying each component of a complex system, its collective behavior cannot be achieved. Therefore, understanding complexity in such systems will require...
understanding the nature of these systems and their structure and components the tendency to study complexity is to develop mathematical, computational or simulation tools based on understanding the physical behaviors that govern them to describe and predict such phenomena.

2.1. Entropy criterion

To calculate the Entropy criterion, must first calculate the wavelet energy, or in other words, the signal energy indicated calculated with the symbol $E_m$ from Equation (1):

$$E_m = |W_m(t)|^2$$

(1)

$W_m(t)$ is a subset of time $M = 1, 2, 3, \ldots, m$. If X is a discrete random variable with the values $x_1, x_2, x_3, \ldots, x_n$, and the corresponding probabilities $P_1, P_2, P_3, \ldots, P_n$, the Shannon Entropy is calculated from Equation (2), (Singh 2011).

$$H(x) = H(P) = - \sum_{i=1}^{n} P(x_i) \log[P(x_i)]$$

(2)

In Equation (2), $H(x)$ is the X Entropy, which is also called the Shannon Entropy function. $P$ is the probability distribution and is defined as $P = \{P_i, i = 1, 2, 3, \ldots, N\}$. The probability of a phenomenon occurring be high, its Entropy rate is low, and vice versa.

**Figure 1** | Study area.

**Table 1** | Statistical features of case study (average from 2005 to 2018)

| Parameter                              | Minimum | Maximum | Average | Standard deviation | Skewness |
|----------------------------------------|---------|---------|---------|--------------------|----------|
| Average groundwater level (meter)      | 1,223.3 | 1,226.5 | 1,224.9 | 2.5                | 0.7      |
| Precipitation (mm)                     | 0       | 117.5   | 38.1    | 47.1               | 1.5      |
| Temperature (degree Celsius)           | 1       | 31.1    | 17.2    | 8.1                | 0.7      |
| Evaporation (mm per month)             | 0       | 365     | 160     | 142.7              | 0.3      |
| Runoff (Cubic meters per second)       | 146.5   | 452.1   | 238.2   | 144.7              | 2.2      |
2.2. Wavelet theory

Wavelet theory is one of the methods of mathematical science, the main idea of which was taken from Fourier in the 19th century. The main purpose of cross wavelet is to obtaining a complete time-frequency representation of a local and temporary event that varies on time scales. Continuous wavelet transform diagrams are examined to identify periods that offer regions with high wavelet spectra. Cross wavelet diagrams to identify periods that provide areas with high wavelet spectra are

Figure 2 | Comparison of time series of changes in precipitation and groundwater level average in Khorramabad.

Figure 3 | Air temperature average time series graph in Khorramabad.
examined. According to Equation (3) with any desired mother wavelet, such as Morlet’s mother wavelet, Equation (4) can estimate the wavelet transform for the time series of each of the hydrological data x(t) (Labat 2010).

\[
C^*_{\psi} (a, b) = \int x(t) \frac{1}{\sqrt{a}} \psi\left(\frac{t - b}{a}\right) \, dt
\]  

(3)

\[\psi_0(\eta) = \Pi^{-\frac{1}{2}} e^{i\omega \eta} e^{-\eta^2/2}\]  

(4)

\(\psi_0\) is a function of the mother wavelet, \(e\) exponential function and \(\omega\) frequency without dimension and \(\eta\) time are dimensionless, the ‘*’ sign also refers to the mixed conjugate of the mother wavelet. The parameter \(a\) is expressed as a scale factor if it is \(a > 1\), the time series expands along the time axis, and if \(a < 1\) the time series contracts along the time axis. also, parameter ‘b’ is used as a position factor and allows you to study the time series x(t) around time b. the concept of wavelet transform can be used to investigate the relationship between two different time series related to two separate hydrological processes. for this purpose, the wavelet spectrum \(W_x(a, b)\) of the time series \(x(t)\) is similar to Fourie analysis and is defined by the absolute value of the wavelet coefficient.

\[W_x(a, b) = |C^*_{\psi} (a, b)|^2\]  

(5)

