Water Qual Expo Health (2014) 6:89–95
DOI 10.1007/s12403-013-0108-0

Trend Analysis of Temporal Changes of Discharge and Water Quality Parameters of Ajichay River in Four Recent Decades

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Received: 8 July 2013 / Revised: 17 December 2013 / Accepted: 17 December 2013 / Published online: 28 January 2014

Abstract This study analyzes changes and trends in discharge—mostly because of climate changes—of Ajichay River at Vanyar station and its water quality. Ajichay basin is located in East Azerbayjan province, Northwest of Iran. Five water quality indicators, including sodium (Na), Chlorine (Cl), Sodium Absorption Ratio (SAR), Total Dissolved Solids (TDS), and Electrical Conductivity (EC) were selected to analyze change in water quality. Trend analysis performed in wet and dry seasons where October and June were indicators of wet and dry seasons in year, respectively. Trend analysis was conducted using the two methods, which are conventional MK (for series having insignificant autocorrelations) and modified MK (for series having significant autocorrelations). Results showed that with decreasing trend in discharge all selected water quality parameters had an increasing trend in both wet and dry seasons. Based on Estimations increasing trend of Na, Cl, EC, TDS, and SAR in dry seasons were more rapid than trends in wet seasons. In conformity with that, Decreasing trend of discharge in wet seasons were more rapid than trends in dry seasons equal to -0.25 and -0.02 (m^3/s/year), respectively for wet and dry seasons. Calculated Slopes indicated a considerable increasing trend in water quality parameters in four recent decades, especially in dry seasons.

Keywords Ajichay basin · Iran · Mann–Kendall · Trend · Vanyar station

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Introduction

Water resources protection is an integral part of the process of multi-barrier approach to safe drinking water (Plummer et al. 2010). Maintaining good water quality in the source area could reduce the process load in water treatment and ensures the safety and health of the drinking water. It is essential to understand how and why water quality is changing over the time in the source area for effective management and protection of the water source. Natural changes in precipitation and stream flow caused by climate change and human activities can influence water quality in watersheds (Sprague and Lorenz 2009; Boeder and Chang 2008).

Trend is defined as continuous and uniform increase or decrease of the mean value of the parameter. A trend is usually defined as long-term changes in studied elements.

In general, there are different parametric and nonparametric statistical techniques to check the existence or absence of trend in time series analysis and climate change studies but the nonparametric methods are used relatively wider in Hydro meteorological studies (Takeuchi et al. 2003). Nonparametric methods are appropriate for the series that have a significant skew and cannot be fitted with statistical distributions. Because most of the hydrological and meteorological series in arid and semi-arid regions have significant skew parametric methods can't be used easily for such series. Since now, many nonparametric statistical tests have been developed to determine trends in data series. Mann–Kendall test is one of the best trend detecting methods. This method is suitable for the non-normal and is not sensitive to observed values. This test has been recommended for detecting trends in environmental time series data by the World Meteorological Organization. Some researchers Yu et al. (1993); Jhajharia et al. (2009); Khaliq et al. (2009); Dinpashoh et al. (2011) and etc. investigated the trends in different hydrological and hydro-meteorological parameters such as air temperature, precipitation, stream flow, water pollutant concentration, drought characteristics, Pan evaporation, and reference crop evapotranspiration over different parts of the world.

