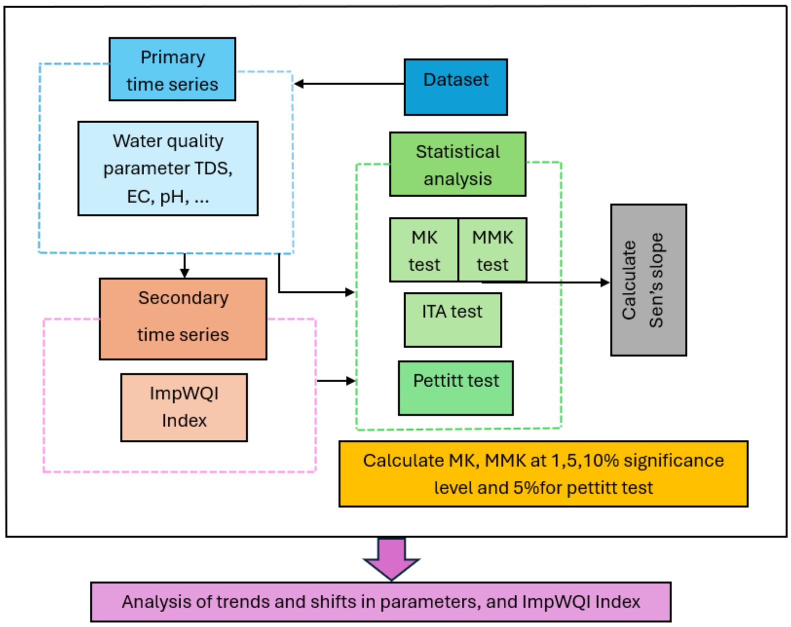
Journal of Applied Research in Water and Wastewater
E-ISSN: 2476-6283
Journal homepage: https://arww.razi.ac.ir

Trend analysis of River water quality: A case study on Gadar-Chai River

Neda Jafari*, **Yagob Dinpashoh**, **Ahmad Fakheri-Fard**

Department of Water Engineering, Faculty of Agriculture, University of Tabriz, Tabriz, Iran.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article type:
Research Article

Article history:
Received xx Month xxx
Received in revised form xx Month xxx Accepted xx Month xxx
Available online x Month xx

Keywords:
ImpWQI
ITA
Mann-Kendall method
Sen's slope estimator
Surface water quality

ABSTRACT

Water quality in rivers is a critical concern in hydrology. This study examines the Gadar-Chai River, situated within Iran's Urmia Lake basin, utilizing data from four selected hydrometric stations: Oshnavieh, Polebahramlu, Bighaleh, and Naghadeh. An improved Water Quality Index (ImpWQI) was calculated for each station using data from 2003 to 2021. Trends in ImpWQI values and the used water quality parameters, including the annual time series of TDS, EC, pH, HCO_3^-, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+, K^+, and TH, were analyzed in the period 2003–2021. Three significance levels, at 1%, 5%, and 10%, were used. The Mann-Kendall (MK), Modified Mann-Kendall (MMK), and innovative trend analysis (ITA) methods, as well as Sen's slope estimator, were used for trend detection and calculating the slope of trend lines. The results showed both upward and downward trends in the time series. MK, MMK, and ITA showed similar results in detecting the trend direction, but differed in estimating trend magnitude. MMK tended to show stronger trends than MK .However, unlike the MK and MMK methods, which only identify monotonic trends, the ITA method is capable of detecting sub-trends. Among all the water quality variables of the Gadar-Chai Basin, the pH parameter had the highest number of positive trends. Trends in the Cl^- parameter were negative in almost all the stations. Trends in the ImpWQI index were negative in the three stations, namely Oshnavieh, Polebahramlu, and Naghadeh; however, station Bighale witnessed an upward trend in ImpWQI. A negative trend line slope was observed for the EC parameter in the station Polebahramlou, whereas a positive slope was obtained for the same parameter in the station Bighaleh.

1. Introduction

Rivers serve as one of the most vital sources of freshwater, supporting essential needs such as drinking, agriculture, and industrial activities. The combined effects of population expansion and intensified industrial and commercial activities have resulted in substantial contamination of surface waters from multiple origins (Mustapha and Abdu, 2012). In contemporary society, empirical evidence has substantiated that the etiology of numerous diseases can be attributed to substandard water quality (Ghamarnia *et al.*,2023).

Due to the vital importance of rivers, controlling and preventing their quality decline is necessary (Rasi Nezami and Aghlmand, 2023).

*Corresponding author Email: jafarineda53@gmail.com

Cite this article: N. Jafari, Y. Dinpashoh, A. Fakheri-Fard, Trend analysis of River water quality: A case study on Gadar-Chai River, *Journal of Applied Research in Water and Wastewater*, x (x), 202x, xx-xx. doi: https://doi.org/10.22126/arww.2026.11727.1355

The Water Quality Index (WQI) is a powerful approach for evaluating water quality by employing a variety of chemical components (Abbasi and Abbasi, 2012). Each of the parameters is weighted in the WQI method according to its importance in water quality (Mukate *et al.*, 2019; Jafari, Hafezparast, and Farhadi, 2021; Jafari and Dinpashoh, 2024). The weights allocated to each of the used chemical parameters indicate the degree to which they significantly influence the assessment of water quality. Consequently, even slight variations in these values can substantially influence the final WQI, thereby clarifying the status of the water (Nguyen *et al*., 2022). To address the limitations associated with parameter weighting, the CRITIC (Criteria Importance Through Intercriteria Correlation) method has been developed and applied extensively across numerous studies (Yu *et al*., 2019). In the ImpWQI, the CRITIC method is used to assign weights to the parameters. The nonparametric techniques are robust, powerful, versatile, and easy to compute (Sawilowsky, 1990). The MK (Mann-Kendall) test is a non-parametric method for detecting trends in a time series (Hamed and Rao, 1998). This method has some advantages. For example, it doesn't require the data to follow any predefined statistical distribution. Another advantage of this method is its minimal sensitivity to sudden disruptions caused by an inhomogeneous time series (Aldughairi, 2025). Due to its non-parametric nature, the MK test is not sensitive to outliers, thereby ensuring a reliable trend detection scheme in hydrological time series with irregular or extreme observations. (Dinpashoh, 2016; Yue and Wang, 2002) As a result, analyzing long-term trends in river water quality is essential for identifying historical changes and forecasting future conditions (Rosenkrantz, 1987). Also, our study employs a new trend analysis method, the ITA method, which is both simple and effective. It also aligns well with established statistical approaches, demonstrating its practicality and utility for trend analysis (Pastagia and Mehta, 2022).

The innovative trend analysis (ITA) method, introduced in 2012 and improved later in 2014, has gained widespread application in identifying trends in environmental, hydrological, and meteorological datasets (e.g., Markus *et al*., 2014; Ay and Kisi, 2015; Kisi, 2015; Onyutha, 2015; Wu, Li and Qian, 2017; Agbo *et al*., 2025). The ITA method has some benefits, such as enabling the detection of sub-trends and providing graphical visualizations of the analysis. By classifying data into ‘low,’ ‘medium,’ and ‘high’ ranges, this method effectively uncovers hidden sub-trends within the overall time series (Asikoglu, Alp and Temel, 2024). The present study employed the mentioned nonparametric methods as well as the Pettitt test (Pettitt,1979) to identify significant change points in the time series.

In the field of changes in river water quality and groundwater, several studies have been conducted in many regions. For example, Bouza *et al*. (2008) examined trends in 34 physicochemical indicators in surface water from Spain’s Ebro River over 24 years. They used a seasonal MK test and Sen’s slope estimator. They showed that fluctuations in the time series over the period 1981- 2004 were predominantly attributable to the decrease in phosphate concentration and the increase in pH levels. Dinpashoh (2016) examined the trends in river water quality in the East Azerbaijan province. He used a non-parametric statistical technique, namely the MK method, after removing the effect of significant autocorrelation coefficients. Moreover, he used Sen’s estimator to calculate the slope of the trend line. They reported an upward trend in the case of positive ions and electrical conductivity (EC) in most of the stations. Yargholi (2021) employed the MK test to detect the trends in the EC parameter across 20 hydrometric stations situated along various rivers in Iran. The results of this test provide a clearer and more reliable view of the salinity trend. Falah and Haghizadeh (2017) employed a software named AqQa to evaluate water quality in the Horroud River flow in Lorestan Province, located in western Iran. They applied Piper, Schuler, Stiff, and Wilcox diagrams to interpret water chemistry. Furthermore, they used the MK test to examine trends. The results showed increasing trends in color, EC, and TDS, alongside a decreasing trend in K^+ concentrations within the station, namely Kakareza. Conversely, at the station, namely Dehno, an upward trend was observed for the Ca^{2+} level and color metrics, while a downward trend was reported for sulfate and K^+ concentrations. For other variables, no specific trends were found. Hashim *et al*. (2021) conducted a comprehensive examination of the temporal variations in water quality within the upstream segment of the Bernam River basin located in Malaysia. They used the MK test and Sen’s slope estimator in their work. The results showed that most of the monitoring stations had an increasing trend for NH3-N, BOD, DO, and pH parameters, while decreasing trends were observed in COD and TSS parameters. Aouiti *et al*. (2021) conducted an assessment of groundwater quality within the Hajib Layoun-Jelma basin, situated in central Tunisia. They investigated water quality indicators, the entropy water quality index, and ImpWQI. They compared the results of these three indicators with each other. Their findings confirmed the lowest level for water quality, as measured by the ImpWQI index. Zhang *et al*. (2020) examined the water quality of 51 groundwater samples in a region of the Guanzhong Basin in China using the WQI index. The weights allocated for the parameters using the CRITIC method. Nguyen *et al*. (2022) evaluated the groundwater quality in Giang Province, Vietnam, using 13 parameters in 11 samples collected during both the wet and dry seasons in the period 2017- 2020. To determine the parameter weights, the researchers employed the Shannon entropy method along with a correlation-based approach to account for intercriteria relationships. They integrated these two methods to calculate the water quality index. Results showed that about 40% of all samples were unsuitable for drinking in 2020. Changes in the water quality index this year ranged from 72 to 7973, which was much higher than in other years. Rezak, Rahal and Bahmani (2023) employed the MK method to examine temporal trends in 11water quality parameters in the northwestern region of Algeria. The findings revealed a statistically significant upward trend in dry residues, organic matter, phosphates, and dissolved oxygen. Nevertheless, parameters such as BOD_5, COD, and NO_3^- exhibited a downward trend. They reported that there were no trends in the parameters NH_4^+, $NO_2^-$and pH. According to the WQI, the groundwater was found to be suitable for drinking purposes. They reported that only 5.85% of samples were unsuitable for drinking. Babamiri and Dinpashoh (2024) assessed different management scenarios for the remediation of Dez River water quality based on self-purification. They used the QUAL2Kw model and five parameters, namely DO, BOD, COD, NO3-N, and NH4-N, for this aim. Results showed that the oxidation rate, nitrification rate, and denitrification rate are the most important parameters in the simulation procedure. Mete, Nacar, and Bayram (2024) analyzed daily changes in dissolved oxygen (DO), water temperature (WT), discharge (Q), and specific conductivity (SC) from 1987 to 2022 at four stations in South Carolina's Broad River basin, focusing on monthly, seasonal, and annual trends. The researchers employed the MK test and ITA methods. The results indicated that the trends in DO concentration and electrical conductivity values in the river varied both spatially and temporally, largely due to human activities. Notably, the observed increase in water temperature and decrease in discharge may be attributed to climate change influences on precipitation and air temperature.