This wavelet spectrum can in time also averaging, which is generally defined as the average wavelet power spectrum and allows to specify the scale specification (Torrence et al. 1998). The vacillation alternation period specification is determined using the overall wavelet spectrum. Similar to the Fourier coherence spectrum and wavelet coherence spectrum \(W_{xy}(a, b)\) between two different hydrological time series \(x(t)\) and \(y(t)\) is defined as follows.

\[W_{xy}(a, b) = C^*_{\psi} (a, b)C^*_{\psi} (a, b)\]  

(6)

Which \(C^*_{\psi} (a, b)\) and \(C^*_{\psi} (a, b)\) to order of continuous-time series wavelet coefficients \(x(t)\) and mixed, the wavelet coefficient is \(y(t)\). The wavelet spectrum averaging technique is used to express the mutual covariance of time series \(x(t)\) and \(y(t)\) and its

Figure 4 | runoff averaging time series graph in Khorramabad.
distribution at different scales. There are many types of mother wavelet functions, the most important and most widely used of which are shown in Figure 5, (Mallat 1998).

2.3. Entropy wavelet criterion

The wavelet transform function can decompose time series into several time subsets with different scales and by studying the time subsets obtained from the general time series, analyzes the small-scale and large-scale behavior of a hydrological process. By combining the concepts of wavelet and Entropy, a new tool called Entropy wavelet is obtained to calculate complexity. Using this method, the time series can be decomposed into several subsets and the wavelet energy of each subset can be calculated, and consequently, the Entropy wavelet criterion can be calculated for each of them. The Entropy criterion actually indicates the amount of time series fluctuations and the value of this criterion is directly relationship to the intensity of the series oscillation. The wavelet energy is calculated in each subset of Equation (7), (Singh 2011).

\[ E_m = r_m^2 = \sum_n |c_m|^2 \]  

In this relation, m is the main signal separation scale and cm are the partial coefficients and n is the number of coefficients on the scale m. the signal total energy \((E_{\text{total}})\) is obtained from Equation (8), (Singh 2011).

\[ E_{\text{total}} = \sum_m \sum_n |Cm(n)|^2 \sum_m E_m \]  

Using Equation (9), the normalized wavelet energy of each subset is calculated:

\[ \rho_m = \frac{E_m}{E_{\text{total}}} \]  

After calculating the normalized energy of each subset, finally, the Wavelet-Entropy criterion is calculated using Equation (2) as follows:

\[ \text{WE} = -\sum_m \rho_m \ln [\rho_m] \]  

Figure 6 shows the process of calculating the wavelet Entropy criterion schematically. In this figure, the time series is first decomposed by converting the wavelet into several time subsets and then the normal energy of each subset is calculated. Finally, using Equation (10), the Wavelet-Entropy criterion is obtained from the normalized energies.

3. RESULTS AND DISCUSSION

3.1. Wavelet Entropy criterion

Figure 2 shows the fluctuations of Khorramabad groundwater level in the period 2005–2018. As can be seen from the figure, from the beginning of 2005 to the end of 2018, the groundwater level average has decreased by about three meters, which from 2009 to 2016, the groundwater level has dropped sharply. In this regard, to evaluated changes and find the effective
factors in this reduction, the Entropy wavelet criterion is used. In the first step of this research, the transformation and decomposition of the time series is used by wavelet transformation. In this regard, the 224-month time series of the average groundwater level is divided into four 56-month periods, and then each of these time series is transformed into a db2 wavelet with a decomposition degree of 1–5. It should be noted that after the decomposition degree 5, the values of normal energy suddenly approach closely to number and the expression $\ln[P_m]$ becomes zero, and as result, the values of normal energy from the degree of decomposition 5 onwards will not affect the Entropy wavelet transform from a degree of decomposition of 1–5. The Entropy wavelet criterion is used to analyze the time series of groundwater level and observe irregular changes in the time series trend. In this regard, the normalized energy ($\rho_n$) is calculated for each of the subsets obtained from the wavelet transform, and finally, the Entropy wavelet (WE) criterion is calculated in all four time intervals (Table 2). Figure 7 shows the groundwater level Entropy wavelet changes in four time periods for 56-months.

