Stoch Environ Res Risk Assess (2013) 27:547–559
DOI 10.1007/s00477-012-0599-4

ORIGINAL PAPER

Trend analysis of groundwater using non-parametric methods (case study: Ardabil plain)

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Published online: 1 July 2012

Abstract In the present study, the trends in groundwater level and fifteen hydro-geochemical elements at 32 piezometric stations located in the Ardabil plain of the northwest of Iran were analyzed using the non-parametric Mann–Kendall method after removing the effect of significant lag-1 serial correlation from the respective time series by pre-whitening. The magnitudes of trends were computed using the Sen's estimator method. The homogeneity of trend was tested using the method proposed by van Belle and Hughes as well. Results showed that significant ($\alpha < 0.1$) negative trends in groundwater level were witnessed for all but five stations of the Ardabil plains during the last 22 years from 1988 to 2009. The groundwater levels over Ardabil plain have declined at the rate of about 18 cm/year, with the strongest decline (1.93 m/year) witnessed at Khalife-loo-sheikh station. The results of homogeneity of trends showed that trends were homogeneous for months but not for stations. Strong positive trends were detected in the groundwater quality concentration across the whole plain. Decline in groundwater level and increase in geochemical elements in the groundwater were attributed to the human activities in the Ardabil plain located in the northwest of Iran.

Keywords Trend · Groundwater level · Groundwater quality · Mann–Kendall · Homogeneity · Ardabil plain · Iran

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1 Introduction

Groundwater is an important source of fresh water to meet the demands of growing industries such as agriculture, fisheries, mining, and manufacturing and the municipal water demands due to rise in population in different parts of the world. Efficient management of groundwater is an essential task in different regions, especially in arid and semi-arid climates that faces chronic shortage of fresh water. Thus, the detection of trends in groundwater levels is very essential in order to constantly monitor the levels of the ground water table and/or the concentration of hydro-geochemical elements in the groundwater. The non-parametric methods have been used for trend analysis of groundwater by various researchers for case studies of different countries that are briefly discussed in the subsequent texts. Gehrels et al. (1994) analyzed the fluctuations in surface water and groundwater levels in the Netherlands, and have reported that the groundwater levels have declined over the wide area due to the drainage, drought and excess overdraft by the farmers. Chen et al. (2004) investigated the correlation between the climatic parameters and the groundwater levels in the Manitoba (Canada) by using the data of the mean, the maximum and the minimum temperatures and precipitation during the hundred-year period from 1900 to 2000. The mean annual temperature and precipitation were found to significantly correlated with the ground water in the Manitoba. Almedeij and Al-Ruwaih (2006) investigated the fluctuations in the groundwater levels in the residential areas of Kuwait. They found that the groundwater levels were negatively correlated with temperature and positively correlated with precipitation. Jan et al. (2007) examined the effects of rainfall intensity and its distribution on the fluctuations of the groundwater levels in Taiwan and reported a linear correlation between the groundwater levels and the precipitation.

Panda et al. (2007) investigated the influence of drought and anthropogenic effects on groundwater levels in Orissa (India) by using the Mann–Kendall (MK) non-parametric test for trend analysis in the pre-monsoon and post-monsoon groundwater level records of 1,002 monitoring stations during the period 1994–2003. They reported that the drawdown due to deficient rainfall during dry years, high temperatures and anthropogenic pressure were not recovered through the recharge in wet years. In the pre-monsoon (the post-monsoon) season, about 59 % (51 %) of the monitoring stations experienced decline in the groundwater in Orissa. Lee et al. (2007) investigated the variability in the groundwater levels at Daegu, Korea and reported that the construction of subway tunnels could have the caused the decline in the ground water levels. Zhang et al. (2009) examined the temporal and spatial variability in annual extreme water level in the Pearl River Delta region, China. They reported that the water levels declined (increased) in the upper parts (the middle and the lower parts) of the Delta region. Shahid and Hazarika (2009) examined the groundwater drought in the northwestern districts of Bangladesh in 85 wells from 1998 to 2002. Analysis of groundwater hydrographs and rainfall revealed that ever increasing groundwater extraction for irrigation in the dry season and recurrent droughts were the two main causes of the drop in the groundwater levels in the region. They found the groundwater scarcity in about half of the area studied in each year in the region. Shamsudduha et al. (2009) studied the recent trends in groundwater levels from the period 1985 to 2005 in a highly seasonal hydrological system in the Ganges–Brahmaputra–Meghna Delta of Bangladesh by using the nonparametric seasonal-trend decomposition procedure. They found that seasonality dominated the observed variance in groundwater levels but declining groundwater levels (>1 m/year) were detected in urban and peri-urban areas, and at the rate of 0.1–0.5 m/year where intensive abstraction of groundwater was conducted for the dry-season rice cultivation. However, rising groundwater levels (0.5–2.5 cm/year) were observed in the estuarine and southern coastal regions.