So far, to the best of our knowledge, a detailed study has not been done on the trend of the ImWQI index in the Gadar-Chai Basin in Iran. This study attempts to investigate the trends in the ImpWQI index for the first time in this region. The present study used the Innovative Trend Analysis (ITA) to assess trends in water quality parameters of the Gadar-Chai River. This is the first study to apply the Mann-Kendall and ITA methods to analyze trends in the ImpWQI index. The main aims of this study are: 1- Analyze trends in the ImpWQI index and water quality parameters series in the Gadar-Chai River basin using the non-parametric MK, MMK, and ITA methods, 2- Calculate the trend line slopes of the ImpWQI index and water quality parameters using Sen's estimator method.

2. Materials and methods

2.1. Study area

The selected study region is the Gadar-Chai River basin, located in the western Urmia Lake basin, Iran. The Gadar-Chai River extends approximately from 36°42′N to 37°10′N latitudes and 44°42′E to 45°41′E longitudes. The length of the main river is about 100 kilometers, and the basin area is about 2100 square kilometers. The mean annual runoff volume discharge is about 400 million cubic meters. This river is the third largest basin in the Urmia Lake basin, following the Zarinerood and Siminerood rivers (Habibi Alagoz and Yasi, 2019). The Gadar-Chai River originates from the hills of Dalamper Bozurg and the Badgole mountains. The Gadar-Chai River receives contributions from several tributaries, including the Ghalazchai, Kani Rash, and Sheykhan rivers. These tributaries converge near the city of Naghadeh. The two smaller branches, named Balghchi and Mohammad Shah rivers, join it later. Finally, the Gadar-Chai River flows parallel to the Mahabadchai after passing the Polesentu (Bahramlu) and discharges to Urmia Lake (Moghadam Yekta, Jozi and Karimi, 2020). One of the important hydrometric stations is the Bighaleh hydrometric station, positioned in the upstream part of the Gadar-Chai River basin. Figure 1 shows the Gadar-Chai River basin and the selected hydrometric stations in it. Based on the Emberger climate classification method, the basin is identified as having a cold semi-arid climate. The average rainfall of 10 years (2006-2016) of Naghadeh Plain is about 365 mm per year. The rainiest season is winter, followed by spring, and the highest amount of in March and April. The rate of evaporation potential in this region is much greater than the rainfall. Its average annual value is about 1445 mm. In Naghadeh synoptic station, the average annual temperature is about 15 degrees Celsius (Mohammadpour, 2019). Fig. 1 shows the location of the Gadar-Chai River basin and the selected stations in it.

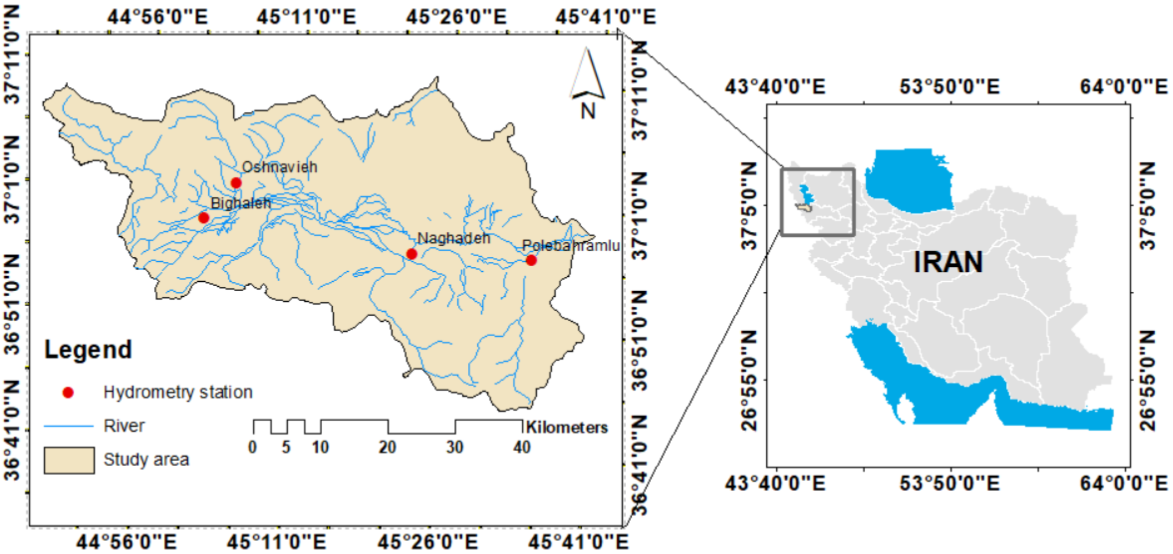


Fig. 1. Geographical location of the Gadar-Chai River basin and the selected stations.

2.2. Data used

This research investigates water quality changes in the Gadar-Chai River (West Azarbaijan province) using data from the regional water organization, encompassing 11 chemical parameters: TDS, EC, pH, HCO_3^-, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+, and TH. We analyzed data from 2003 to 2021 (19 years) for four hydrometric stations: Oshnavieh, Polebahramlou, Bighaleh, and Naghadeh. In this study, one sample was considered for each year and at a given station. For the stations studied, we used years that were common to the stations. These data were measured on a specific day in each month and in some months over several days. Therefore, for each year, we used the average parameters of all months of the year for this research.

2.3. Improved water quality index (ImpWQI)

The WQI is utilized to assess the suitability of available water sources for drinking purposes. As this index aims to enhance the understanding of fundamental water quality issues caused by multiple parameters, it provides a comprehensive assessment of complex datasets by scoring multidimensional parameters on a common scale (Fatima *et al.*, 2022). In the ImpWQI method, the importance of criteria is calculated through inter-criteria correlation (CRITIC), proposed by Diakulaki, which is categorized as an objective weighting technique. This method mainly consists of two parts, using the following equations. First, the value of r_{ij} is calculated, where r_{ij} is the correlation coefficient. (Zhang, Xu and Qian, 2020):

$$r_{ij}=\frac{\sum(x_{ij}-\bar{x}_{ij})(y_{ij}-\bar{y}_{ij})}{\sqrt{\sum(x_{ij}-\bar{x}_{ij})^2\sum(y_{ij}-\bar{y}_{ij})^2}} \tag{1}$$

where, x_{ij} is the j[th] chemical parameter corresponding to the i[th] water sample, y_{ij} is the normalized value for the i[th] sample and the j[th] parameter. $\bar{x}_{ij}$ and $\bar{y}_{ij}$ represent the average values of x_{ij} and y_{ij}, respectively. The next step, the C_j parameter, is obtained as follows:

$$C_j=\delta_j\sum_{j=1}^{m}(1-r_{ij}) \tag{2}$$

The weight of the j[th] parameter is calculated from the following equation:

$$w_j=\frac{C_j}{\sum_{j=1}^{m}C_j} \tag{3}$$

where, C_j is the value of the j[th] sign, δ_j denotes the standard deviation associated with the j[th] parameter, m is the total number of chemical parameters, and w_j is the weight of the j[th] comparison. In the next step, a quality rating (Q_j) is found for each center as follows.

$$Q_j=\frac{C_j-C_{jp}}{S_j-C_{jp}}\times 100\% \tag{4}$$

where C_j denotes the concentration associated with each of the used chemical parameters in the water sample, measured in mg/L, and C_{jp} is the ideal value of the parameter in pure water, (for all parameters the value of C_{jp} = 0 is considered, except for pH where C_{jp} = 7) and S_j is the standard value for each chemical parameter in terms of milligrams per liter is the same parameter for drinking water quality according to the international standard (Eid *et al.*, 2024). Finally, the ImpWQI index is calculated from the following formula:

$$\text{ImpWQI}=\sum_{j=1}^{m}w_jQ_j \tag{5}$$

Drinking water quality assessed using the Improved Water Quality Index (ImpWQI) is categorized into five distinct classes. An ImpWQI value of less than 50 indicates "Excellent" water quality (Rank 1), while values between 50 and 100 represent "Good" quality (Rank 2). Values from 100 to 150 correspond to "Medium" quality (Rank 3), and scores between 150 and 200 signify "Poor" quality (Rank 4). Finally, an ImpWQI exceeding 200 is classified as "Extremely poor" water quality (Rank 5). This classification system provides a clear, ordinal scale for interpreting the overall suitability of water for drinking purposes (Zhang et al. 2020; Aouiti et al. 2021).

2.4. Mann-Kendall (MK) test

The MK test, a non-parametric method, was first proposed by Mann (1945) and later improved by Kendall (1975). The MK test is a widely used statistical test for analyzing the trends of climatological and hydrological time series (Nguyen, Phan, and Huynh, 2022). The first step in this method involves calculating the S statistic using Equation 6 (Kumar, Prasad, and Baghel, 2023; Dinpashoh *et al.*, 2014). The simplicity of the MK test makes it still popular for trend detection (Dinpashoh et al., 2011; Nourani, Danandeh Mehr and Azad, 2018; Chen, Ghadami and Epureanu, 2022; Imani et al., 2024).

$$S=\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\operatorname{sgn}(x_j-x_i) \tag{6}$$

$$\operatorname{sgn}(\theta)=\begin{cases}1 & \text{if } \theta>0\\ 0 & \text{if } \theta=0\\ -1 & \text{if } \theta<0\end{cases} \tag{7}$$

The S statistic has a mean of zero, and its variance is calculated as:

$$V(S)=\frac{n(n-1)(2n+5)-\sum_{i=1}^{m}t_i(t_i-1)(2t_i+5)}{18} \tag{8}$$

In this context, t_i indicates the number of the same values within the i[th] group, and m is the number of groups with the same data. The Z statistic is calculated as follows:

$$Z=\begin{cases}\frac{S-1}{\sqrt{V(S)}} & S>0\\ 0 & S=0\\ \frac{S+1}{\sqrt{V(S)}} & S<0\end{cases} \tag{9}$$

A positive value of the computed Z statistic indicates an upward trend in the data, whereas a negative value signifies a downward trend. A trend is considered statistically significant when the absolute value of the Z exceeds the critical thresholds as follows. If the absolute value of the Z is greater than 1.64, then the trend is considered to be significant at the 10% level. If it is greater than 1.96, then the trend is considered to be significant at 5% level. Finally, if the absolute value of Z is greater than 2.33, then the trend is considered to be significant at 1% level. (Dinpashoh, 2016; Javan, 2019). It should be noted that the condition for the application of this test is the absence of any significant autocorrelation in the used time series. In this study, when significant autocorrelation coefficients were detected, a modified Mann–Kendall (MMK) approach was employed to eliminate their influence on the time-series data (Kumar *et al*., 2009). This method is known as the modified MK test, which is explained in the following subsection.

2.5. Modified Mann-Kendall (MMK) test

If a significant autocorrelation coefficient is present in the data series, the modified method of the MK test is employed to detect the trend (Yue & Wang, 2004; Mondal, Kundu and Mukhopadhyay, 2012). To do this, the ratio of $\frac{n}{n_s^*}$ is calculated from the following equation.

$$\frac{n}{n_s^*}=1+\frac{2}{n(n-1)(n-2)}\times\sum_{k=1}^{n-1}(n-k)(n-k-1)(n-k-2)\,\rho_k \quad (10)$$

where, n is the sample size and ρ_k is the k[th] autocorrelation coefficient of the data. Once the ratio of $\frac{n}{n_s^*}$ calculated modified variance is calculated from the following equation:

$$V^*(S)=V(S)\times\frac{n}{n_s^*} \quad (11)$$

Finally, we used $V^*(S)$ Instead of V(S) in equation (9), to calculate the Z-statistic. In this study, three significance levels (0.1, 0.05, and 0.01) were used to test the trends.