Chiueh et al. (2011) used the seasonal Mann–Kendall's test to examine the spatial pattern of water quality parameters in Feitsui reservoir watershed. Results showed an increase in pH and phosphorus; the significant seasonal trends may correspond to the increase of agricultural activities in the same region. Results also indicated that the percentage of land use had an influence on water quality. Bouza-Deano et al. (2008) studied the changes in Spanish Ebro River's water quality with 34 physical–chemical and chemical parameters over a 24-year-period using Mann–Kendall seasonal test. Results revealed changes in parameters over time are mainly because of reduction in phosphate concentration and increase pH levels at the Ebro Basin during the selected period. Chang (2008) investigated spatial patterns of water quality trends in 118 sites of the Han River basin of South Korea with eight parameters using the non-parametric seasonal Mann–Kendall's test. Wahlin and Grimvall (2009) used Mann–Kendall test for the spatial trend of Swedish groundwater quality. Results indicated that true upward trends in acid-neutralizing capacity and downward trends in sulfate but there was not any trend in alkalinity level. Yenilmez et al. (2010) investigated the water quality parameters' trends in Ankara Eymir Lake using Mann–Kendall test. According to Mann–Kendall test results, there were increasing trends in tested parameters. Delju et al. (2013) analyzed Annual average of climate data time series by statistical methods in Urmia Lake basin; results indicated mean precipitation has decreased by 9.2 % and the average maximum temperature has increased by 0.8 °C over four decades. Due to the significant role of Vanyar dam to supply water for different downstream demands, this study considered the effect of climate change through its main parameters rainfall and temperature on discharge and water quality parameter trends. The trend of water quality parameters of Vanyar station which is located at the upstream of Vanyar dam, were investigated using Mann–Kendall test, including: Sodium (Na), Chlorine (Cl), Sodium Absorption Ratio (SAR), Total Dissolved Solids (TDS), and Electrical Conductivity (EC) in comparison with discharge trends in this station. Changes in water quality correspond with discharge changes which are directly affected by climatic parameters like rainfall and temperature. This study has considered wet and dry seasons; October and June were indicators of wet and dry months in the year, respectively. The study area and the location of Vanyar dam in Iran is shown in Fig. 1.

Methodology

Water quality data were collected since 1967–2007, including Sodium (Na), Chlorine (Cl), Sodium Absorption Ratio (SAR), Total Dissolved Solids (TDS), and Electrical Conductivity (EC), also discharge in wet and dry seasons. The rainfall and temperature data of Tabriz synoptic station which is located near Vanyar station were obtained form IRIMO (Islamic Republic of Iran Meteorological Organization). Monthly average of the data time series has been analyzed by statistical methods. The non-parametric Mann–Kendall (MK) method (Mann 1945; Kendall 1975) was applied in this study, as it is distribution-free, robust against outliers, and has a higher power than other commonly used tests (Hess et al. 2001). If there is a positive correlation (persistence) in the time series, the non-parametric test will suggest a significant trend in time series that is, in fact, random more than specified by the significance level (Zhang et al. 2001). One of the main problems in detecting trends in data is the effect of serial dependence. Therefore, to eliminate effect of serial data correlation, first of all, the significance of lag-1 serial correlation (r_1) for all the time series should be tested at the 10 % significance level. To achieve this absolute value of r_1 was compared with the critical threshold, which depends on the number of data. If the absolute value of r_1 was greater than the critical value at a certain level it would be considered significant; otherwise, it would be regarded insignificant. The original MK test was employed for all the time series having insignificant r_1. Lag-one autocorrelation coefficient of data series (1) are computed in monthly, seasonal and annual scales (Kumar et al. 2009):

$$r_k = \frac{\frac{1}{n-k}\sum_{i-1}^{n-k}(X_i - X)(X_{i+k} - \bar{X})}{\frac{1}{n}\sum_{i=2}^{n}(X_i - \bar{X})^2} \quad K = 1, 2, \ldots, \frac{n}{4} \tag{1}$$

In which X_i = ith data, r_k = lag-k autocorrelation coefficient and $\bar{X}$ = mean of time series. If $\frac{-1-1.645\sqrt{n-2}}{n-2} \leq r_1 \leq \frac{-1+1.645\sqrt{n-2}}{n-2}$ data would be assumed to be serially independent at 10 % significance level (CL = 90 %).The effect of serial correlation would be removed from the time series by pre-whitening prior to applying the MK test. The pre-whitening method would be described in the "Modified Mann–Kendall Method" section.