Tabari and Nikbakht Some'e (2011) investigated the temporal trends in annual, seasonal and monthly groundwater levels using the MK test and the Sen's slope estimator in the Mazandaran province located at the north of Iran during the period from 1985 to 2007. The results indicated a mixed combination of negative and positive trends in the groundwater level series. However, the positive trends were much more pronounced than negative ones. The results of spatial analysis showed that the significant positive trends were concentrated in the central parts of Mazandaran province where paddy fields are the major source of fresh water consumption.

Several studies were also conducted to investigate the groundwater quality parameters in different parts of the world. Lambrakis et al. (1997) investigated the impacts of simultaneous action of drought and over pumping on Quaternary aquifers of Glafkos basin (Patras region, western Greece) during the period 1990–1993. During the last few decades, the depletion in the aquifers was recorded due to the decreases in groundwater recharge caused due to the rainfall decreases over the basin and the increased water pumping. Chemical analyses showed a constant decline in the groundwater quality parameters mainly due to the chlorides. Kampbell et al. (2003) witnessed increases in the nitrate (>0.1 mg/l), orthophosphates (>0.1 mg/l), chlorides (>MCL), and sulfates (>MCL) on analyzing the groundwater quality data of 55 wells in Texoma Lake during drought. They witnessed the higher increases in nitrate concentration under both agriculture lands and in septic tank areas and increase in ammonium–nitrogen only in the septic tank areas. Liu et al. (2003) applied factor analysis for the assessment of groundwater quality in a blackfoot disease areas in Taiwan for 13 hydro-chemical parameters. They showed that Factor 1 (seawater salinization) includes concentrations of EC, TDS, Cl, SO, Na, K and Mg. Factor 2 (arsenic pollutant) includes concentrations of Alk, TOC and arsenic. They showed that over extraction of groundwater is the major cause of groundwater salinization and arsenic pollution in the coastal area of Yun-Lin, Taiwan. Broers and Grift (2004) studied the trends in groundwater quality through the MK non-parametric test at specific depths and the time-averaged concentration-depth profiles due to anthropogenic-induced changes in agricultural practices over the Dutch province of Noord–Brabant. Almasri and Kaluarachchi (2004) evaluated the nitrate pollution trend of groundwater in agriculture-dominated watersheds in Whatcom County, Washington. They combined the concentration data of different wells having few observations to reduce the uncertainty of predictions and conclusions. Bouza-Dean et al. (2008) analyzed the trend of surface water quality for thirty-four physical–chemical and chemical variables along the Spanish Ebro River surface water by using the MK seasonal test and the Sen's slope estimator. Results revealed parameter variation over time due mainly to the reduction in phosphate concentration and increasing pH levels at the Ebro basin from 1981 to 2004. Elhatip et al.

(2008) evaluated the water quality at Tahtali dam watershed in Izmir-Turkey by means of statistical tests. The major chemical loads of surface water at the Tahtali dam reservoir were evaluated statistically by using the monthly averaged values. Chang (2008) studied the spatial patterns of water quality trends for 118 sites in the Han River basin of South Korea for eight parameters includes temperature, pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended sediment (SS), total phosphorus (TP), and total nitrogen (TN) through the non-parametric seasonal MK's test for the period from 1993 to 2002. No significant trends were observed in temperature, but significant increasing trends were witnessed in the TN concentrations for the majority of the monitoring stations. DO, BOD, COD, pH, SS, and TP show increasing or decreasing trends with approximately half of the stations exhibiting no trends. Houben et al. (2009) observed the increases in the concentrations of the nitrate and faecal bacteria and the pH in the Kabul Basin (Afghanistan) due to the frequent occurrence of drought. Wahlin and Grimvall (2009) assessed the regional trends in the groundwater quality in Sweden and found increasing trends in acid-neutralizing capacity and declining trends in sulfate (SO_4^{-2}).