2.6. Innovative trend analysis (ITA) method

The ITA method was first proposed by Şen (Şen, 2012). In the ITA method, the time series is split into two half-subseries. If the number of data is odd, then the first one is removed, and then the time series is divided into two equal parts. Each of the subseries is sorted in ascending order, separately. In a two-dimensional Cartesian coordinate system, two subseries are plotted as a scatterplot in which the horizontal axis is devoted to the first subseries (x), and the vertical axis (y) is attributed to the second half. When the points on the plot were aligned directly on the 1:1 (45°) line, then the time series is trendless (Agbo *et al*., 2025). However, if all the points are positioned above the 1:1 line, then the time series is considered to have an upward trend. In contrast, if all the points are positioned below the 1:1 line, then the time series has a downward trend (Şen, 2012; Birpınar Kızılöz and Şişman, 2023). If some points are located above the 1:1 line and some others are positioned below it, then the first part of the series has an upward trend and the second one has a downward trend (Agbo *et al*., 2025). The magnitude of the upward or downward trend is reflected in the observed pairwise differences for the two subseries (Cui *et al*., 2017). In a trendless series, all the pairwise differences are equal to zero. However, in an upward trend series, the values of $(y_i-x_i)/\bar{x}$ for i=1, 2, … are positive. These values were negative for downward trends. Therefore, it can be used to quantify trends, with mean differences reflecting the overall direction of the time series. For change detection, given that the analysis is based on the initial sub-series, the trend indicator is computed by dividing the average of the differences by the mean value of that primary sub-series. To maintain scale uniformity with the MK and linear regression techniques, the indicator is scaled by a factor of 10, facilitating direct comparability among the methods (Wu, Li and Qian, 2017). Thus, the formulation of the ITA indicator is given by:

$$D=\frac{1}{n}\sum_{i=1}^{n}\frac{10(y_i-x_i)}{\bar{x}} \quad (12)$$

where, D is the trend component, with positive values indicating an upward trend, n represents the number of observations within each subseries, while $\bar{x}$ corresponds to the mean value of the initial sub-series. To ensure that the latest data are fully leveraged, the first observation is excluded when the time series comprises an odd number of data points before it is divided into sub-series.

2.7. Sen's slope estimator

Sen's slope estimator is employed to determine the trend line's slope, allowing for the quantification of the rate of increase or decrease in water quality parameters over time. The value of the slope of the trend presented by Thiel (1950) and Sen (1966) is calculated using the following formula (Kumar *et al*., 2023):

$$\beta = \text{Median}\left(\frac{x_j-x_i}{j-i}\right) \qquad \forall\ j>i \quad (13)$$

where, β is the estimator of the slope of the trend line, x_j is the j[th] observed value, and x_i is the i[th] observed value in historical order. A positive value of β represents an upward trend in the data, while a negative value reflects a downward trend.

2.8. Pettitt test

To identify potential significant change points within the time series data, Pettitt's non-parametric test (Pettitt 1979) is employed (Piyoosh and Ghosh, 2017). This method detects a possible significant change point during the period used, when the precise timing of the change is unknown (Gao *et al*, 2011). The H_0 hypothesis, no sudden change point in time series, is tested against the H_1 hypothesis: there is a change point in the used series. This test started with the calculation of the U_{tn} from the following equation (Güçlü, 2020; Imani et al., 2024):

$$U_{t,T}=\sum_{i=1}^{t}\sum_{j=t+1}^{T}sgn(x_i-x_j) \quad (14)$$

where, $sgn\ (x_j-x_i)$ is the sign function calculated as follows:

$$sgn(\theta)=\begin{cases}1 & if\ \theta>0\\ 0 & if\ \theta=0\\ -1 & if\ \theta<0\end{cases} \quad (15)$$

And t is the length of the period, n is the number of data points in the series. The test statistic K_T is defined as follows: (Jaiswal, Lohani and Tiwari, 2015; Imani *et al*., 2024):

$$K_T= max|U_{t,T}| \quad (16)$$

To calculate the value of P, the obtained K_T is put into equation (17).

$$P=2.\exp\left(-\frac{6K_T^2}{T^3+T^2}\right) \quad (17)$$

If the calculated P-value, from (17), is close enough to zero, the sudden change is considered to be significant (Laasya *et al*., 2024). In this study, the significance level of 0.05 was used for the detection of sudden change points in time series.

3. Results and discussion

Table 1 presents descriptive statistics for the 11 investigated variables in the period of 2003-2021 and four selected stations in the Gadar-Chai River basin. This table includes the maximum and minimum, median, and standard deviation of the time series for all parameters.

Table 1. Descriptive statistics of qualitative variables of selected stations in the Gadar-Chai River basin in the period of 2003-2021.

Station	Parameter	Minimum	Maximum	Median	Standard deviation	Unit
	TDS	172.26	279.5	205.71	26.27	(mg/L)
	EC	269.167	430	328.099	40.201	(µS/cm)
	pH	7.676	8.310	8.023	0.187	-
	HCO_3^-	130.133	209.840	171.084	19.982	(mg/L)
	Cl^-	6.390	11.618	8.688	1.488	(mg/L)
Oshnavieh	SO_4^{2-}	13.964	30.720	22.053	5.016	(mg/L)
	Ca^{2+}	35.833	56.889	46.968	5.166	(mg/L)
	Mg^{2+}	7.560	17.280	11.388	2.584	(mg/L)
	Na^+	3.067	9.529	5.107	1.577	(mg/L)
	K^+	1.17	3.9	3.9	0.8	(mg/L)
	TH	115	334.167	209.285	54.058	(mg/L $CaCO_3$)
	TDS	165.75	508.083	279.142	87.483	(mg/L)
Polebahramlu	EC	255	781.667	477.458	135.635	(µS/cm)
	pH	7.512	8.391	8.002	0.258	-

	HCO_3^-	1.850	5.617	3.618	1.002	(mg/L)
	Cl^-	0.155	1.083	0.544	0.261	(mg/L)
	SO_4^{2-}	0.500	1.678	0.904	0.337	(mg/L)
	Ca^{2+}	1.875	3.733	2.759	0.531	(mg/L)
	Mg^{2+}	0.425	2.950	1.532	0.610	(mg/L)
	Na^+	0.200	1.750	0.706	0.422	(mg/L)
	K^+	2.95	7.8	3.9	0.99	(mg/L)
	TH	124.615	188.181	141.071	14.983	(mg/LCaco₃)
Bighaleh	TDS	137.107	268.863	178.517	28.53	(mg/L)
	EC	214.231	413.636	287.264	43.076	(µS/cm)
	pH	7.746	8.406	8.040	0.196	-
	HCO_3^-	2	3.082	2.343	0.248	(mg/L)
	Cl^-	0.327	0.157	0.228	0.048	(mg/L)
	SO_4^{2-}	0.273	0.836	0.481	0.120	(mg/L)
	Ca^{2+}	1.738	2.442	2.041	0.179	(mg/L)
	Mg^{2+}	0.510	1.464	0.800	0.233	(mg/L)
	Na^+	0.129	0.473	0.227	0.087	(mg/L)
	K^+	0	5.85	3.9	1.59	(mg/L)
	TH	145	203	175.714	14.315	(mg/LCaco₃)
Naghadeh	TDS	206.4	358.4	256.64	41.65	(mg/L)
	EC	322.500	560	412.082	65.143	(µS/cm)
	pH	7.709	8.243	7.971	0.188	-
	HCO_3^-	2.217	4.038	3.164	0.532	(mg/L)
	Cl^-	0.150	0.875	0.350	0.158	(mg/L)
	SO_4^{2-}	0.613	1.325	0.872	0.207	(mg/L)
	Ca^{2+}	1.958	3.238	2.605	0.360	(mg/L)
	Mg^{2+}	0.725	2.138	1.331	0.366	(mg/L)
	Na^+	0.200	1	0.410	0.171	(mg/L)
	K^+	1.95	3.9	3.9	0.45	(mg/L)
	TH	136.25	206	169	16.27	(mg/LCaco₃)

The median values of EC range from 287 µS/cm (in station Bighaleh) to 477 µS/cm (in station Polebahramlu). The pH values varied from 7.97 to 8.04. However, TDS in the station ranges from 279.14 in Polebahramlu to 178.51 in Bighaleh. From the perspective of temporal variation, EC exhibited a wide range of fluctuations during the period. For example, in Oshnavieh, EC varied from 269.16 µS/cm (in the year 2014) to 430 µS/cm (in the year 2020). In the station, Polebahramlu EC varied from 255 µS/cm (in the year 2017) to 781.66 µS/cm (in the year 2007). In the station, Bighaleh EC varied from 214.23 µS/cm (in the year 2005) to 413.63 µS/cm (in the year 2020). And finally, in the station, Naghadeh EC varied from 322.50 µS/cm (in the year 2014) to 560 µS/cm (in the year 2008).

Fig. 2 shows the results of calculating the ImpWQI index for the four studied stations, Oshnavieh, Polebahramlou, Bighaleh, and Naghadeh. According to the figure, Polebahramlou station exhibits the highest Water Quality Index WQI value, while Bighaleh station shows the lowest. This indicates that Polebahramlou has the poorest water quality among the observed sites, whereas Bighaleh has the best. At Naghadeh station, the highest WQI value of 65.12 was recorded in 2007. Oshnavieh station reached its peak value of 56.83 in 2019, while Bighaleh station registered its highest index of 46.79, also in 2019. The highest index value was observed at Polebahramlou station with a value of 92.87 in 2007. At Naghadeh station, in 8 years (42.10%), this station was in the excellent water quality category according to the improved water quality index, and in the rest of the years it was in the average water quality category. At Oshnavieh station, it was in the good category only in two years, namely 2009 and 2020 (10.52%). In the rest of the years, Oshnavieh water quality was in the good category. At Polebahramlu station, the water quality was in the excellent water quality category for 6 years (31.57%). In the rest of the years, the water quality of this station was in the good category. But at Bighaleh station, the water quality was in the excellent water quality category in all the years studied. Table 2 represents the findings of the trend analysis for all qualitative indicators in the 19 years (2003-2021) at Oshnavieh, Polebahramlu, Bighaleh, and Naghadeh stations in the Gadar-Chai Basin located in West Azarbaijan province, at significance levels of 0.1, 0.05, and 0.01. The trend of changes in parameters and ImpWQI at four sites of Oshnavieh, Polebahramlu, Naghadeh, and Bighaleh was investigated by MK, MMK, and ITA methods. First, the trend of parameters and ImpWQI was investigated by the MK method, then the MMK test was used to remove the effect of autocorrelation of time series. The table of the results of the MK, MMK, and D in the ITA method is given. According to the results of the table, all three tests had similar results in determining the trend, but the results of the tests were different from each other in terms of the intensity of the run.

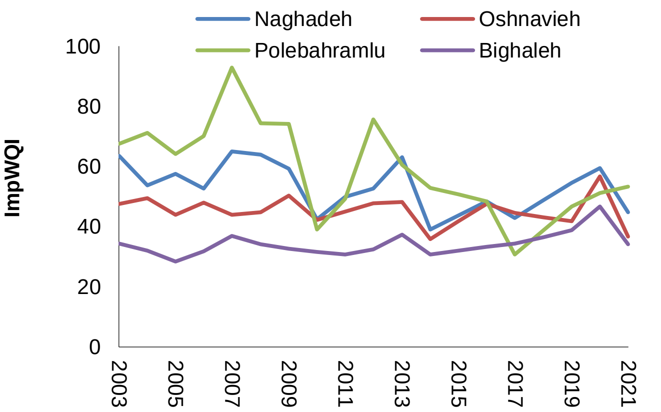


Fig. 2. ImpWQI index results for Oshnavieh, Polebahramlu, Naghadeh, and Bighaleh stations in the statistical period (2003-2021).