Original Mann–Kendall (MK) Test

The original MK trend test was first carried out by computing an S statistic as

$$S = \sum_{i=2}^{n-1}\sum_{j=i+1}^{n}\operatorname{sgn}(x_j - x_i) \tag{2}$$

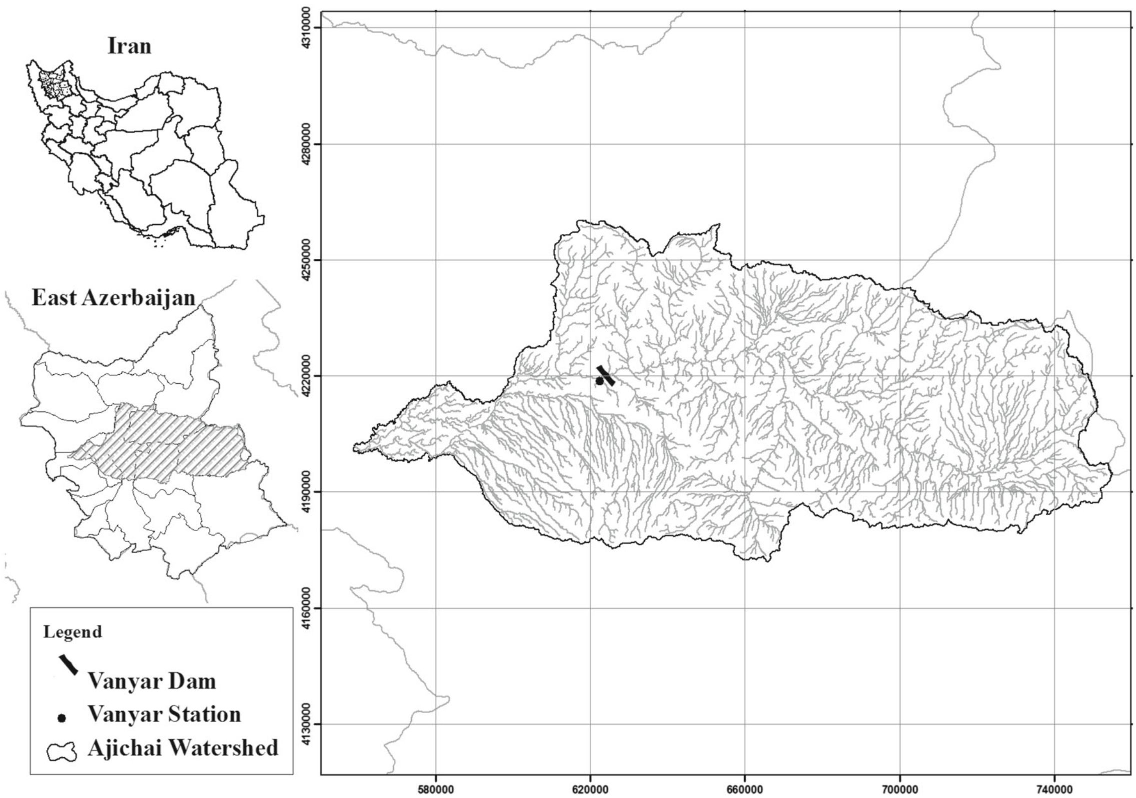

Fig. 1 Ajichay watershed

where n is the number of observations, x_j is the jth observation, and sgn (.) is the sign function and is expressed as follows:

$$\operatorname{sgn}(x_j - x_i) = \begin{cases} 1 & \text{if } (x_j - x_i) > 0 \\ 0 & \text{if } (x_j - x_i) = 0 \\ -1 & \text{if } (x_j - x_i) < 0 \end{cases} \tag{3}$$

Under the assumption that the data are independent and identically distributed, the mean and variance of the S statistic in Eq. (2) are expressed as follow:

$$E(S) = 0 \tag{4}$$

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

where m is the number of tied rank groups each with t_i tied observations. The original MK statistic, designated by Z, was computed as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\mathrm{Var}(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{\mathrm{Var}(S)}} & S < 0 \end{cases} \tag{6}$$

If $-Z_{1-\alpha/2} \le Z \le Z_{1-\alpha/2}$ then the null hypothesis of no trend would be accepted at the significant level of α. Otherwise, the null hypothesis would be rejected and the alternative hypothesis would be accepted at the significant level of α.

