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Trend Analysis of Groundwater Quality Using Coherence and Cross Wavelet (Case Study of Khorramabad City)

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ABSTRACT

Today, monitoring groundwater quality and the trend of its changes for drinking, industrial and agricultural uses is very important for the general health of society. Due to changes in groundwater quality that can be due to climatic or human factors, it is necessary to consider and study these resources to maintain their quality. The purpose of this study is to investigate the quality and effective factors in groundwater quality changes in Khorramabad from 2005 to 2018 using the global water quality index (WQI) and coherence and cross wavelet. To achieve this goal, first, the drought assessment of Khorramabad city has been studied according to precipitation data using the index (SPI). Then, using the world water quality index (WQI), the groundwater quality of Khorramabad has been studied. The results showed that the quality of groundwater in Khorramabad during the years 2005 to 2018 was in standard condition. Also, the correlation between the chemical parameters of groundwater has been evaluated. The results of coherence and cross wavelet showed that the relative effect of precipitation with a wavelet coherence coefficient of 0.5 had been more compared to other factors in changes in groundwater quality in Khorramabad city. Therefore, it can be said that the relative impact of climatic factors on changes in groundwater quality in Khorramabad has been more than the other factors. Accordingly, appropriate management strategies for groundwater quality resources and mitigation solutions are imperatively needed to ensure the sustainability of the groundwater resource and the protection of public health in Khorramabad city.

Keywords: SPI, Water Quality, Khorramabad, WQI, Coherence Wavelet.

1. INTRODUCTION

Water is the most important vital resource for all humans and living organisms. Therefore, declining groundwater quality is one of the current concerns worldwide. Today, climate change and its effect on increasing temperature, amount, and precipitation type in reducing the quality of water resources are important topics in hydrology. Chemical parameters in drinking water are so important that increasing or decreasing them directly has a great impact on human health. Most attention is paid to finding groundwater aquifers suitable for drinking water supply, agriculture, and industry in developing countries. At the same time, less attention is paid to maintaining the quality of aquifers. The main purpose of studying the quality of drinking water is to maintain consumers' health and general health. There are many studies on groundwater quality in different parts of the world; for example, the drinking water quality assessment results in the south of Sind by Memon et al. (2011) showed that the water in this area is very turbid [1]. In this regard, Vijai et al. (2021), studied the analysis of groundwater quality for irrigation purposes in the Pennagaram block of Dharmapuri District, Tamilnadu, India. The results showed that PS and Sodicity index of the groundwater of marginal quality, i.e., closely unfit for the irrigational purpose [2]. Also, Udeshani et al. (2020), studied the in Sri Lanka assessment of groundwater quality using the water quality index (WQI). The calculation of the Water Quality Index (WQI) indicated that over 50% of groundwater samples of the study area are poor in quality [3]. The WQI index was developed in 1970 and is a tool for assessing and monitoring the temporal and spatial variation of water quality parameters that can provide us with very useful information on water quality (Boyacioglu., 2007) [4]. In this regard, Mohd and Abhishek. (2020), the investigated groundwater quality assessment in the Lower Ganga Basin using entropy information theory and GIS. The results obtained in this paper are useful for identifying suitable sites for tube-wells and bore-wells for drinking and agricultural purposes and also for developing an effective strategy to avoid further contamination of groundwater aquifers in the region [5]. Krishan et al. (2016) evaluated the quality of India's groundwater resources using the WQI index, and the result showed that the quality of this water is suitable for drinking purposes [6]. Ghaffari et al. (2021), studied the Spatial and temporal variation of groundwater quality around a volcanic mountain in the northwest of Iran. The results indicated that groundwater quality in the studied area is deteriorating [7]. The WQI index reflects the combined effect of several water quality parameters that have received much attention in recent years for monitoring groundwater quality for drinking purposes due to the inclusion of comprehensive, complete, and understandable information on water quality status (Tiwari & Singh. 2014) [8]. Today, more than one billion people in the world do not have access to safe drinking water, and 80 percent of all diseases in developing countries have unhealthy water sources (Grom & Theodor. 2003) [9]. Drought is one of the important factors in changing the quality of water resources. Reducing the water incoming the water sources or evaporating it increases the concentration of elements in the water; therefore, it is very important to determine the relationship between drought and water quality (Sprague 2005) [10]. Discharge of municipal and industrial wastewater, runoff, and wastewater disposal site are factors that reduce the quality of groundwater (Dorgham. 2004 [11] & Lucassen. 2004 [12]). Soleimani (2015) evaluated the changes in water quality in the Kashkan river in Lorestan province; the results showed that drought has a great impact on quality parameters such as chlorine, sodium, total dissolved solids in water, and electrical conductivity of water [13]. Sarti et al. (2021), studied the integrated assessment of groundwater quality beneath the rural area of R'mel, Northwest of Morocco. The comparison between WQI and HCA showed that the combined use of the two methods might lead to a better classification of groundwater samples [14]. Kumar, in 2010, surveyed the quality of drinking water in the villages of Songonar, India, using multivariate statistical analysis, which results showed that the water quality of the villages was deteriorating. Determining the quality status of water resources is essential to adopt appropriate strategies to prevent reducing quality (Ramirez & Solano. 2004) [15]. Gintamo et al. (2021), in Cape Town, studied the GIS-based modeling of climate variability impacts on groundwater quality. Modeling analysis based on GIS showed that the southern and central suburbs of the study area are more susceptible to groundwater contamination and have high surface runoff and higher average temperatures [16]. Varol et al. (2021) in Şuhut plain studied the assessment of groundwater quality and human health risk related to arsenic using index methods and GIS. It has been determined that groundwater samples are generally in "excellent" and "good" water class according to the WQI and IWQI assessment; at the same time, groundwater in the study area is suitable for agricultural irrigation water [17]. Water quality is one of the most important factors that should be considered when assessing the proper development of an area (Cordoba et al. 2010) [18]. In a study, Zeinali et al. (2016) investigated the effect of drought on groundwater quality in the Marand plain. The results showed that the increase in the area under cultivation and also the increase in groundwater abstraction had caused a change in the quality of groundwater [19]. Astraie et al. (2012) evaluated the quality of water resources in the UK, and the results showed that climate change is the most important factor in reducing water quality. Healthy drinking water must have appropriate quality indicators (such as physical and chemical properties) [20]. One of these indicators is the concentration value of the main ions in the water. Also, groundwater salting is becoming a very serious problem in the world, so the problem of salinity is expressed as the most common groundwater pollution (Khosravi et al. 2016) [21]. To predict the qualitative changes of water resources, it is necessary to statistically study other phenomena in that place (Rabah et al. 2011) [22]. Kawagoshi et al. (2019), investigated the understanding of nitrate contamination based on the relationship between changes in groundwater levels and changes in water quality with precipitation fluctuations. This study demonstrates the importance of temporally intensive, long-term monitoring for capturing changes in groundwater level and water quality with precipitation fluctuations [23]. Based on the research background, this study purpose of evaluating the quality and correlation between chemical parameters of groundwater quality in Khorramabad city using the WQI index. Also, coherence and cross wavelet has been used to investigate the factors affecting the changes in groundwater quality in Khorramabad city.