Because the time series are autocorrelated, the MMK test yields a larger Z value, so this test shows trends more strongly. In the MK test, 8 series (16.67%) showed a significant upward trend, and 14 series (29.17%) showed a significant negative trend. In the MMK test, 14 series (26.17%) showed a significant upward trend, and 25 series (52.08%) showed a significant negative trend. Using the MK test on the TDS parameter indicated a significant upward trend at the 1% level at the Bighaleh station and a downward trend at the 5% level at the Polebahramlu station. Using the MMK test on the TDS parameter indicated a downward trend at the 1% level at the Polebahramlu station and an upward trend at the 1% level at the Bighaleh station. Using the MK test on the EC parameter indicated an upward trend at the 1% level at the Bighaleh station and a downward trend at the 5% level at the Polebahramlu station. The MK test indicated upward trends at the 1% and 5% levels at the Bighaleh and Oshnavieh stations and downward trends at the 1% and 5% levels at the Polebahramlu and Naghadeh stations. Using the MK test in the pH parameter indicated upward trends at the 1%, 5%, and 10% levels at the Bighaleh, Naghadeh, and Oshnavieh stations, respectively. Using the MMK test indicated upward trends at the 1% level at Oshnavieh, Polebahramlu, and Bighaleh stations, and an upward trend at the 5% level at Naghadeh station. Using the MK test in the Cl^- parameter showed a significant downward trend at Polebahramlu station, and the MMK test showed a significant downward trend at the 1% level at Polebahramlu, Bighaleh, and Naghadeh stations. Using the MK test on the SO_4^{2-} parameter indicates a significant downward trend at the 5% level at the Naghadeh station.

Using the MMK test on the SO_4^{2-} parameter indicates an upward trend at the 1 and 5% levels at the Oshnavieh and Bighaleh stations and a downward trend at the 1 and 5% levels at the Naghadeh and Polebahramlu stations. In the MK test, there was a significant downward trend in the Ca^{2+}parameter at the 5% level in Polebahramlu. Using the MMK test, significant downward trends at the 1% level were shown in Polebahramlu and Naghadeh stations, and an upward trend at the 10% level in Bighaleh station. Using the MK test on the Mg^{2+} parameter indicates a significant downward trend at the 1% level at Polebahramlu station and a significant upward trend at the 1% level at Naghadeh station. Using the MMK test indicates a downward trend at the 1% level at Polebahramlu and Naqadeh stations and a significant upward trend at the 1% level at Bighaleh station. Using the MK test, a significant downward trend was observed in the Na^+ parameter at the 1% level at the Polebahramlu station. In the MK test, two significant downward trends were observed at the 1% level at Polebahramlu and Naghdeh stations. Using both MK and MMK tests, no significant trend was observed in the K^+ parameter at any of the four stations. Using the MK test on the TH parameter revealed downward trends at the 1%, 5%, and 10% levels in the Bighaleh, Naghadeh, and Oshnavieh stations, and a significant upward trend at the 1% level in the Bighaleh station. In the MMK test, downward trends were observed at the 1% level at the Oshnavieh, Polebahramlu, and Naghadeh stations, and an upward trend at the 1% level was observed at the Bighaleh station. The results of the ITA method showed that the D statistics are unequal among different parameters, even with opposite signs. According to the values of D in the ITA analysis, positive and negative trends were identified in different parameters at the stations. In the TDS and EC parameters, the most severe negative trend was observed in the Polebahramlu station. A positive trend was observed in this parameter at the Bighaleh station. The pH parameter showed a positive and partial trend. In the HCO_3^-, Ca^{2+}, Mg^{2+}, and Na parameters, except for the Bighaleh station, the rest of the stations showed a negative trend. The most severe negative trend was observed in the Polebahramlu station. In the Cl^- parameter, all stations showed a negative trend. In the SO_4^{2-} and K^+ parameters, both positive and negative trends were observed with different intensities. Finally, the ImpWQI index, which involves all these parameters in its final value, showed a negative trend in all stations except the Bighaleh station, and this negative trend is more severe at the Polebahramlu station.

The results of the improved water quality index trend study indicate that water quality is deteriorating at the Beghaleh station and improving at other stations. All three methods, MK, MMK, and ITA, produced similar results in identifying the sign of the trend (i.e., increasing or decreasing). However, their estimates of trend magnitude were not fully consistent. Specifically, the MMK test tended to indicate stronger trends compared to the MK test.

Table 2. Summary of the results of the MK test and the Sen slope at Oshnavieh, Polebahramlu Bighaleh, and Naghadeh stations.

Station	Variable	S Statistic	Z- MK	Z -MMK	D-ITA	Trend direction
Oshnavieh	TDS	9	0.280	0.797	0.138	Upward
Polepahramlu		-63	-2.169**	-4.431***	-2.694	Downward
Bighaleh		91	3.148***	7.539***	1.974	Upward
Naghadeh		-31	-1.049	-2.440***	-0.935	downward
Oshnavieh	EC	21	0.700	2.284**	0.007	Upward
Polepahramlu		-65	-2.239**	-4.668***	-2.698	Downward
Bighaleh		95	3.288***	8.155***	1.950	Upward
Naghadeh		-31	-1.049	-2.216**	-0.951	Downward
Oshnavieh	pH	49	1.679*	4.845***	0.305	Upward
Polepahramlu		43	1.469	3.703***	0.377	Upward
Bighaleh		89	3.078***	6.509***	0.388	Upward
Naghadeh		67	2.309**	7.308***	0.258	Upward
Oshnavieh	HCO_3^-	-69	-2.379***	-7.465***	-0.040	Downward
Polepahramlu		-83	-2.868***	-5.446***	-3.135	Downward
Bighaleh		11	0.349	0.558	0.589	Upward
Naghadeh		-51	-1.749*	-3.672***	-0.989	Downward
Oshnavieh	Cl^-	-3	-0.069	-0.152	-0.276	Downward
Polepahramlu		-56	-1.925*	-3.446***	-3.871	Downward
Bighaleh		-41	-1.399	-3.470***	-0.204	Downward
Naghadeh		-39	-1.329	-2.977***	-2.331	Downward
Oshnavieh	SO_4^{2-}	45	1.539	2.406***	0.138	Upward
Polepahramlu		-29	-0.979	-2.311**	-2.788	Downward
Bighaleh		47	1.060	2.112**	1.310	Upward
Naghadeh		-61	-2.029**	-3.403***	-2.641	Downward
Oshnavieh	Ca^{2+}	-22	-0.735	-2.091**	-0.118	Downward
Polepahramlu		-63	-2.164**	-5.873***	-2.191	Downward
Bighaleh		25	0.839	1.738*	0.079	Upward
Naghadeh		-47	-1.609	-4.712***	-0.875	Downward
Oshnavieh	Mg^{2+}	-9	-0.279	-0.851	-0.0304	Downward
Polepahramlu		-73	-2.518***	-5.829***	-3.396	Downward
Bighaleh		85	2.938***	6.131***	4.290	Upward
Naghadeh		-46	-1.575	-3.485***	-1.952	Downward
Oshnavieh	Na^+	-5	-0.139	-0.248	-1.780	Downward
Polepahramlu		-69	-2.379***	-5.144***	-5.112	Downward
Bighaleh		1	0	0	1.790	Upward

Naghadeh		-44	-1.469	-2.900***	-2.190	Downward
Oshna-vieh	K^+	-4	-0.148	-0.232	-1.581	Downward
Polepah-ramlu		0	0	0	0.008	-
Bighaleh		8	0.289	0.530	0.952	Upward
Naghadeh		15	1.060	2.432***	-0.555	Upward
Oshna-vieh	TH	-55	-1.889	-4.654***	-0.023	Downward
Polepah-ramlu		-79	-2.728***	-6.190***	-2.639	Downward
Bighaleh		69	2.379***	4.889***	1.114	Upward
Naghadeh		-60	-2.065**	-5.675***	-1.199	Downward
Oshna-vieh	ImpWQI	-43	-1.469	-4.653***	-0.088	Downward
Polepah-ramlu		-69	-2.39***	-5.087***	-2.909	Downward
Bighaleh		53	1.819*	3.377***	1.380	Upward
Naghadeh		-49	-1.679*	-3.797***	-1.048	Downward

Note: The ***, **, and * represent significance levels at 0.01, 0.05, and 0.1 levels corresponding to critical z values of 2.33, 1.96, and 1.645, respectively. NS indicates non-significant.

The station Bighaleh showed the most significant positive trend, and the negative trend was observed in Naghadeh and Polepahramlu stations. Among all the water quality variables of the Gadar-Chai Basin, the pH parameter has the highest number of significant positive trends in MMK at the 1% level, so all the stations have an upward trend in MMK at 1% level for this parameter. Regarding the negative trend of the Cl^- parameter, it has experienced the largest number of negative trends, so four stations have negative trends for this parameter. As shown in Fig. 3, the ITA results for ImpWQI reveal an overall downward trend at the Oshnavieh, Polebahramlu, and Naghadeh stations, where the majority of the data points are below the 1:1 line. The results at Bighaleh show that the majority of points lie above the 1:1 line, indicating an upward trend at this station.