Theil–Sen's Estimator

The slop of n pairs of data was estimated using the Theil–Sen's estimator (Sen 1968 and Theil 1950):

$$\beta = \mathrm{Median}\left(\frac{x_j - x_l}{j - l}\right) \quad \forall 1 < l < j \tag{7}$$

According to Yue et al. (2002), the slope estimated by Theil–Sen's estimator is a robust estimate of the magnitude of trend, which has been widely used to identify the slope of the trend line.

Modified Mann–Kendall Method

In the presence of serial correlation in a time series, application of the original MK procedure cannot be recommended for the data set, because the effect of lag-1 serial correlation on trend statistic is a major source of uncertainty. To eliminate the influence of serial correlation on the MK test, the lag-1 serial correlation component from the time series must be removed prior to applying the MK test to assess the influence of trend. This process is called "pre-whitening". The MK test was used to detect trends in the residual (or pre-whitened) series. The new time series can be estimated using the following formula (Kumar et al. 2009):

$$x_i' = x_i - (\beta \times i) \tag{8}$$

The r_1 of new time series would be computed and used to determine the residual series as:

$$y_i' = x_i' - r_1 \times x_{i-1}' \tag{9}$$

The value of $\beta \times i$ was added again to the residual data set as follows:

$$y_i = y_i' + (\beta \times i) \tag{10}$$

The y_i series was subjected to trend analysis.

Result and Discussion

Box Plot diagrams of studied parameters were plotted during 1967–2007 (Fig. 2). The horizontal line inside the boxes represents the median, the upper, and lower lines of the boxes indicate the 75 and 25 % percentiles, respectively. The vertical lines show the minimum (Maximum) values for observations. The height of the box represents the variance between the 25 and 75 % percentiles.

Observed trends of temperature parameters in Tabriz station had an increasing trend by 0.05 °C every year. In contrast, rainfall had a decreasing trend by −2.20 mm every year that is correspond with decreasing trend in observed discharges. Figure 3 shows observed annual trends in temperature and rainfall of Tabriz station.

According to box plots, minimum, maximum, and median of parameters in dry seasons are more than the wet seasons because of lower flow in dry seasons. Also, variances of all parameters in the dry seasons are more than the wet seasons and variances of flow in the dry seasons are less than the wet seasons.

Before the investigation of trend in data time series, the autocorrelation coefficient charts of data were drawn. For example Fig. 4 shows autocorrelation coefficient of electrical conductivity at Vanyar station. The upper and lower dashed lines represent 95 % significance band. None of the autocorrelations has passed the significance band, so classic Mann–Kendal test was used to determine trends. As Fig. 5 shows some of chlorine autocorrelation coefficients at Vanyar station are out of significance band range, so modified Mann–Kendal test was used in chlorine trend determination. Table 1 shows the results of the Mann–Kendall tests in wet and dry seasons at Vanyar station during 1967–2007. All parameters have increasing trend in both dry and wet seasons while discharge has decreasing trend. Although the discovered trends in water quality parameters are not significant (except EC and TDS that are significant at 1 % level), discharge trend is significant at 5 % significant level in wet season and is significant at 1 % in dry seasons. EC and TDS indicate salinity level of water and significant increasing trend of them in wet and dry seasons shows water salinity is increasing at Vanyar station.

Table 2 indicates the slope of studied parameters' trend in wet and dry seasons at Vanyar station. The slope of trends