2. MATERIALS AND METHODS

2.1. Case Study

Khorramabad city is located in western Iran is the capital 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 city has a Mediterranean climate with favorable rainfall, especially in spring. The most important studies conducted in this area of water resources census operations in the study areas of the Lorestan province in 2003 and 2009 and also semi-detailed studies of water resources in the study area of Khorramabad have been performed. The study area is 2501 square kilometers, and the average height of the area is 1903 meters. Also, this plain has rivers such as the Khorram River, Karganeh, Bahramjoo, Navehkesh, and Changaei. Khorramabad study area is one of the study areas of the Karkheh watershed. According to the year 2009 census, the Khorramabad study area has 611 wells, 7 aqueducts, 230 springs spring, 23 creeks, 115 mobile motor pumps, 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 the Khorram River, Karganeh, Bahramjoo, Navehkesh, and Changaei. Figure 2 shows the groundwater quality (WQI) and precipitation in the study area. Figure 3 shows the runoff changes in the study area. Table (1) shows the statistical characteristics of the study area.

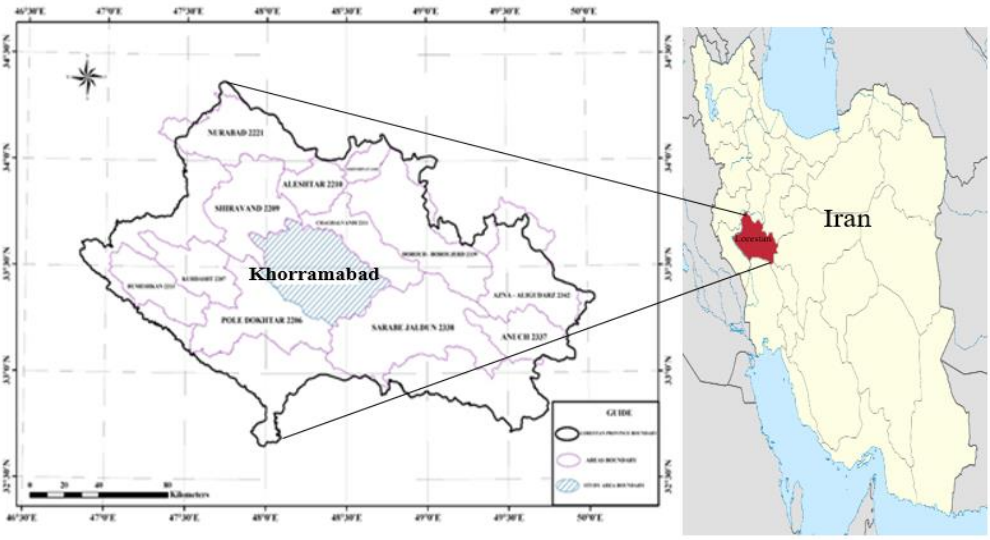

Figure 1. study area