According to the Table 2, the Entropy wavelet criterion for groundwater time series has decreased for 21.3% in the second period, but it has increased in the third and fourth periods at 145.8 and 272%, respectively. Reducing the Entropy wavelet criterion indicates a reduction in the rate of complexity or, in fact, a reduction in the fluctuation of the second time series. Reduction of fluctuations in hydrological time series, Indicates the getting sick that hydrological feature (Nourani et al. 2015). Therefore, the groundwater level of the study area has involved by the disease in the second period and the main purpose of this study is to identify the cause of the disease among climatic and human factors. Hence, by recognizing the effective factors in the occurrence of this anomaly, it is expected that with the correct, efficient, and timely management measures and methods by the relevant institutions, the progress of the anomaly in the groundwater cycle can be prevented.

3.2. Investigating the effect of climatic and human factors on reducing the average level of groundwater

In recent decades, due to increasing population, industry, agriculture, and uncontrolled and unprofessional harvesting of groundwater, as well as changes in cultivation patterns that are not compatible with the state of water resources in the region have caused a great need for water in the study area. As a result, exploitation of groundwater resources by digging multiple wells, directly, and exploitation of surface water has directly and indirectly affected the reduction of groundwater level. Also, rising air temperatures and consequent climate changes are some of the biggest challenges facing the world which has changed climate patterns. Figure 8 shows the location of aquifers and water sources in the study area. According
Figure 8, 611 wells have been drilled in the study area. In this study, to investigate the impact of climatic and human factors on reducing the groundwater level have been used of three parameters precipitation, runoff (runoff refers to the water flow in the study area), and air temperature. Precipitation and air temperature representative of climatic factors and the runoff parameter due to increased human harvesting from surface water resources to meet the needs of drinking, agriculture, and industry reduces the water flow is considered as human factor. It should be noted that changes runoff parameter cannot be the clear criterion and exact for the effect rate of human actions on groundwater resources because the runoff of surface currents is somehow affected by atmospheric and climatic factors, but because there is no accurate criterion to assess the impact of human, the runoff water is considered as human factor. It can be clearly said that the withdrawal from this groundwater for various uses has played an important role in reducing the level of these waters. On the other hand, land-use changes also affect reduce resources groundwater level, but due to the lack of accurate information from land-use change in the study area, only been investigated the parameters of precipitation, temperature, and runoff. These time series are divided into four 56-months periods and then placed under the wavelet function db2 and the degree of decomposition 1–5. Then the normalized energy is calculated for each decomposed subset. And at the end, the entropy wavelet criterion is obtained for each precipitation interval time, air temperature, and runoff (Table 3–5). Figure 9 shows a graph of changes in precipitation, air temperature, and runoff in four time periods.

The reviews in the Table 3 show that the Entropy wavelet criterion rate for the runoff time series in the second, third, and fourth periods increased for 36.1%, 13.4%, and 24.1%, respectively. As a result, there no have been any fluctuation reduction in the runoff time series. Also according to the Table 4, the Entropy wavelet criterion rate for the air temperature time series in the second and fourth periods increased for 29.65% and 34.7%, respectively, and decreased for –26.8% in the third period.
Table 5 shows the Entropy wavelet changes in four periods for the precipitation time series. As it is known, the fluctuations of this time series have decreased by 35.2% in the second period, 32.8% in the third period and 10.06% in the fourth period. So it can be concluded that, the precipitation time series in the second period has been the greatest decrease in entropy wavelet criterion compared to runoff time and air temperature series. To better understanding of the changes in this criterion, a graph of its changes for all three-time series is drawn in Figure 9. According to Figure 9 and according to the results obtained from the investigation of the complexity of runoff time series, air temperature, and precipitation and its correspondence with the time period when the groundwater level has decreased, it is concluded that in the time period Second, the precipitation parameter has had the is the greatest effect by decrease the complexity for 35.2% in decrease the complexity for 21.3% and changing the oscillating pattern of groundwater level. Also, in the second period, when the groundwater level has decreased,
only the precipitation parameter has decreased according to the Entropy wavelet criterion, and the temperature and runoff parameters show an increase. The time series of air temperature also in the third period has decreased by 26.8% according to the Entropy wavelet criterion, but as it can be seen, the time series of groundwater level has increased in this period, so we