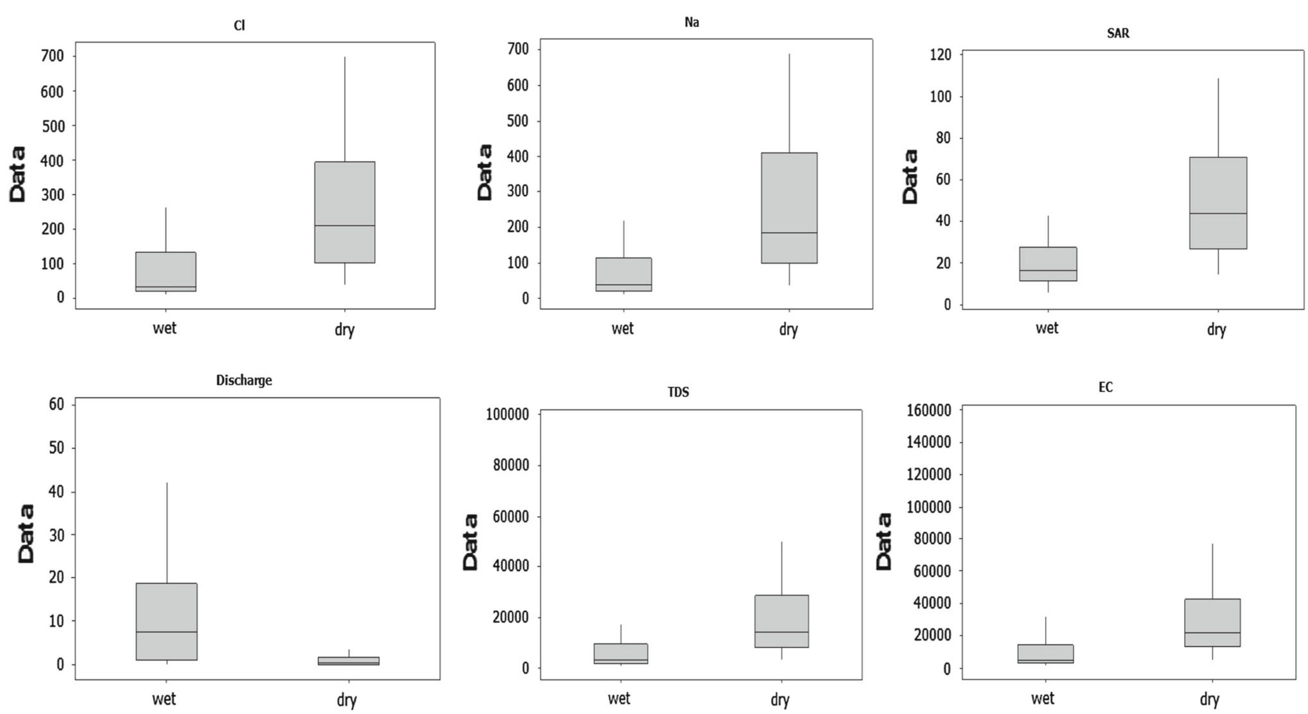

Fig. 2 *Box plots* of studied parameters in monthly scale at Vanyar station

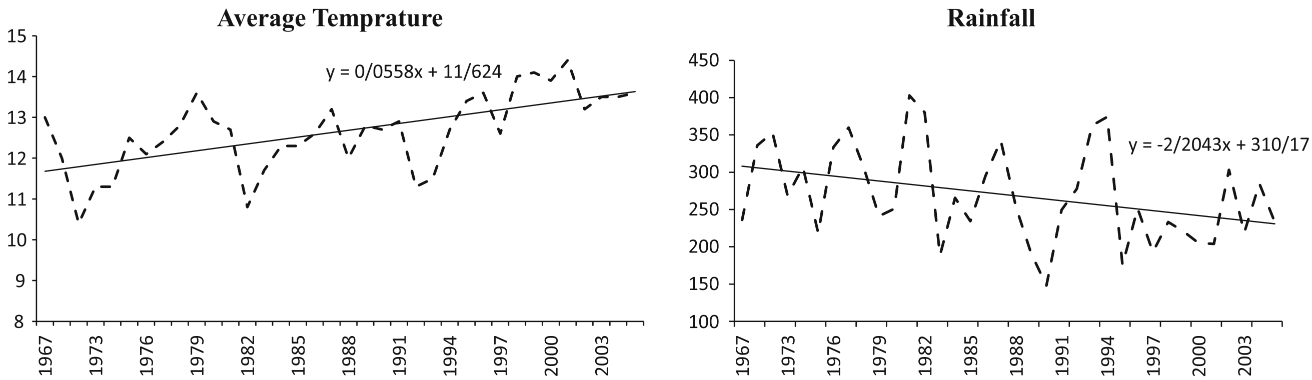

Fig. 3 Trend of temperature and rainfall at Tabriz station during 1967–2007

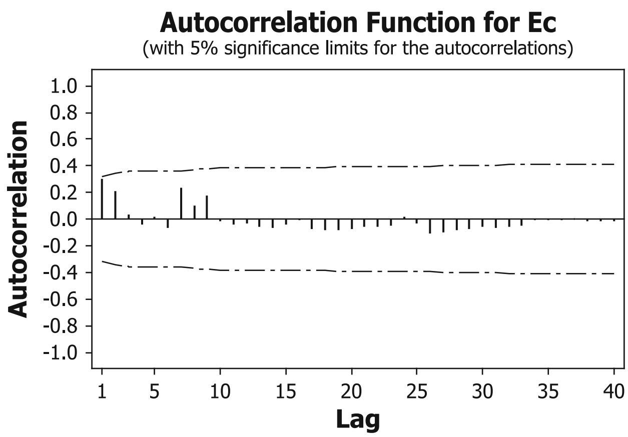

Fig. 4 Example of electrical conductivity autocorrelation coefficient at Vanyar station (1967–2007)

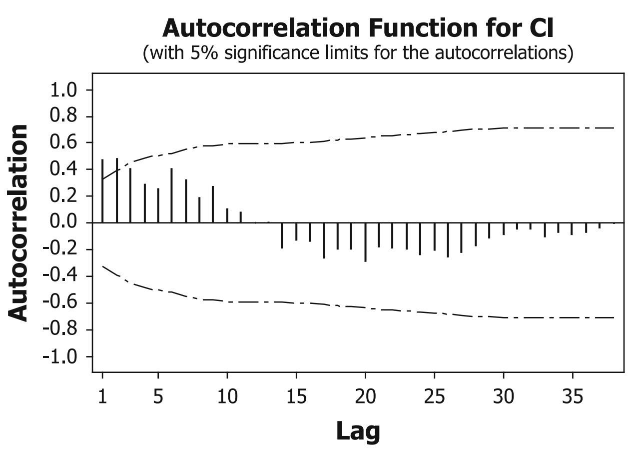

Fig. 5 Example of chlorine autocorrelation coefficient at Vanyar station (1967–2007)

Table 1 Mann–Kendall Z statistics for studied parameters in wet and dry seasons at Vanyar station

Parameters	Z	
	Dry season	Wet season
SAR	1.492	1.372
Na	1.520	1.343
Cl	1.471	1.308
EC	1.523	**2.853****
TDS	1.561	**2.965****
Discharge	**−2.686****	**−2.100***

The bold numbers indicate significant at 10, 5, and 1 % without *, with one * and two ** respectively

Table 2 Sen's slope values for studied parameters in wet and dry seasons at Vanyar station

Parameters	Sen's slope values (β)	
	Dry season	Wet season
SAR	1.31	0.36
Na	9.68	1.46
Cl	10.10	1.53
EC	1065.75	164.66
TDS	678.22	108.69
Discharge	−0.02	−0.25

The dimension of trend line slope is "dimension of parameter per year"

in water quality parameters is upward in both wet and dry seasons at Vanyar stations. In other words, in four recent decades, chemical quality of water has had a downward trend and water salinity has had an upward trend. Water salinity is one of the processes of desertification; increasing of water salinity is not only detrimental to irrigation uses but also causes soil degradation. The trend of discharge is downward in both dry and wet seasons. Maximum slopes of increasing trends occur in dry seasons in contrast slope of decreasing runoff in wet season is more than dry seasons. Filling up reservoirs with water in wet seasons to use in dry seasons accomplished with difficulties because future required water won't be supplied.

To evaluate Mann–Kendall method in trend discovering, we compared the results with those of linear regression method. Figures 6, 7, 8, 9 and 10 show linear regression plots of parameters in dry and wet season.