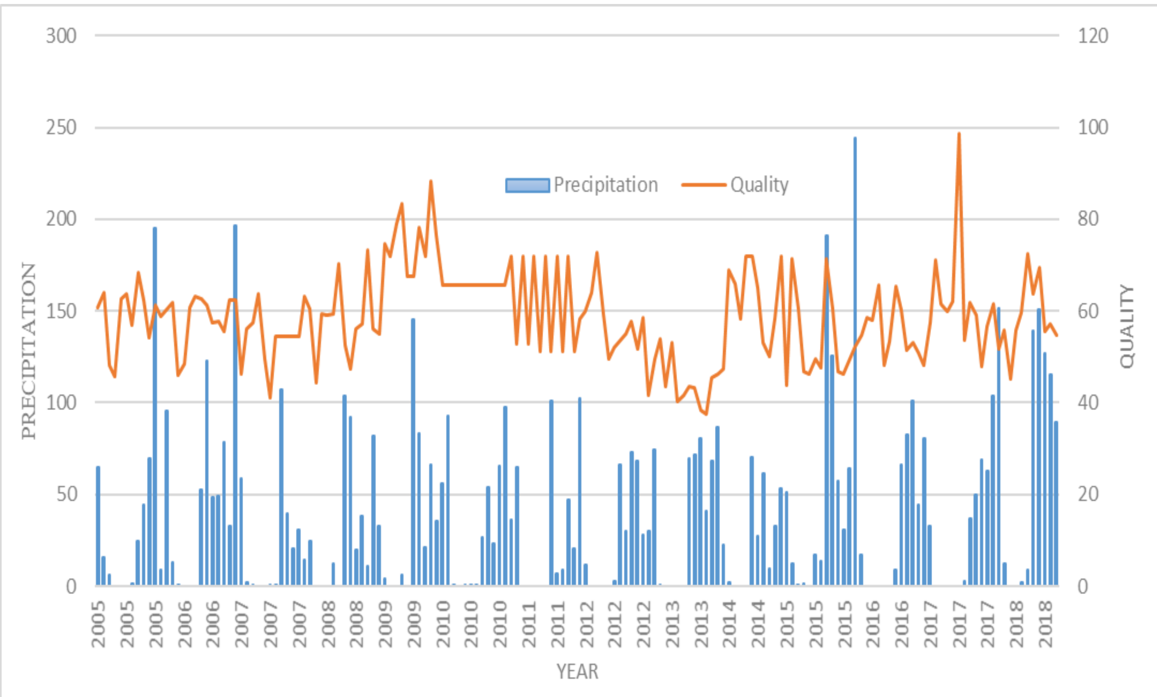

Figure 2. the groundwater quality (WQI) and precipitation in the study area

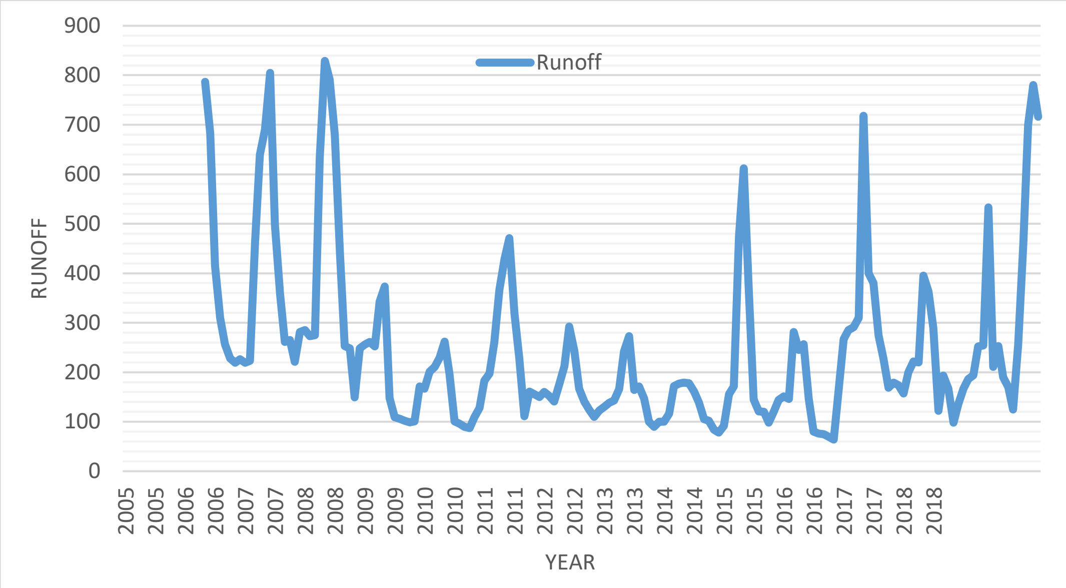

Figure 3. the runoff changes in the study area.

Table 1. Meteorological information of the study area (from 2005 to 2018)

Parameter	Minimum	Maximum	Average	Standard deviation	Skewness
Precipitation (mm)	0	117.5	38.1	47.1	1.5
Temperature (Degree Celsius)	-2	42.1	19.3	8.1	0.7
Evaporation (mm in month)	0	365	350.5	142.7	0.3

2.2. Standard Precipitation Index (SPI)

The SPI index is a powerful tool to process the precipitation data, and its purpose is to assign a numerical value to rainfall through which areas with different climates can be compared together. One of the advantages of SPI is that the calculation of SPI is based on rainfall data and does not depend on soil moisture conditions; another advantage is that this index is not affected by topography (Komasi et al. 2013) [24]. In general, this index is defined to express drought as followed: when the SPI is permanently negative and reaches a value -1 or less and when the value is positive. Therefore, positive values indicate above-average rainfall, and negative values indicate less rainfall from average rainfall, which is shown in table (2) (Komasi et al. 2013) [24].