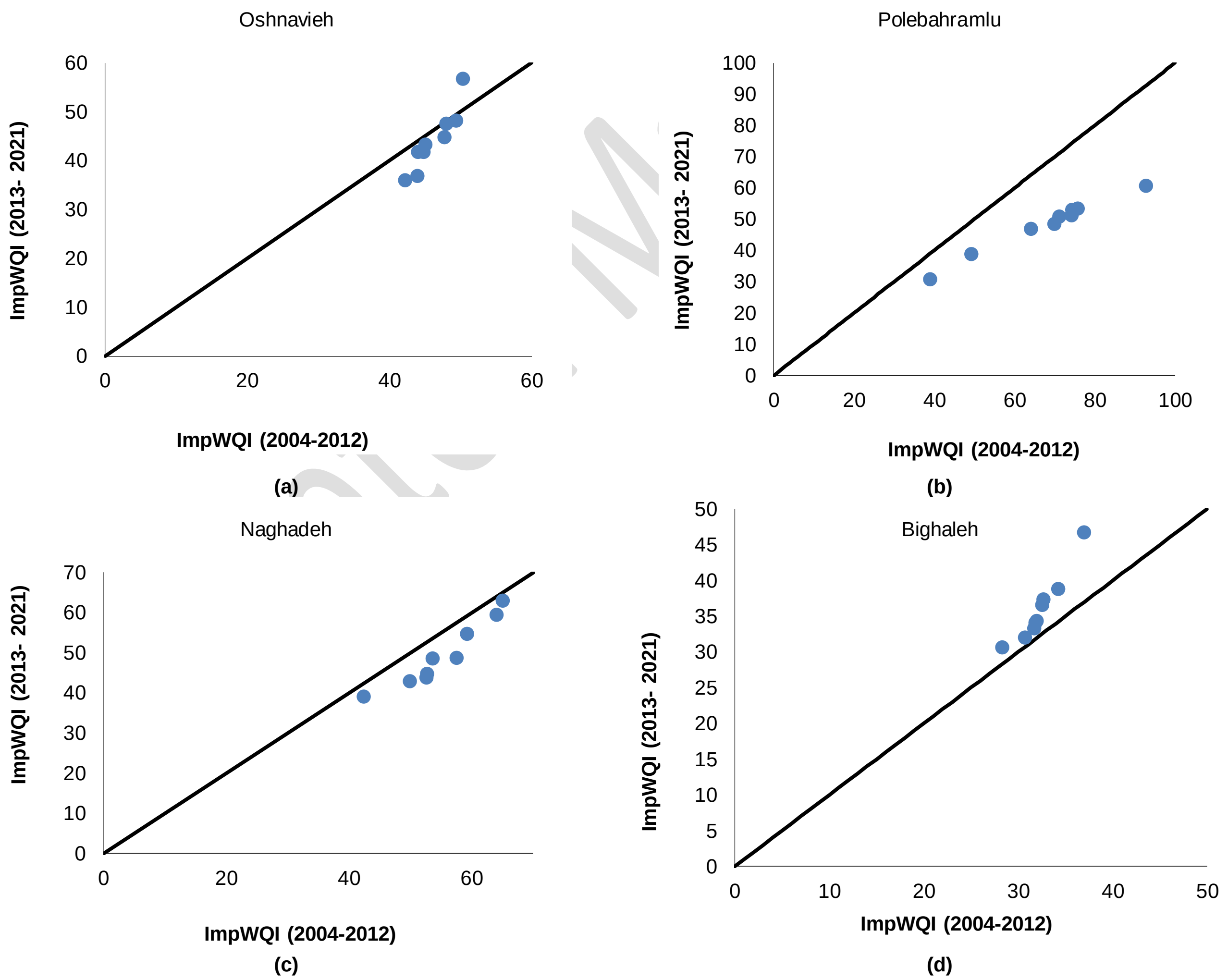


Fig. 3. ITA results for ImpWQI at stations (a) Oshnavieh, (b) Polebahramlu, (c) Naghadeh, and (d) Bighaleh.

At Oshnavieh station, high and low ImpWQI values have more severe increasing and decreasing trends, respectively; the index with a value of 47.5 has no clear trend. While the moderate values show fewer decreasing trends (Fig. 3a). At Polebahramlu station, the decreasing trends increase with increasing ImpWQI values (Fig. 3b). At Naghadeh station, fewer decreasing trends occurred in high and low values, and more severe decreasing trends occurred in moderate values (Fig. 3c). Fig. 3d shows the gradual strengthening of the increasing trend of ImpWQI at station Bighaleh. Table 3 presents the slopes of the trend lines for the qualitative variables at the four selected stations. As can be seen from Table 3, the steepest descending trend in EC belonged to Polebahramlu, with an EC trend line of -10.7 μS/cm. Furthermore, station Naghadeh showed a descending trend line slope, too. However, the steepest increasing line belonged to Bighaleh with a slope of 4.7 μS/cm.

Across all stations, the pH parameter exhibited a positive trend, with an increasing slope observed in each case. The most pronounced upward trend was identified at the Bighaleh station, where the slope of the pH trend line reached 0.026. The steepest descending trend in HCO_3^- belonged to the Oshnavieh, having the HCO_3^- trend line equal to -1.612 mg/L. Furthermore, just station Bighaleh showed an increasing trend line slope with a slope of 0.03mg/L. The steepest descending trend in Cl^- belonged to the Polebahramlu, having the Cl^- trend line equal to -10.7 mg/L. However, the steepest increasing line belonged to Bighaleh with a slope of 4.7 mg/L. The Cl^- parameter exhibited a descending slope across all monitoring stations. The steepest descent was observed at the Polebahramlu station, with a slope of −0.023 mg/L. The steepest descending trend in SO_4^{2-} belonged to the Polebahramlu, having the SO_4^{2-}trend line equal to -0.019 mg/L. However, the steeply increasing line belonged to Oshnavieh with a slope of 0.430 mg/L. The most notable decreasing trend in Ca^{2+} concentration was observed at the Oshnavieh station, where the slope of the trend line was −0.2 mg/L. In contrast, Bighaleh was the only station to exhibit an increasing trend, characterized by a slope of 0.006 mg/L. The steepest descending trend in Mg^{2+} belonged to the Polebahramlu, having the Mg^{2+} trend line equal to -0.068 mg/L. Furthermore, just station Bighaleh showed an increasing trend line slope with a slope of 0.018 mg/L. The steepest descending trend in Na^+ belonged to the Polebahramlu, having the Na^+ trend line equal to -0.033 mg/L. Only at the Bighaleh station, the slope of the trend line is zero. The steepest descending trend in SAR belonged to the Polebahramlu, having the SAR trend line equal to -0.014 mg/L. Furthermore, station Naghadeh showed a descending trend line slope, too. However, the slope of the trend line is zero in the two stations of Oshnavieh and Bighaleh. The steepest descending trend in ImpWQI belonged to Polebahramlu, with an ImpWQI trend line of -1.633. Only Bighaleh station shows an increasing slope, with a slope of 0.265. The median slope for the EC parameter shows that every 10 years, the value of EC has decreased by 9.23 µS/cm in this area. So, it can be deduced from this table that, except for the pH parameter, the other parameters and slopes are decreasing. Also, the ImpWQI index has a negative median slope with a value of -0.415, which has decreased by 4.15 points from the ImpWQI index every 10 years. The largest negative slope of the trend line related to the EC parameter is at Polebahramlu station with a value of -10.667 µS/cm, and the largest positive slope of the trend line related to the EC parameter is at Bighaleh station (Table 4).

Table 3. Trend line slope values of the time series of qualitative variables of Gadar-Chai Basin (2003-2021).

Station	Variable	The median of the slopes	Sen's slope
Oshnavieh	TDS	-9045	0.219
Polebahramlu			-6.608
Bighaleh			3.204
Naghadeh			-2.028
Oshnavieh	EC	-0.9235	0.847
Polebahramlu			-10.667
Bighaleh			4.669
Naghadeh			-2.694
Oshnavieh	pH	0.0185	0.016
Polebahramlu			0.018
Bighaleh			0.026
Naghadeh			0.019
Oshnavieh	HCO_3^-	-0.077	-1.612
Polebahramlu			-0.112
Bighaleh			0.003
Naghadeh			-0.042
Oshnavieh	Cl^-	-0.009	-0.011
Polebahramlu			-0.023
Bighaleh			-0.003
Naghadeh			-0.007
Oshnavieh	SO_4^{2-}	-0.005	0.430
Polebahramlu			-0.019
Bighaleh			0.007
Naghadeh			-0.017
Oshnavieh	Ca^{2+}	-0.041	-0.200
Polebahramlu			-0.060
Bighaleh			0.006
Naghadeh			-0.022
Oshnavieh	Mg^{2+}	-0.04	-0.054
Polebahramlu			-0.068
Bighaleh			0.018
Naghadeh			-0.026
Oshnavieh	Na+	-0.0095	-0.012
Polebahramlu			-0.033
Bighaleh			0.000
Naghadeh			-0.007
Oshnavieh	TH	-2.001	-1.222
Polebahramlu			-6.032
Bighaleh			1.138
Naghadeh			-2.780
Oshnavieh	ImpWQI	-0.4145	-0.258
Polebahramlu			-1.633
Bighaleh			0.265
Naghadeh			-0.571

Fig. 4 shows the ImpWQI time series at four selected stations. As illustrated in Fig. 4, the ImpWQI index demonstrates an upward trend at the Bighaleh station during the studied statistical period, while showing a downward trend across the other three stations. Table 4 represents the results of the Pettitt test applied for water quality parameters and the ImpWQI index in the four stations, Oshnavieh, Polebahramlou, Naghdeh, and Bighaleh. In general, out of 44 series on quality parameters, 12 significant shifts were recorded: one in TDS at the Polebahramlou station, two in EC at the Polebahramlou and Bighaleh stations, and one in pH at the Bighaleh station. In the HCO_3^- parameter, one significant shift was found, which occurred at Polebahramlou station. In the SO_4^{2-} and Na^+ parameters, one significant shift was observed, which occurred at Bigaleh and Polebahramlou stations, respectively. The most significant shift was observed in the Mg parameter, in which the Naghdeh, Polebahramlou, and Bighaleh stations had a significant shift in the average of their series. However, no significant shift occurred in the Cl^-, Ca^{2+}, and K^+ parameters. According to the results, the most significant shift was observed at the Polebahramlou station. The downward shifts at Polebahramlou station are related to TDS, EC, and HCO_3^- parameters, all three of which occurred in 2009. Upward shifts were observed at the Bighaleh station, which occurred for the EC parameter in 2012, the pH parameter in 2011, and the SO_4^{2-} parameter in 2016. In the figure related to the Pettitt test, mu1 represents the mean before the shift, and mu2 represents the mean after the shift. Fig. 5 shows the results of the jumps observed in several parameters, including TDS, EC, pH, HCO_3^-, SO_4^{2-} and the ImpWQI index.

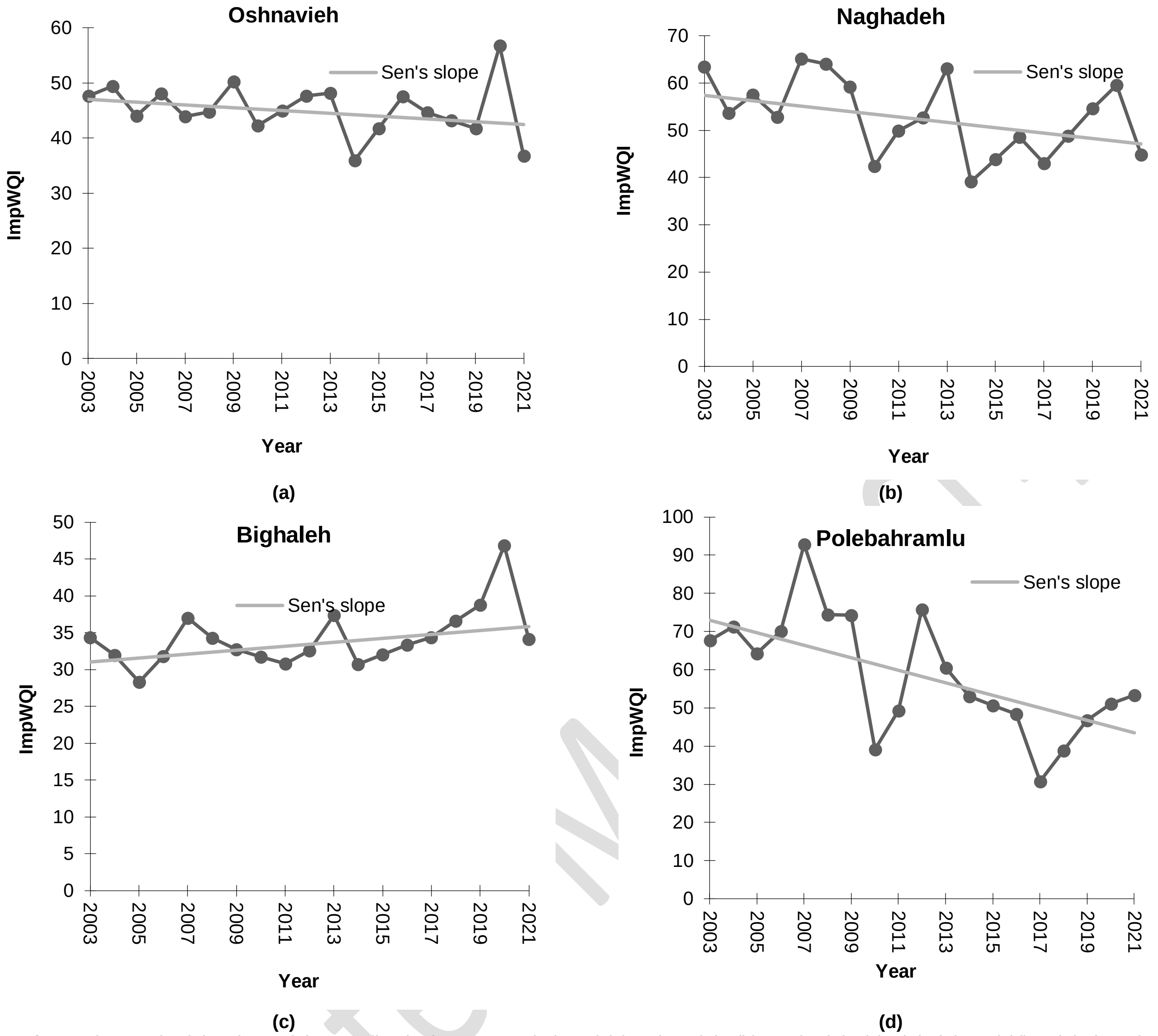


Fig. 4. The graph of the slope of the Sen line in the ImpWQI index of (a) Oshnavieh, (b) Naghadeh, (c) Bighaleh and (d) Polebahramlu stations.