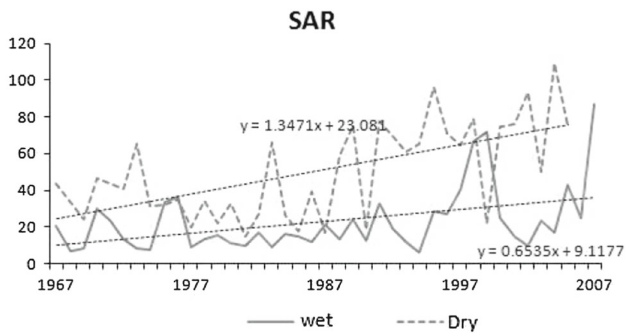

Fig. 6 Trend of SAR changes in wet and dry seasons at Vanyar station during 1967–2007

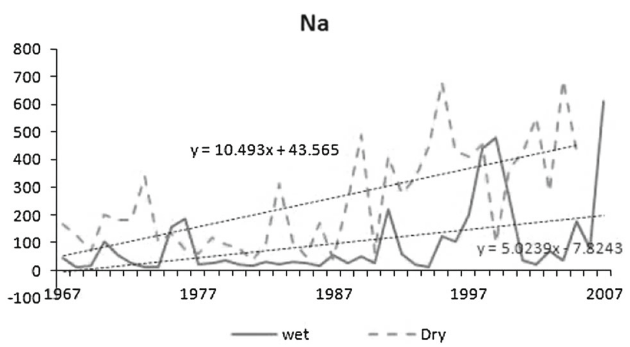

Fig. 7 Trend of Na changes in wet and dry seasons at Vanyar station during 1967–2007

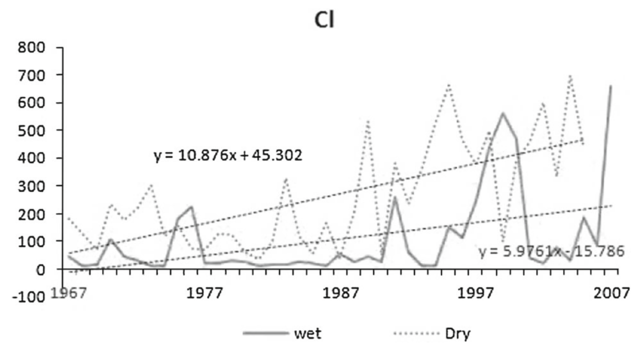

Fig. 8 Trend of Cl changes in wet and dry seasons at Vanyar station during 1967–2007

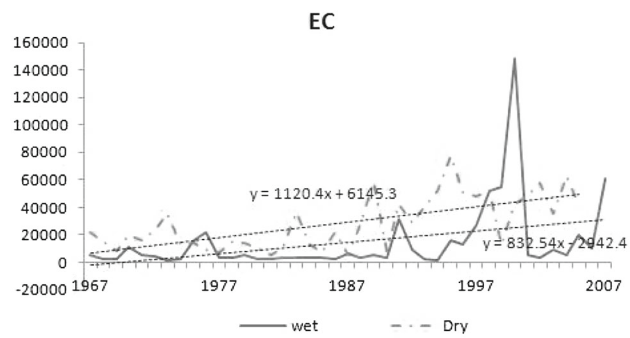

Fig. 9 Trend of EC changes in wet and dry seasons at Vanyar station during 1967–2007

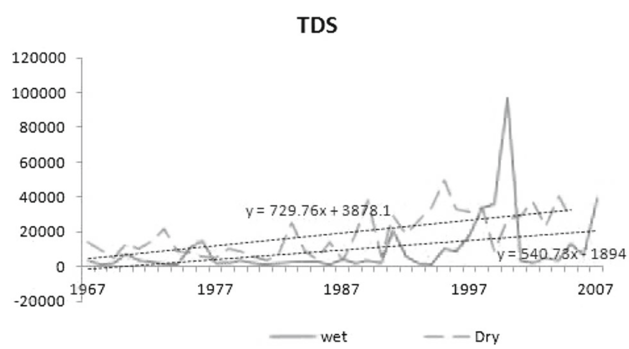

Fig. 10 Trend of TDS changes in wet and dry seasons at Vanyar station during 1967–2007

Figure 6 shows the trend of SAR at Vanyar station. In general, it can be inferred from this figure that SAR has an upward trend. the slope of the SAR trend line which was estimated using linear regression are 0.65 and 1.35 in the wet and dry seasons, respectively, which are approximately close to slopes estimated with Sen's Estimation method equal to 0.36 and 1.31 per year, respectively.