Table 2. Drought classification based on SPI index (Hassanzadeh et al. 2012) [25]

Index values	Drought intensity
2 and more	**extremely wet**
1.5 to 1.99	**very wet**
1 to 1.49	**Gentle wet**
-0.99 to 0.99	**Near to normal**
-1.49 to -1	**Gentle drought**
-1.99 to -1.5	**very drought**
-2 and lees	**extremely drought**

The main data of the SPI index are the rainfall data of rain gauge stations. After ensuring the homogeneity and randomness of the monthly data, times series is formed in the intervals of 6 and 12 months, and its time series is fitted with a gamma distribution which is a function of probability density given in equation (1) (Mckee et al. 1993) [26].

$$f(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} X^{\alpha-1} e^{-x/\beta} \tag{1}$$

In this relationship x≥0 amount of rainfall, α>0 shape parameter, β>0 scale parameter, and Γ(α) is a function gamma introduced by equation 2.

$$(\alpha) = \int_0^{\infty} y^{\alpha-1} e^{(-y)} dy \tag{2}$$

In equation (2), the parameters α and β related to the gamma density function are estimated for each station and for each time scale, and for each month of the year. Mckee et al. estimated α and β coefficients using the optimal maximum proofing based on equations (3) to (5). (Mckee et al. 1993) [26].

$$\alpha = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{a}}\right) \tag{3}$$

$$A = \ln(\overline{X}) - \frac{\sum \ln(X)}{n} \tag{4}$$

$$\beta = \frac{\overline{x}}{a} \tag{5}$$

In the above equation, n is the number of rainfall observations, and x is the average rainfall for several months. The calculated parameters to find the cumulative probability of precipitation used for a specific time in each station, this probability can be converted to an incomplete gamma function according to equation 6 with the assumption t=x/β.

$$G(X) \int_0^X g(X) dX = \frac{1}{\Gamma(\alpha)} \int_0^X t^{(\alpha-1)} e^{(-t)} dt \tag{6}$$

Since the gamma function is not defined for x=0, the rainfall distribution has a value of zero the cumulative Probability is calculated as equation 7.

$$H(X) = q + (1 - q)G(X) \tag{7}$$

The probability of rainfall is zero, and m is the number of zeros in the rainfall time series, which estimates (q) as the product of m divided by the total number of data (n) then having H(x) and relation 8 to 11, SPI is obtained.

$$SPI = -\left[t - \frac{C_0 + C_1 t + C_2 t}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right] \quad 0 \le H(X) \le 0.5 \tag{8}$$

$$SPI = +\left[t - \frac{C_0 + C_1 t + C_2 t}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right] \quad 0.5 \le H(X) \le 1 \tag{9}$$

$$t = +\sqrt{\ln\left(\frac{1}{H(X)^2}\right)} \quad 0 \le H(X) \le 0.5 \tag{10}$$

$$t = +\sqrt{\ln\left(\frac{1}{(1-H(X))^2}\right)} \quad 0.5 \le H(X) \le 1 \tag{11}$$

In these relation, the coefficients are constant C_0,C_1,C_2,d_1, d_2,d_3 which should be placed from table 3 in relationships 8 to 11 (Mckee et al. 1993) [26].

Table 3. Coefficients values of SPI calculation formulas (Mckee et al. 1993) [26]

Coefficient	**d_1**	**d_2**	**d_3**	**C_0**	**C_1**	**C_2**
Value	1.43	0.18	0.01	2.51	0.80	**0.10**

2.3. Coherence Wavelet Transformation

The main purpose of a coherence wavelet is to obtain a complete time-frequency representation of a local and temporary event that varies on time scales. Coherence wavelet transformation diagrams are examined to identify periods that offer regions with high wavelet spectra. Coherence wavelet diagrams identify periods that provide areas with high examined wavelet spectra examined. According to equation 12 with any desired mother wavelet, like Morlet's mother wavelet, equation 13 can estimate the wavelet transform for the time series of each hydrological data x(t) (Labat. 2010) [27].

$$C^{*x}_{\psi}(a,b) = \int x(t)\frac{1}{\sqrt{a}}\psi\left(\frac{t-b}{a}\right) \quad (12)$$

$$\psi_0(\eta) = \Pi^{-1/4}e^{i\omega_0\eta}e^{-\eta^2/2} \quad (13)$$

Ψ_0 is a function of the mother wavelet, e exponential function and ω frequency without dimension η time are dimensionless, and also mark "*"refers to a mixed mating of the mother wavelet. The parameter "a" is expressed as a scale factor if it is $\alpha > 1$, the time series expands along the time axis, and if $\alpha < 1$, the time series contracts along the time axis. 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 Fourier analysis and is defined by the absolute value of the wavelet coefficient.

$$W_x(a,b) = C^{x}_{\psi}(a,b)C^{*x}_{\psi}(a,b) = |cx(a,b)|^2 \quad (14)$$

This wavelet spectrum can be averaged in time, which is generally defined as the average wavelet power spectrum and allows to specify the scale specification (Torrence et al. 1998) [28]. The vacillation alternation period specification is determined using the overall wavelet spectrum. Similar to the Fourier coherence spectrum and wavelet reciprocal spectrum $W_{xy}(a,b)$ is defined between two different hydrological time series x(t) and y(t), as follows.

$$Wxy(a,b) = C^{x}_{\psi}(a,b)\, C^{*x}_{\psi}(a,b) \quad (15)$$

Which $C^{x}_{\psi}(a,b)$ and $C^{*x}_{\psi}(a,b)$ are the 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 distribution at different scales.