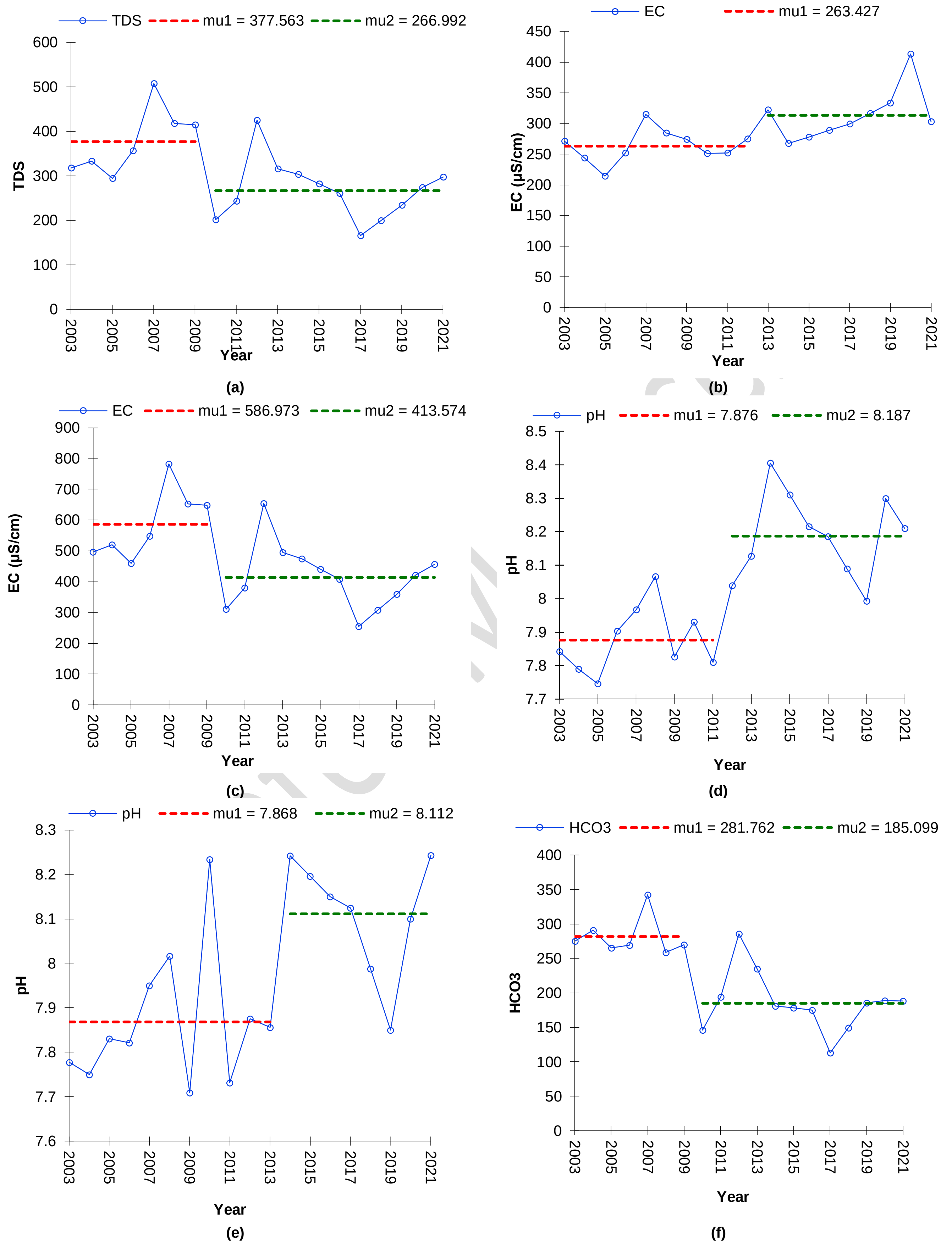
Table 4. Summary of the Pettitt test results for selected parameters at the studied stations.

Station name	Index	K_T	Change point year	Shift	P-value	Mean before shift	Mean after shift
Oshnavieh	TDS	19	-	-	0.08	-	-
Polebahramlu	TDS	66	2009	Downward	0.04	377.56	266.92
Bighaleh	TDS	68	-	-	0.06	-	-
Naghadeh	TDS	52	-	-	0.100	-	-
Oshnavieh	EC	29	-	-	0.06	-	-
Polebahramlu	EC	68	2009	Downward	0.02	586.97	413.57
Bighaleh	EC	70	2012	Upward	<0.000	263.42	313.74
Naghadeh	EC	54	-	-	0.08	-	-
Oshnavieh	pH	58	-	-	0.100	-	-
Polebahramlu	pH	56	-	-	0.18	-	-
Bighaleh	pH	86	2011	Upward	<0.0001	7.87	8.18
Naghadeh	pH	66	-	-	0.08	-	-
Oshnavieh	HCO_3^-	52	-	-	0.12	-	-
Polebahramlu	HCO_3^-	74	2009	Downward	<0.0001	281.76	185.1
Bighaleh	HCO_3^-	38	-	-	0.72	-	-
Naghadeh	HCO_3^-	60	-	-	0.06	-	-
Oshnavieh	SO_4^{2-}	48	-	-	0.28	-	-
Polebahramlu	SO_4^{2-}	44	-	-	0.5	-	-
Bighaleh	SO_4^{2-}	66	2018	Upward	0.02	20.69	29.72
Naghadeh	SO_4^{2-}	71	-	-	<0.0001	-	-

Fig. 6 shows the box-whisker diagram for the trend line of the concentration of 10 qualitative parameters and ImpWQI in the four stations of Oshnavieh, Polebehramlu, Naghadeh, and Bighaleh in the study area. The slope of the trend line in the case of parameter K^+ was zero, indicating no temporal variation; no box was generated for this variable in the trend analysis. According to this figure, it can be seen that the mean slopes in most of the parameters are negative, which shows that, on average, the slope of the trend line for most of the stations is decreasing in most of the parameters. So, among the 10 qualitative parameters investigated, only pH and SO_4^{2-} parameters have median slopes greater than zero. The height of the box represents the interval between the 25th and 75th percentiles in the data.

As it is clear from the figure, the distance between the 75th and 25th percentiles are greater for EC compared to the other parameters.

Also, among the parameters, the SO_4^{2-} parameter, the distance between the 75th percentile and the median substantially exceed that between the 25th percentile and the median, indicating that the data above the median exhibit greater variance than those below it.



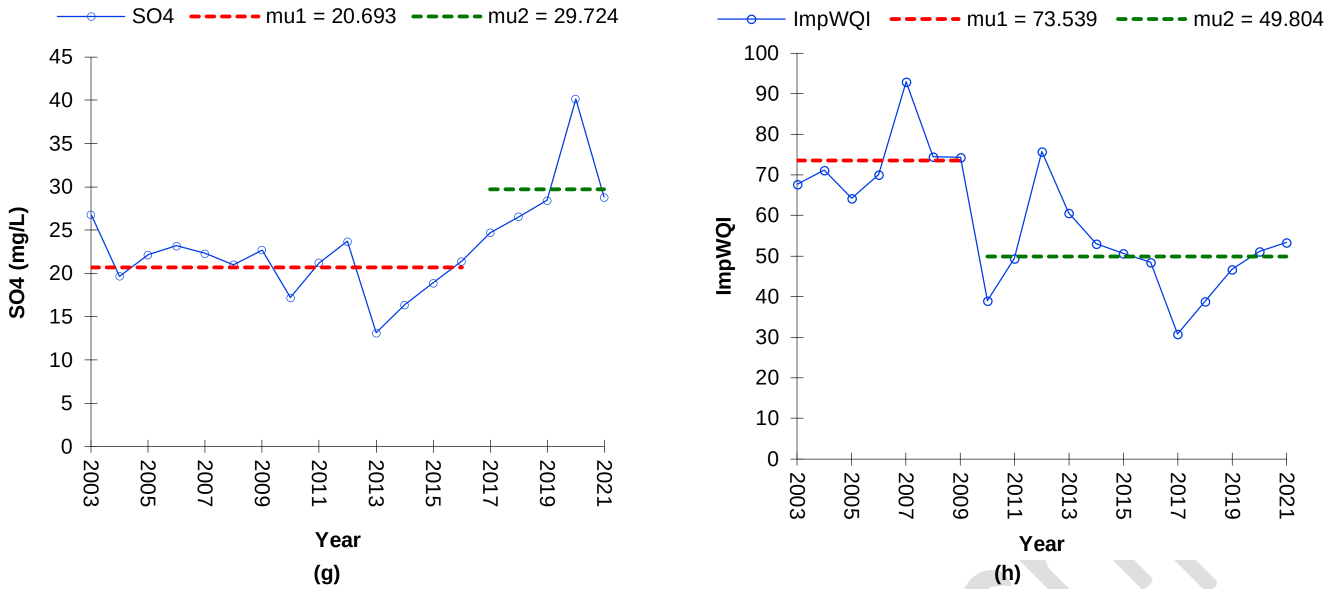


Fig. 5. Pettitt test graphs related to (a) TDS at Polebahramlu, (b) EC at Bighaleh, (c) EC at Polebahramlu, (d) pH at Bighaleh, (e) pH at Naghadeh, (f) HCO_3^- at Polebahramlu, (g) SO_4 at Bighaleh, and (h) ImpWQI index at Polebahramlu stations.