Table 4 | Entropy wavelet criterion for time series of air temperature

| Normalized energy of subsets | First period | Second period | Third period | Fourth period |
|-------------------------------|-------------|--------------|-------------|--------------|
| $\rho_1$                      | 0.00032250  | 0.0005988    | 0.00027663  | 0.0006321    |
| $\rho_2$                      | 0.0023      | 0.0064       | 0.0024      | 0.0062       |
| $\rho_3$                      | 0.0302      | 0.0369       | 0.0286      | 0.0354       |
| $\rho_4$                      | 0.0075      | 0.0102       | 0.0066      | 0.0106       |
| $\rho_5$                      | 0.9596      | 0.9460       | 0.9622      | 0.9472       |
| Entropy wavelet criterion (WE)| 0.1986      | 0.2575       | 0.1884      | 0.2539       |
| Percentage of changes         | ***         | −26.8%       | 34.7%       |

Table 5 | Entropy wavelet criterion for time series of precipitation

| Normalized energy of subsets | First period | Second period | Third period | Fourth period |
|-------------------------------|-------------|--------------|-------------|--------------|
| $\rho_1$                      | 0.0433      | 0.0189       | 0.0094      | 0.0118       |
| $\rho_2$                      | 0.0243      | 0.0341       | 0.0078      | 0.0168       |
| $\rho_3$                      | 0.0738      | 0.0297       | 0.0416      | 0.0153       |
| $\rho_4$                      | 0.0558      | 0.0102       | 0.0105      | 0.0127       |
| $\rho_5$                      | 0.8028      | 0.8921       | 0.9307      | 0.9434       |
| Entropy wavelet criterion (WE)| 0.7559      | 0.4892       | 0.3287      | 0.2956       |
| Percentage of changes         | ***         | −35.2%       | −32.8%      | −10.06%      |

Figure 9 | Entropy wavelet criterion changes for precipitation, runoff, and air temperature in 4 different periods.
can say that air temperature has no significant effect on groundwater level fluctuations. Also, the runoff time series has not decreased according to the entropy wavelet criterion, so the role of human factors in reducing the groundwater level of Khorramabad is low. Therefore, because precipitation changes are the most important example of climate change effects in this region, as a result, it can be said that the impact of climate change factors than the human factor in the occurrence of adverse trends groundwater level has been more in Khorramabad. On the other hand, human intervention in the environment of the region, lack of management in the use of running water resources, misuse and traditional use of groundwater, population increase, land-use change and, change in cultivation pattern leads also, to a decrease in groundwater level has been in Khorramabad. The impact of climatic factors on the decrease of groundwater level has been investigated by Kaur et al. (2021) so that using MODFLOW, it has been concluded that precipitation has had the greatest impact on groundwater level fluctuations in Punjab.

4. CONCLUSION

Identifying the factors or the most important factor in lowering the groundwater level is very important for future planning. In this research, to analyze the time series of groundwater level in the Khorramabad aquifer, first, this series was divided into four time periods, and finally, the Entropy wavelet criterion was obtained for each period of the groundwater level time series. The results showed that in the second period (between 2008 and 2011) the Entropy wavelet criterion had a decrease of 21.3%. Decreasing this criterion indicates a decrease rate in groundwater level time series fluctuations and finally indicates the occurrence of an unfavorable trend in groundwater level changes in the study area. After examining the changes in the Entropy wavelet criterion in the same four periods for time series precipitation, air temperature, and runoff, it was shown that in the second period, the Entropy wavelet complexity criterion for precipitation time series decreased at the rate of 35.2%, and this issue proved the significant effect of changes in precipitation relative to runoff and temperature on the disease or in fact the occurrence of an undesirable trend in groundwater level fluctuation in Khorramabad. Therefore, climatic factors have the greatest impact on decrease the groundwater level of Khorramabad. According to the results that show the effects of climatic factors in decrease the groundwater level of Khorramabad, it is recommended to prevent the uncontrolled abstraction of groundwater by performing proper management practices and increasing the efficiency of irrigation systems if the groundwater level decreases in the future with the same trend, it will not be long other precipitation cannot be effective in this trend and the region will face a major crisis. In completing the present study, the proposed method is suggested to be applied in daily and annual data to compare the results with the obtained results from monthly data. Other wavelets such as coherence and cross wavelet and Man-Kendal can be used to analyze data to examine different time series at different time scales.

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COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest. Open Access

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DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.
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