2.4. Cross Wavelet Transformation

The cross wavelet spectrum was inappropriate to express the interrelationship between the two processes. Hence, the use of coherence wavelet transforms in time series processing is more appropriate to find a criterion of correlation between two-time series at different frequencies and time (Nourani et al. 2016) [29]. In this regard (Torrence. 2011) [28], suggested that the wavelet correlation be determined using wavelet spectrum smooth estimation. Smooth wavelet spectrum $SW_{xx}(a,b)$ and wavelet reciprocal spectrum $SW_{xy}(a,b)$ is defined as below:

$$SWxx(\alpha,b) = \int_{t-\delta/2}^{t+\delta/2} W^{*}_{xx}(a,b)\, W_{xx}(a,b)dadb \quad (16)$$

$$SW_{xy}(\alpha,b) = \int_{t-\delta/2}^{t+\delta/2} W^{*}_{xx}(a,b)\, W_{yy}(a,b) \quad (17)$$

In this regard, δ represent the size of the two-dimensional filter (Luterbacher et al. 2002) [30]. Finally, the criterion of coherence wavelet transform relation can also be defined similarly to Fourier coherence as follows:

$$WC(\alpha,b) = \frac{|SWxy(a,b)|}{\sqrt{|SWxx(a,b)|.|SWyy(a,b)|}} \quad (18)$$

2.5. Water Quality Index (Wqi)

Water quality index WQI is one of the techniques used to evaluate water quality. This method was first proposed by Horton [31] in the year 1970. This factor is usually obtained with the number of general parameters of water, including dissolved oxygen, acidity, hardness, water-soluble solids, temperature, turbidity, the electrical conductivity of water, nitrite, nitrate, chlorine, and some of the main ions. Some studies of this statistical technique have been analyzed using the weight score of each parameter, used to evaluate the water quantity index (Toledo et al. 2002) [32] (Table 4). The WQI index for easy determines water quality classification in the ratio of numbers less than 50 to more than 300, in which high values indicate lower quality and lower values indicate higher water quality. This method helps to interpret water quality in numerical values. In this study, the parameters PH, TDS, Ca, Mg, Na, K, HCO_3, Cl, SO_4, TH, and EC were used for the WQI index. In WQI index calculation, the first step is weighting for each parameter. According to its relative importance, specific weight is assigned (table 4). The second step is the calculation of relative weight based on equation (19):

$$W=\frac{Wi}{\sum_{i=1}^{n} Wi} \qquad (19)$$

Where, w_i weight of each parameter in the number of parameters.

Table 4. Weight ratio of chemical parameters (WHO Standard)

Chemical parameters	Unit	WHO Standard	Weight	Weight ratio
PH	-	6.5-8.5	4	0.129
TH	Mg/l	200	2	0.064
EC	µ mhos/cm	250	3	0.096
Ca	Mg/l	75	2	0.064
Mg	Mg/l	50	1	0.032
K	Mg/l	12	2	0.064
Na	Mg/l	200	2	0.064
HCO3	Mg/l	120	3	0.096
Cl	Mg/l	250	3	0.096
SO4	Mg/l	250	4	0.129
TDS	Mg/l	600	5	0.161
Total	-	-	31	-

The third step is to calculate the quality rate scale. This scale (q_i) is calculated by dividing the concentration of each parameter in each water sample by the standard value of that parameter according to equation (20).

$$q_i=\frac{c_i}{s_i}\,100 \qquad (20)$$

Which in Ci concentration and Si chemical standard, each parameter in the water sample is in Mg/l. Then to estimate WQI, S_i for each chemical parameter is determined by equations (21) and (22):

$$SI_i=W\,q_i \qquad (21)$$

$$WQI=\sum_{i=1}^{n} SI_i \qquad (22)$$

Table 5. Water quality classification based on WQI index (Ramakrishanaiah et al. 2009) [33]

Quality class	Value of the index obtained
Unsuitable	300
Very weak	200-300
Weak	100-200
good	50-100
Excellent	<50

3. RESULT AND DISCUSSION

3.1. Drought Index Result

To calculate the drought index and its effects on water quality, precipitation data obtained from the meteorological organization of Lorestan province have been used. The results of the SPI drought index with an annual scale are shown in figure (4). According to the results of the SPI drought, it can be said that Khorramabad in the years 2008 and 2012 was in a gentle drought situation and the year 2016 was gentle wet. It has been near to normal in other years as well.