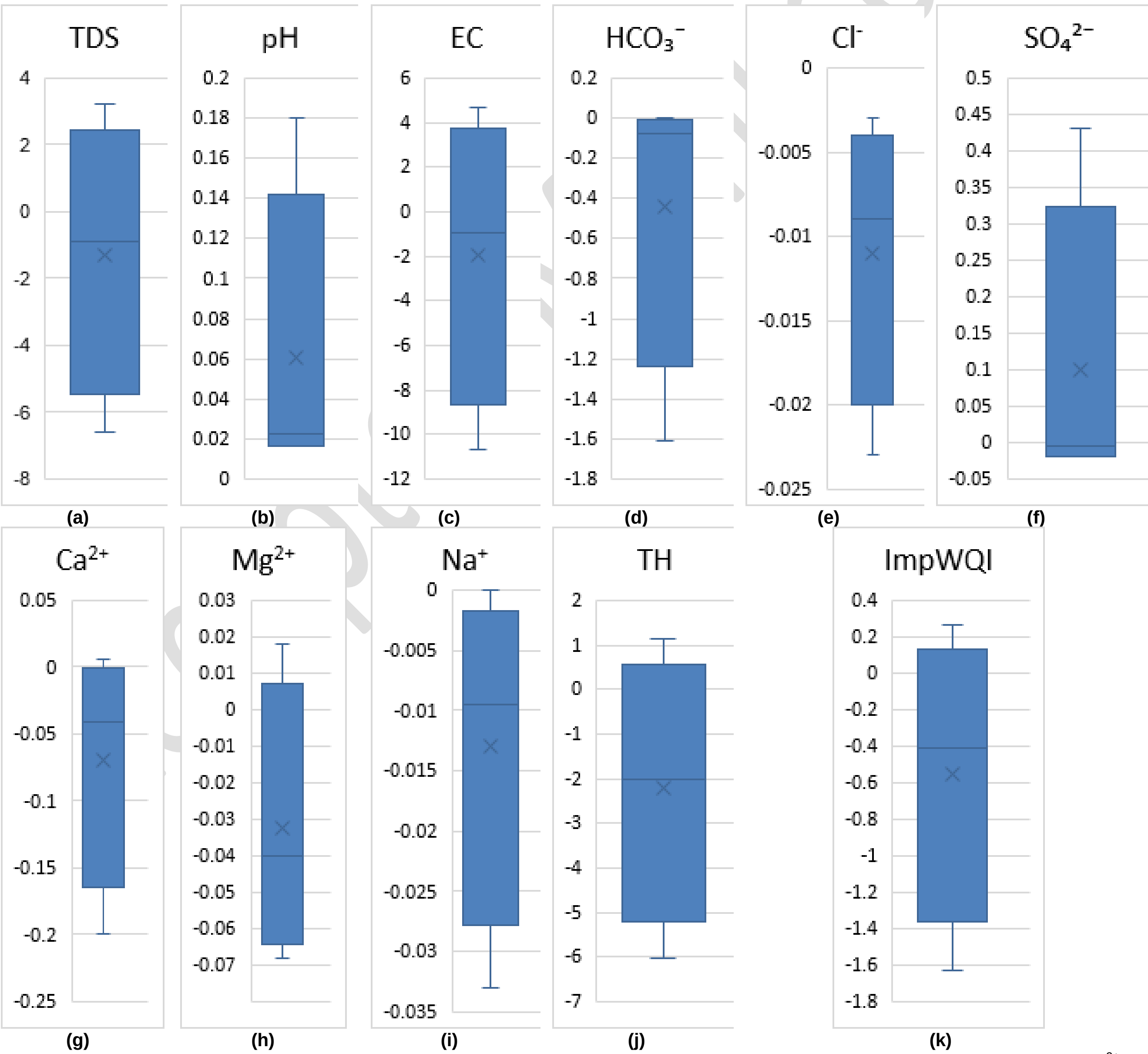


Fig. 6. Box-whisker diagram for the slope of the trend line of water quality (a) TDS, (b) pH, (c) EC, (d) HCO_3^-, (e) Cl^-, (f) SO_4^{2-}, (g) Ca^{2+}, (h) Mg^{2+}, (i) Na^+, (j) TH, and (k) ImpWQI of Gadar-Chai Basin in four stations of Oshnavieh, Polebehramlu, Naghadeh, and Bighaleh.

4. Conclusions

This study investigates the trend of the ImpWQI index and 11 water quality parameters in the Gadar-Chai Basin (West Azarbaijan Province) using data from four monitoring stations. The parameters (TDS, EC, pH, HCO_3^-, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+, K^+, and TH) were analyzed through MK, MMK, and ITA tests, and their trend slopes were estimated by Sen's method. The MK and MMK tests revealed that decreasing trends in water quality parameters were more prevalent than increasing ones. Out of 11 parameters and the ImpWQI, 29 stations showed consistent negative trends, and 17 showed positive trends across all three tests. Neutral trends were observed for sodium at the Bighaleh station and for potassium at the Polebahramlou station. In the MK test specifically, 14 stations had significant negative trends, while 8 showed significant positive trends. The MMK test identified 25 significant negative and 14 significant positive trends. The strongest positive trend occurred at Bighaleh station, while the most negative trends were found at Naghadeh and Polebahramlu stations. Among all parameters, pH showed the highest number of significant positive trends at the 1% level, indicating an overall upward trend across all stations. For the ImpWQI index, Oshnavieh and Polebahramlu stations exhibited significant downward trends, whereas Bighaleh showed a significant upward trend at the 1% level. Regarding the negative trend of the Cl^- parameter, it has experienced the largest number of negative trends, so four stations have negative trends for this parameter. For EC, the steepest negative slope (−10.667 µS/cm) was observed at Polebahramlu station, while the steepest positive slope (+4.669 µS/cm) occurred at Bighaleh station. The results of the Pettitt test indicated that at the station Polebahramlou, there was a downward shift in the time series of TDS, EC, and HCO_3^- in 2009. Upward shifts were observed at the Bighaleh station, which occurred for the EC parameter in 2012, the pH parameter in 2011, and the SO_4^{2-} parameter in 2016. Therefore, according to ImpWQI, the general trend of water quality in Oshnavieh station, Polebahramlu, and Naghadeh is decreasing, and the water quality in this station has improved. But in Bighaleh station, the trend of ImpWQI is upward, and the water quality has worsened. In the following, we attempt to compare the results of the present study with the findings of the other relevant studies. In particular, the ITA method has demonstrated a superior ability to uncover subtle or obscured trends, especially in datasets exhibiting significant fluctuations or nonlinear patterns. The results of this study show an upward trend in pH levels at most of the stations.

Authors Contributions

Neda Jafari: Writing, investigation, software, and analyzing the results and conclusion
Yagob Dinpashoh: Supervisor, writing, review, and control of results, analyzing the results and conclusion
Ahmad Fakheri Fard: Advisor, methodological feedback, manuscript revision for technical accuracy.

Acknowledgments

The authors express our gratitude for the cooperation of the West Azarbaijan Regional Water Company, West Azarbaijan, Iran, in collecting data for this research.

Data Availability Statement

Data can be obtained from the corresponding author upon reasonable request.

Conflict of Interest

The authors declare there is no conflict.

References

Abbasi, T. and Abbasi, S. A. (2012) *Water quality indices*. Amsterdam: Elsevier. doi; https://doi.org/10.1016/C2010-0-69472-7

Agbo, E. P. *et al.* (2025) 'Innovative trend analysis of precipitation changes over Nigeria: A case study of locations across the Niger and Benue Rivers'. *Journal of the Nigerian Society of Physical Sciences*, 1868-1868. https://doi.org/10.1002/eng2.12131

Aldughairi, A. A. (2025). 'Climate change assessment in middle and northern Saudi Arabia: Alarming trends'. *DYSONA-Applied Science*, 6(1), pp. 60-69. doi: https://doi.org/10.30493/das.2024.477412

Aouiti, S. *et al*. (2021) 'Groundwater quality assessment for different uses using various water quality indices in semi-arid region of central Tunisia', *Environmental Science and Pollution Research, 28*, pp. 46669-46691. doi: https://doi.org/article/10.1007/s11356-020-11149-5

Asikoglu, O. L., Alp, H. and Temel, I. (2024) 'Modified data classification for extreme values in Şen's innovative trend analysis: A comparative trend study for the Aegean and Eastern Anatolia Regions of Türkiye'. *Theoretical and Applied Climatology*, *155*(8), pp. 8415-8434. doi: https://doi.org/10.1007/s00704-024-05129-9

Ay, M., and Kisi, O. (2015) 'Investigation of trend analysis of monthly total precipitation by an innovative method'. *Theoretical and Applied Climatology*, *120*, pp. 617-629. doi: https://doi.org/article/10.1007/s00704-014-1198-8

Babamiri, O., and Dinpashoh, Y. (2024) 'Assessment of management scenarios for the remediation of river water quality based on self-purification (case study: Dez River)', *Journal of Water and Wastewater*, 34 (6), pp. 23-38. doi: https://doi.org/10.22093/wwj.2024.407654.3360

Birpınar, M. E., Kızılöz, B. and Şişman, E. (2023) 'Classic trend analysis methods' paradoxical results and innovative trend analysis methodology with percentile ranges', *Theoretical and Applied Climatology*, *153*(1), pp. 1-18. doi: https://doi.org/article/10.1007/s00704-023-04449-6

Bouza-Deaño, R.*et al*. (2008) 'Trend study and assessment of surface water quality in the Ebro River (Spain)', *Journal of Hydrology,* 361 (3-4), pp. 227-239. doi: https://doi.org/10.1016/j.jhydrol.2008.07.048

Chen, S., Ghadami, A., and Epureanu, B. I. (2022) 'Practical guide to using Kendall's τ in the context of forecasting critical transitions', *Royal Society Open Science*, *9*(7), pp. 211346. doi: https://doi.org/10.1098/rsos.211346

Cui, L. *et al*. (2017) 'Innovative trend analysis of annual and seasonal air temperature and rainfall in the Yangtze River Basin, China during 1960–2015', *Journal of Atmospheric and Solar-Terrestrial Physics,* 164, pp. 48-59. doi: https://doi.org/10.1016/j.jastp.2017.08.001

Dinpashoh, Y. (2016). 'Trend analysis of water chemical quality of East Azerbaijan rivers'. *Journal of Geography and Planning* 20 (55), pp.105-124 (In Persian with English Abstract). doi: https://geoplanning.tabrizu.ac.ir/article_4734_en.html

Dinpashoh, Y. *et al*. (2011) 'Trends in reference crop evapotranspiration over Iran', *Journal of Hydrology*, 399, pp. 422-433. doi: https://doi.org/10.1016/j.jhydrol.2011.01.021

Dinpashoh, Y. *et al.* (2014) 'Effect of short-term and long-term persistence on identification of temporal trends'. *Journal of Hydrologic Engineering*, 19, pp. 617-625. doi: https://doi.org/10.1061/(ASCE)HE.1943-5584.0000819

Eid, M. H. *et al*. (2024) 'Comprehensive approach integrating water quality index and toxic element analysis for environmental and health risk assessment enhanced by simulation techniques', *Environmental Geochemistry and Health*, *46*(10), p. 409. doi: https://doi.org/article/10.1007/s10653-024-02182-1

Falah, F., and Haghizadeh, A. (2017) 'Hydrochemical evaluation of river water quality—a case study: Horroud River', *Applied Water Science,* 7, pp. 4725-4733. doi: http://dx.doi.org/10.1007/s13201-017-0635-0

Fatima, S. *et al*. (2022). 'Geospatial assessment of water quality using principal components analysis (PCA) and water quality index (WQI) in Basho Valley, Gilgit Baltistan (Northern Areas of Pakistan)', *Environmental Monitoring and Assessment,* 194 (3), p. 151. doi: http://dx.doi.org/10.1007/s10661-022-09845-5

Gao, P. *et al*. (2011) 'Changes in streamflow and sediment discharge and the response to human activities in the middle reaches of the Yellow River', *Hydrology and Earth System Sciences*, *15*(1), pp. 1-10. doi: https://doi.org/10.5194/hess-15-1-2011

Ghamarnia, H. *et al*. (2023) 'Evaluation of Golin river quality in Kermanshah province using the standard surface water resources quality index of Iran (IRWQISC)', *Journal of Applied Research in Water and Wastewater*, *10*(1), pp. 7-14. doi: https://doi.org/10.22126/arww.2022.7722.1247

Güçlü, Y. S. (2020) 'Improved visualization for trend analysis by comparing with classical Mann-Kendall test and ITA', *Journal of Hydrology*, *584*, p. 124674. doi: https://doi.org/10.1016/j.jhydrol.2020.124674

Habibi Alagoz, S. and Yasi, M. (2019) 'Determination of environmental flow contribution of Gadar River to the Urmia Lake using Eco-Hydrological methods', *Water and Soil Science 29* (2), pp. 73-84 (In Persian with English Abstract). Available at: https://water-soil.tabrizu.ac.ir/article_9272_en.html (Accessed date: 11 October 2025).