Figure 7 shows the trend of Na at Vanyar station. In general, Na has an upward trend with 10.49 and 5.02 meq/l/year slope which are estimated by linear regression in the wet and dry seasons, respectively, which are approximately equivalent to slopes estimated by Sen Estimator in wet seasons and bigger than those estimated by Sen Estimator in dry seasons.

As Fig. 8 shows Cl has an upward trend with 5.98 and 10.88 meq/l/year slope using linear regression in wet and dry seasons, respectively, which are approximately equal to slopes estimated by Sen Estimator in dry seasons and bigger than those estimated by Sen Estimator in wet seasons.

Electrical Conductivity at Vanyar station as shown in Fig. 9 has an upward trend with 832.54 and 1120.4 mmhos/cm /year slopes estimated by linear regression in wet and dry seasons, respectively, which are equivalent to Sen's Estimations in dry seasons and bigger than Sen's Estimations in wet seasons. Figure 10 illustrates the trend of TDS at Vanyar station. TDS has an upward trend in general with 540.73 and 729.76 mg/l/year slope estimated using linear regression in the wet and dry seasons, respectively, which are equivalent to slopes estimated using Sen's Estimator in dry seasons and more than Sen's Estimations in wet seasons equal to 108.69.

Figure 11 shows the trend of discharge at Vanyar station; discharge has a downward trend; the slope of discharge trend line which estimated using linear regression are −0.39 and −0.06 m^3/s/year in the wet and dry seasons, respectively, which are a little more than slopes estimated with Sen's Estimation method equal to −0.25 and −0.02, respectively.

Difference of two methods' results is because of methods' nature, which in the first method (Sen's Estimator) data

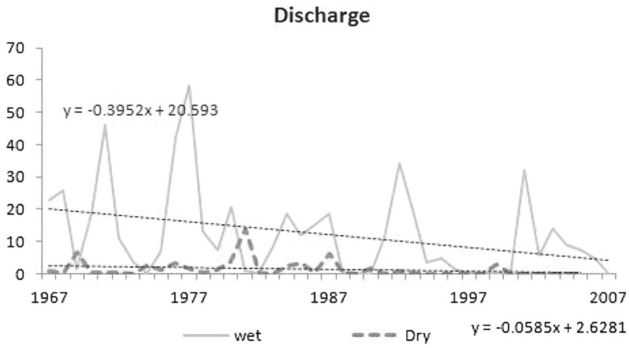

Fig. 11 Trend of discharge changes in wet and dry seasons at Vanyar station during 1967–2007

ranking used for slope estimation while in the second method (linear regression) observed data themselves used for trend line slope. Upward trend of water quality parameters in four recent decades indicate decrease in chemical quality of surface water with regard to downward trend of discharge which is related to climate fluctuations in study area.

Conclusion

Climate change has influenced streamflow in Ajichay river basin; to evaluate the corresponding change in water quality, five water quality parameters trends in the wet and dry seasons during the period of 1967–2007 were carried out using the Mann–Kendall method at Vanyar station which located at the upstream of Vanyar dam. The effect of significant lag-1 serial correlation was removed from data series by pre-whitening prior to trend analysis. Results indicated that with decreasing trend in discharge all selected water quality parameters had an increasing trend in both wet and dry seasons. Based on estimations increasing trend of Na, Cl, EC, TDS, and SAR in dry seasons were more rapid than trends in wet seasons. In other words, in four recent decades, water salinity has had an upward trend. Water salinity is one of the processes of desertification; increasing of water salinity is not only detrimental to irrigation uses but also causes soil degradation. Decreasing trend of discharge in wet seasons was more rapid than trends in dry seasons. Filling up reservoirs with water in wet seasons to use in dry seasons accomplished with difficulties because future required water won't be supplied and won't have proper quality to use.

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