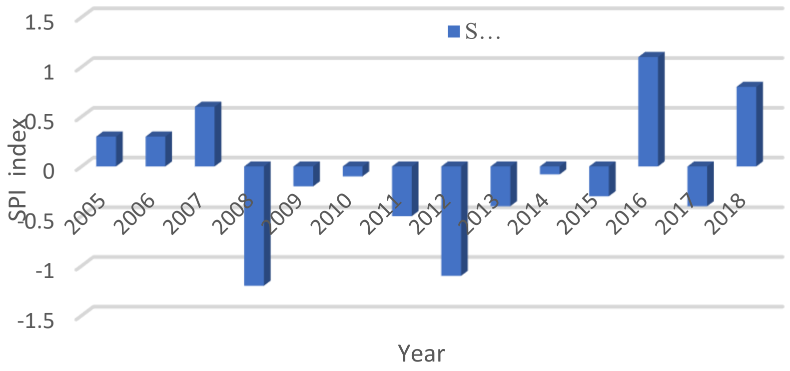

Figure 4. Results of drought in the years 2005 to 2018 in the area of study

3.2. Water Quality Index Result

To calculate the WQI index, water quality data obtained from Lorestan province regional water company have been used. The results of the WQI with an annual scale are shown in table (6). According to the results of this index, it can be said that the quality of groundwater in Khorramabad in the period of 2005 to 2018 was in a favorable condition. So in 2007, 2012, and 2014, the groundwater quality of Khorramabad has been in excellent condition, and other years it was in good condition. This means that the groundwater of Khorramabad has been suitable for drinking, agriculture, and industry use. Table (7) shows the annual average value of chemical parameters of water quality. Also, in table (8), the correlation between different parameters of water quality with the influencing factors is investigated. Examination of the results in table 8 shows that the highest and lowest correlations in the WQI quality index are WQI-EC and WQI-K, respectively. The results of the correlation table do not show the relation of quantities well, so used the quantities relation solution based on reciprocal and coherence and cross wavelet transform.

Table 6. Values and description of water quality index (WQI) for the years 2005 to 2018

Year	WQI index	Descriptive equivalent
2005	55.8	good
2006	58.1	good
2007	46.7	excellent
2008	58.5	good
2009	72.5	good
2010	65.7	good
2011	57.6	good
2012	44.2	excellent
2013	60.7	good
2014	48.2	excellent
2015	55.9	good
2016	61.4	good
2017	58.5	good
2018	55.1	good

Table 7. Value of water quality parameters (annual average 2005 to 2018)

Parameter	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
TDS	422.4	418.3	358.2	411.3	478.6	320.9	387.5	355.6	284.5	376.7	319.5	330.5	372.5	366.1
SO_4	0.5	0.6	1.1	0.5	0.6	0.5	0.7	0.2	0.4	0.3	0.3	0.4	0.7	0.7
Cl	0.6	0.5	0.4	0.7	1	0.6	0.7	0.5	0.6	0.9	0.7	0.8	1.1	0.9
Ca	3.7	3.8	3.7	3.8	3.4	3.7	2.4	3.1	2.7	2.6	3.1	2.7	3.1	2.6
HCO_3	5.2	5.1	4.1	5.1	5.3	3.2	4.5	4.6	3.2	4.5	4.6	3.9	3.9	3.6
Mg	2.1	1.7	1.3	1.9	2.8	1.8	2.4	1.8	1.1	2.1	1.2	1.6	1.6	1.9
TH	295.4	278.3	255.8	288.3	308.7	240	245	266.5	188.7	241.6	217.5	219.1	239.1	230.4
Na	0.3	0.5	0.5	0.5	0.7	0.5	1.1	0.2	0.4	0.9	0.5	0.7	1.2	0.7
PH	7.2	7.6	7.8	7.5	7.8	7.8	7.8	7.5	7.5	7.5	7.5	7.3	7.1	7.7
K	0.1	0.02	0.02	0.02	0.01	0.04	0.05	0.04	0.02	0.02	0.02	0.02	0.02	0.04
EC	653.6	652.5	584.1	652	715	750	600	508.1	444.1	584.3	497.3	516.5	592.1	572.1

Table 8. Results of correlation coefficients between water quality parameters

Parameter	TH	SO_4	Ca	Cl	Na	TDS	PH	EC	K	mg	WQI	SPI	precipitation	Runoff
TH	1													
SO4	0.19	1												
Ca	0.38	0.8	1											
Cl	0.33	0.11	0.09	1										
Na	0.33	0.05	0.06	0.50	1									
TDS	0.65	0.16	0.20	0.44	0.60	1								
PH	0.01	0.07	0.04	0.01	0.01	0.06	1							
EC	0.76	0.18	0.34	0.52	0.62	0.91	0.05	1						
K	0.01	0.05	0.03	0.01	0.03	0.04	0.01	0.08	1					
mg	0.48	0.02	0.01	0.20	0.13	0.36	0.04	0.42	0.01	1				
WQI	0.77	0.16	0.20	0.49	0.57	0.89	0.03	0.94	0.02	0.48	1			
SPI	0.03	0.06	0.1	0.01	0.01	0.09	0.01	0.04	0.03	0.05	0.07	1		
precipitation	0.0002	0.001	0.01	0.01	0.01	0.001	0.04	0.0001	0.04	0.01	0.0005	0.07	1	
Runoff	0.002	0.008	0.01	0.01	0.02	0.0004	0.003	0.0002	0.11	0.002	0.0007	0.32	0.15	**1**

3.3. Results of Coherence and Cross Wavelet

To investigate the impact of climatic and human factors on reducing the groundwater quality, this study has used three parameters: precipitation, runoff (runoff refers to the water flow in the study area), and drought. Precipitation and drought 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 effective 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 exist accurate criterion to assess the impact of human, the runoff water is considered as human factor. Coherence and cross wavelet estimate the amount of interaction and phase delay of two-time series relative to each other. This conversion indicates in what period and with what phase delay the two-time series are related. For this purpose, the time series of Quality-precipitation, Quality-drought, and Quality-Runoff in pairs are entered into the coherence and cross wavelet algorithm entered in Matlab software, and the degree of impact and interrelationship between these time series are measured. As the results of coherence and cross wavelet, the areas marked with bold lines and dense arrows are the areas where the coherence and cross wavelet have shown local behavior. This concept means that there is a significant correlation between the corresponding fluctuations of the two time series in the periodicity (coherence band). The arrows to the right indicate that the two-time series are in the same phase and the arrows to the left indicate that they are not in the same phase, and the up or down arrows indicate that a time series with a 90-degree angle leads to another. Figure 5 shows the process of determining the impact of time series groundwater quality in Khorramabad city by coherence and cross wavelet. The results of coherence and cross wavelet transform for the time series mentioned in figures 6, 7, and 8 are shown.