Hamed, K. H., and Rao, A. R. (1998) 'A modified Mann-Kendall trend test for autocorrelated data', *Journal of Hydrology*, *204*(1-4), pp. 182-196. doi: https://doi.org/10.1016/S0022-1694(97)00125-X

Hashim, M. *et al*. (2021) 'Analysis of water quality trends using the Mann-Kendall test and Sen's estimator of slope in a tropical river basin', *Pollution* 7 (4), pp. 933-942. doi: https://doi.org/10.22059/poll.2021.325794.1118

Imani, S. *et al*. (2024) 'Assessing the impact of climate change by using Mann-Kendall, Pettitt and statistical down-scaling model (Case study: Tabriz station)', *Acta Geophysica*. 73(2), pp. 2047-2079. doi: https://doi.org/article/10.1007/s11600-024-01464-7

Jafari, N. and Dinpashoh, Y. (2024) 'Application of TOPSIS Method in the Investigation of River Water Quality (Case Study: Aji Chai River)', *Water and Soil*, *37*(6), pp. 855-869. doi: https://doi.org/10.22067/jsw.2023.84882.1344 (In Persian with English Abstract).

Jafari, N., Hafezparast, M., and Farhadi, B. (2021) 'Qualitative evaluation of water resources for drinking and agricultural uses (Case study: Gamasiab catchment, Kermanshah province)', *Journal of Environmental Science Studies*, *6*(2), pp. 3525-3532. (In Persian with English Abstract). Available at: https://www.jess.ir/article_129049_en.html?lang=en (Accessed date: 11 January 2025).

Jaiswal, R. K., Lohani, A. K., and Tiwari, H. L. (2015) 'Statistical analysis for change detection and trend assessment in climatological parameters', *Environmental Processes*, *2*, pp. 729-749. doi: https://doi.org/article/10.1007/S40710-015-0105-3

Javan, Kh. (2019) 'Identification of hydrological drought trends in the Lake Urmia Basin', *Hydrogeomorphology,* 25 (7), pp. 138-119. doi: https://doi.org/10.22034/hyd.2021.43326.1562 (In Persian with English Abstract).

Kendall, M. G. (1975) *Rank Correlation Methods*. 4th edn. London: Charles Griffin. Available at: https://www.scirp.org/reference/referencespapers?referenceid=2099295 (Accessed date: 11 January 2025).

Kisi, O. (2015) 'An innovative method for trend analysis of monthly pan evaporations', *Journal of Hydrology*, 527, pp. 1123-1129. doi: https://doi.org/10.1016/j.jhydrol.2015.06.009

Kisi, O., and Ay, M. (2014) 'Comparison of Mann–Kendall and innovative trend method for water quality parameters of the Kizilirmak River, Turkey', *Journal of Hydrology*, 513, pp. 362-375. doi: https://doi.org/10.1016/j.jhydrol.2014.03.005

Kumar, A., Prasad, V. and Baghel, S. (2023) 'Estimation and evaluation of trend analysis of the Penman-Monteith reference evapotranspiration of Raipur region, Chhattisgarh central India', *Mausam,* 74(1), pp. 199-206. doi: https://doi.org/10.54302/mausam.v74i1.6129

Kumar, S. *et al*. (2009) 'Streamflow trends in Indiana: effects of long term persistence, precipitation and subsurface drains', *Journal of Hydrology,* 374 (1-2), pp.171-183. doi: https://doi.org/10.1016/j.jhydrol.2009.06.012

Laasya, K. N. V. L. *et al*. (2024) 'Statistical assessment of temperature trends and change points in Telangana State, India', *International Journal of Environment and Climate Change*, *14*(4), pp. 397-407. doi: https://doi.org/10.9734/ijecc/2024/v14i44126

Markus, M. *et al*. (2014) 'Sensitivity analysis of annual nitrate loads and the corresponding trends in the lower Illinois River', *Journal of Hydrologic Engineering*, 19(3), pp. 533-543. doi: https://doi.org/10.1061/(ASCE)HE.1943-5584.0000831

Mete, B. *et al*. (2024) 'Trend analysis of the flow and water quality data for the Broad River Basin, South Carolina, USA', *Journal of Agricultural Faculty of Gaziosmanpaşa University (JAFAG)*, *41*(3), pp. 226-235. doi: https://doi.org/10.55507/gopzfd.1556000

Moghadam Yekta, N. *et al.* (2020) 'Study of quality & pollution of Urmia Gadar-Chai catchment, using water quality index and WRASTIC vulnerability model', *Journal of Environmental Science and Technology, 22* (2), pp.79-91 (In Persian with English Abstract). doi: https://doi.org/10.22034/jest.2020.34714.4184

Mohammadpour, M. (2019) 'Water use management effect on the Oshnavieh and Naghadeh Plain's surface-water resource using WEAP Model (case study: Oshnavieh and Naghadeh plains)', *Journal of Water Resources Engineering*, 13 (47), pp. 71-84. dor: https://dorl.net/dor/20.1001.1.20086377.1399.13.47.6.3 (In Persian with English Abstract).

Mondal, A. *et al*. (2012) 'Rainfall trend analysis by Mann-Kendall test: A case study of north-eastern part of Cuttack district, Orissa', *International Journal of Geology, Earth and Environmental Sciences,* 2 (1), pp. 70-78. Available at: https://www.scirp.org/reference/referencespapers?referenceid=2330036 (Accessed date: 11 January 2025).

Mukate, S. *et al*. (2019) 'Development of new integrated water quality index (IWQI) model to evaluate the drinking suitability of water', *Ecological Indicators,* 101, pp. 348-354. doi: https://doi.org/10.1016/j.ecolind.2019.01.034

Mustapha, A. and Abdu, A. (2012) 'Application of principal component analysis & multiple regression models in surface water quality assessment', *Journal of Environment and Earth Science,* 2(2), pp. 16-23. Available at: https://www.iiste.org/Journals/index.php/JEES/article/view/1516 (Accessed date:11 January 2025).

Nguyen, T. G. *et al*. (2022) 'Application of integrated-weight water quality index in groundwater quality evaluation'. *Civil Engineering Journal,* 8 (11), pp. 2661-2674. doi: http://dx.doi.org/10.28991/CEJ-2022-08-11-020

Nourani, V. *et al*. (2018) 'Trend analysis of hydroclimatological variables in Urmia Lake basin using hybrid wavelet Mann–Kendall and Sen tests', *Environmental Earth Sciences*, *77*, pp. 1-18. Available at: https://link.springer.com/article/10.1007%2Fs12665-018-7390-x (Accessed date: 11 January 2025).

Onyutha, C. (2016) 'Identification of sub-trends from hydro-meteorological series', *Stochastic Environmental Research and Risk Assessment*, 30(1), pp. 189-205. doi: https://doi.org/article/10.1007/s00477-015-1070-0

Pastagia, J. and Mehta, D. (2022) 'Application of innovative trend analysis on rainfall time series over Rajsamand district of Rajasthan state', *Water Supply*, *22*(9), pp. 7189-7196. doi: https://doi.org/10.2166/ws.2022.276

Pettitt, A. N. (1979) 'A non-parametric approach to the change-point problem', *Journal of the Royal Statistical Society: Series C (Applied Statistics)*, *28*(2), pp. 126-135. doi: https://doi.org/10.2307/2346729

Piyoosh, A. K. and Ghosh, S. K. (2017) 'Effect of autocorrelation on temporal trends in rainfall in a valley region at the foothills of Indian Himalayas', *Stochastic Environmental Research and Risk Assessment*, *31*, pp. 2075-2096. Available at: 10.1007/s00477-016-1347-y (Accessed date: 11 January 2025).

Rasi Nezami, S. and Aghlmand, R. (2023), 'Assessing the suitability of river water quality using water quality indices: A Case study on Balikhlou river in northwest of Iran', *Journal of Applied Research in Water and Wastewater*, *10*(1), pp. 1-6. doi: https://doi.org/10.22126/arww.2022.7574.1239

Rezak, S. *et al*. (2023) 'Water quality trend analysis of Cheurfas II dam, Algeria', *Revista Facultad de Ingeniería Universidad de Antioquia,* 106, pp. 9-24. doi: http://dx.doi.org/10.17533/udea.redin.20211267

Sawilowsky, S. S. (1990) 'Nonparametric tests of interaction in experimental design', *Review of Educational Research*, *60*(1), pp. 91-126. doi: https://doi.org/10.3102/00346543060001091

Sen, P. K. (1968) 'Estimates of the regression coefficient based on Kendall's tau', *Journal of the American Statistical Association,* 63 (324), pp. 1379-1389. doi: https://doi.org/abs/10.1080/01621459.1968.10480934

Shabrang, M.M. *et al*. (2024) 'Evaluation of spatial qualitative changes in surface water using cluster analysis and factor analysis (Case study: the Aras river within the boundaries of Iran)', *Journal of Applied Research in Water and Wastewater*, *11*(2), pp. 143-150. doi: https://doi.org/10.22126/arww.2025.10788.1337

Şen, Z. (2012) 'Innovative trend analysis methodology', *Journal of Hydrologic Engineering*, 17(9), pp. 1042-1046. doi: https://doi.org/10.1061/(ASCE)HE.1943-5584.0000556

Wu, H., Li, X. and Qian, H. (2017). 'Detection of anomalies and changes of rainfall in the Yellow River Basin, China, through two graphical methods', *Water*, *10*(1), 15. doi: https://doi.org/10.3390/w10010015

Yargholi, B. (2021) 'Analysis of salinity time-trend for the country's surface water resources using the Mann-Kendall method', *Iranian Journal of Irrigation & Drainage, 15* (3), pp. 483-493. (In Persian with English Abstract). doi: https://doi.isc.ac/dor/20.1001.1.20087942.1400.15.3.1.5

Yu, S. *et al.* (2019) 'Study on the suitability of passive energy in public institutions in China'. *Energies,* 12 (12), p. 2446. doi: https://doi.org/10.3390/en12122446

Yue, S., and Wang, C. (2004) 'The Mann-Kendall test modified by effective sample size to detect trend in serially correlated hydrological series', *Water Resources Management*, *18*(3), pp. 201-218. doi: https://doi/10.1023/B:WARM.0000043140.61082.60

Yue, S., and Wnag, C.Y. (2002) 'Applicability of the pre-whitening to eliminate the influence of serial correlation on the Mann-Kendall test'. *Water Resources Research,* 38 (6), pp. 4-1. doi: https://doi.org/10.1029/2001WR000861

Zhang, Q. *et al*. (2020) 'Groundwater quality assessment using improved water quality index (WQI) and human health risk (HHR) evaluation in a semi-arid region of northwest China', *Exposure and Health, 12*, pp. 487-500. Available at: https://link.springer.com/article/10.1007/s12403-020-00345-w (Accessed date: 11 January 2025).