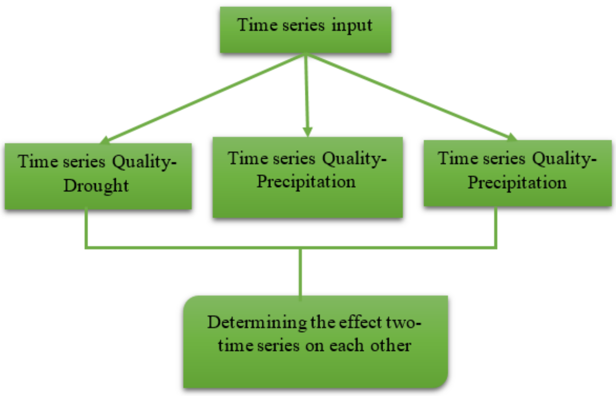

Figure 5. The process of determining the impact of time series on the groundwater quality of Khorramabad city by coherence and cross wavelet.

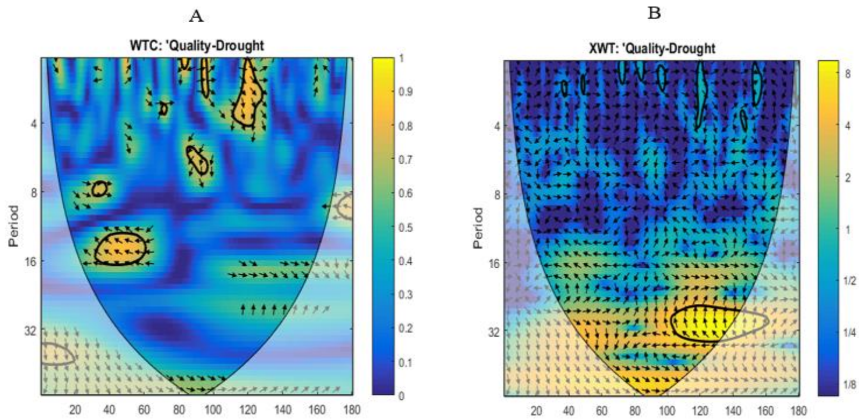

Figure 6. Results coherence wavelet (figure A) and cross wavelet transform (figure B) for compare time series quality-drought.

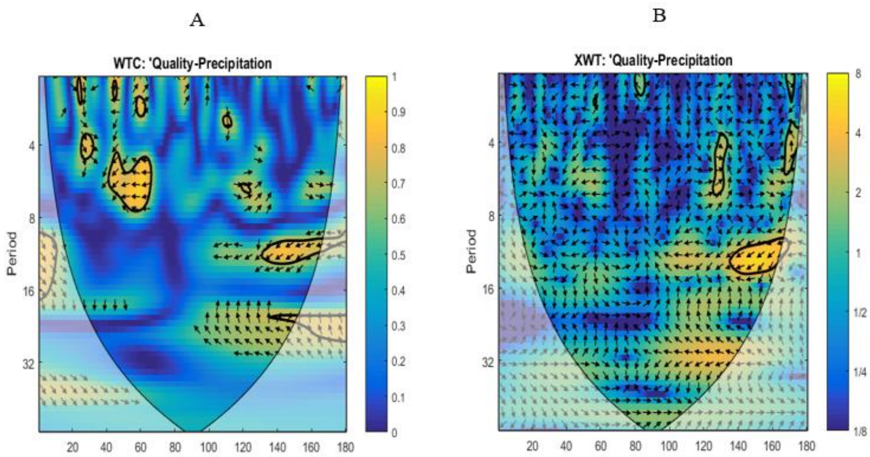

Figure 7. Results coherence wavelet (figure A) and cross wavelet (figure B) for compare time series quality-precipitation.

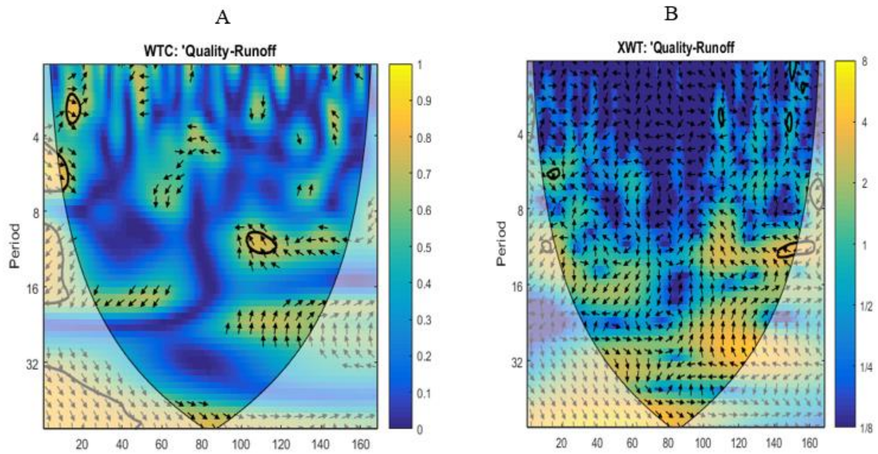

Figure 8. Results coherence wavelet (figure A) and cross wavelet transform (figure B) for compare time series quality-runoff.

Figure 6 shows the coherence and cross wavelet of two-time series quality-drought, with band range coherence of about 16 to 32 months. On the other hand, the wavelet coherence coefficient obtained from this conversion is estimated to be 0.2. While in Figure 4, the interaction and coherence and cross wavelet transform of two-time series quality-precipitation with band range of 10 to 16 months has a coherence wavelet coefficient of about 0.5 is estimated. Also, figure 8 shows the results of the coherence and cross wavelet two-time series quality-runoff with a coherence band range of 16 to 32 months. The wavelet coherence coefficient obtained from this conversion is estimated to be 0.4. The phase difference between time series the quality-drought, quality-precipitation, and quality-runoff according to the direction of the arrows, which are generally vertical, is 90 degrees. Based on this interpretation, it can be said that the relative impact time series of precipitation compared to time series runoff and drought on changes in groundwater quality in Khorramabad city in the years 2005 to 2018 has been more. Therefore, has been more the impact of climatic factors over human factors in changing the quality of groundwater in Khorramabad.

Table 9. the wavelet coherence coefficient average between hydrological time series

Time series	Quality-Drought	Quality-Precipitation	Quality-Runoff
Wavelet coherence coefficient average	0.2	0.5	0.4

Table (9) shows that the low wavelet coherence coefficient of quality drought indicates their low effects on changes in the quality of groundwater resources in Khorramabad. Also, the high wavelet coherence coefficient of quality-precipitation and quality-runoff indicates that precipitation has had more impact on changes in groundwater quality. During the years 2005 to 2018, due to the decrease in precipitation and also the uncontrolled withdrawals of human beings from groundwater for various uses such as drinking, agriculture, and industry, the groundwater level in Khorramabad decreased, and as a result, the concentration of this waters has increased, leading to a decrease in the quality of groundwater resources. Also, the fall of the acid rain and sometimes out of the rainy season has caused its infiltration into groundwater, which has reduced the quality of groundwater in Khorramabad. Therefore, according to the results of coherence and cross wavelet, it can be said that the precipitation time series has had the greatest impact on reducing the quality of groundwater in Khorramabad. In a study conducted by Ashrafi et al. (2006) on the quality of groundwater in Khorramabad, the quality of these water resources was considered standard for drinking [34]. Also, Dolatshahi et al. (2015) stated in a study that the quality of groundwater resources in Khorramabad has the necessary standards for drinking consumption [35]. It is worth mentioning that the most important parameter that is effective for accurately recognizing time series fluctuations by these two criteria is data continuity. Data continuity means that there does not be exist dissociation in the process of changing the time series of hydrological data so that there is no unrecorded data during the fluctuations of the time series of hydrological data, and all data is being recorded overtime to maintain continuity over time series. On the other hand, the coherence and cross wavelet criteria deal only with time series, so the physical parameters will have no effect on the results of these two criteria.

4. CONCLUSION

In this study, first, the drought of Khorramabad in the years 2005 to 2018 was studied using the SPI index, which the results showed that in 2008 and 2012, Khorramabad was in a mild drought situation, in the year 2016, it was moderately wet, and in other years it was near to normal. Also, the correlation between drought and water quality in Khorramabad was 0.07, and the correlation between precipitation and quality was 0.02. Then the water quality of Khorramabad was analyzed using the index WQI. The results showed that the groundwater quality of Khorramabad in the years 2005 to 2018 was in good condition and had the necessary standards for drinking, agriculture, and industry. Using different methods and criteria to determine and classify the factors affecting the quality of aquifers is a useful step towards managing groundwater resources. In this regard, this research has tried to determine the relationship between different parameters on changes in groundwater quality in Khorramabad by coherence and cross wavelet. For this purpose, the rate of impact and interrelationship between the time series of quality-drought, quality-precipitation, and quality-runoff was determined by coherence and cross wavelet. According to the findings, the relative effect of precipitation with a wavelet coherence coefficient of 0.5 in Khorramabad groundwater quality changes was more. According to the results of the wavelet coherence coefficient time series, it can be concluded that due to the decrease in precipitation and also the uncontrolled withdrawals of human beings from groundwater for various uses such as drinking, agriculture, and industry, the groundwater level in Khorramabad decreased and as a result the concentration of this water has increased, leading to a decrease in the quality of groundwater resources and also fall of acid rain and sometimes out the rainy season has caused the infiltration on groundwater in Khorramabad and as a result, the quality of this water has decreased. Therefore, climatic factors have been more impact on changes in groundwater quality in Khorramabad than human factors. In completing the present study, it is suggested that the proposed method be applied to daily and annual data to compare the results with the results obtained from monthly data. The use of other criteria and methods of analysis of time series trends, such as the Entropy wavelet criterion, can be a suitable suggestion to investigate the effects of climate change on the quality of water resources for future research.

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CONFLICT OF INTEREST

The author (s) declared no potential conflicts of interests with respect to the authorship and/or publication of this paper.

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