Elci and Polat (2010) assessed the variability in the parameters of the groundwater quality in seasonal time scale in a karstic aquifer system near Izmir-Turkey. The results showed that the trend of the most parameters were statistically non-significant. However, significant increases in the EC values and aluminum concentrations were witnessed in the seasonal time scales, i.e., from the winter season to the summer season. A few other parameters, i.e., sodium (Na^+), iron, manganese and arsenic had witnessed significant trends. On the other hand, concentration of chloride (Cl^-) witnessed significant decline in the rainy season. Decreasing trends were also witnessed in the temperature and the other parameters of groundwater, like, nitrates, phosphates and total hardness (TH). Ketata et al. (2010) investigated the hydro-chemical analysis of groundwater in Gabes-south deep aquifer (south-eastern Tunisia) by using the data collected from nine boreholes during the period of 1995 to 2003. The water samples were investigated for the salinity, the pH, the concentrations of calcium (Ca^{+2}), magnesium (Mg^{+2}), Na^+, potassium (K^+), Cl^-, sulphate (SO_4^{-2}) bicarbonates HCO_3^- and fluoride (F^-) ions. Results indicated that the salinity and the major elements concentrations remained more or less stable. Yidana et al. (2010) analyzed the groundwater quality in the Keta basin, Ghana by using the multivariate and spatial analyses methods. They found that the salinity, nitrate and fluoride of groundwater had high concentration mainly due to the seawater intrusion, domestic waste discharge and agricultural activities. SAR appears to display weak seasonal variations due to the influence of seawater intrusion.

Based on our best knowledge, no reference study is available till day on the trend analysis of groundwater levels in Iran through the use of the non-parametric, though references are available with respect to analysis of groundwater quality for other regions (Chitsazan et al. 2009; Karami and Bayatie 2009; Malakutian and Karami 2004). Therefore, the data of the groundwater levels of 32 piezometric stations and 15 hydro-geochemical parameters are used in the present study in estimating the trends through the non-parametric methods in the Ardabil plains of Iran. The data of the groundwater levels used in the analysis were obtained through the national hydrograph network stations of Iran from the period 1988 to 2009. The data of various parameters of the groundwater quality during the period 1996–2009 were also used in estimating the trends through the MK test. The test of homogeneity was also carried out to examine the overall groundwater levels trend scenario. The novelty of this test lies in the fact that the homogeneous vulnerable zones were delineated in both the spatial and the seasonal context. The objectives of the present study are: (1) to identify the trends and magnitude of trends in groundwater levels on monthly time scales; (2) to test homogeneity of trends in groundwater levels; (3) to determine the trends and magnitudes in 15 different groundwater quality parameters in the Ardabil plains in Iran.

2 Methodology

2.1 Study area and data set

Ardabil Plain (38°03′–38°27′N and 47°55′–48°20′E), located in the north-western Iran, covers an area of about 990 km^2 (see Fig. 1). There are two high mountains, namely, Alborz and Sabalan, which are located around the Ardabil plain. The mean areal annual rainfall over the Ardabil plain is about 304 mm. May and August are known as the wettest and driest months of the region, respectively. The mean temperature in the Ardabil plain is about 9 °C, and this plain is well known as the one of the coldest region in Iran. The average number of freezing days in the Ardabil plain is about 130 days in a year. In the present study, the trend analysis was carried out on the groundwater levels of 32 piezometric stations located in the Ardabil plain from the period of 1988 to 2009 using the non-parametric MK test. Figure 1 shows the locations of the groundwater monitoring stations in the study area.

The groundwater quality parameters used in this study are shown in Table 1. The groundwater hydro-geochemical data of 32 stations were collected from the duration of 1996 to 2009. The groundwater hydro-geochemical data are measured twice in a year, i.e., once in the wet season (the expected time to attain the comparatively higher water levels), and on the other occasion in the dry season (time of comparatively lower water levels). Hereafter, the wet and dry seasons are referred

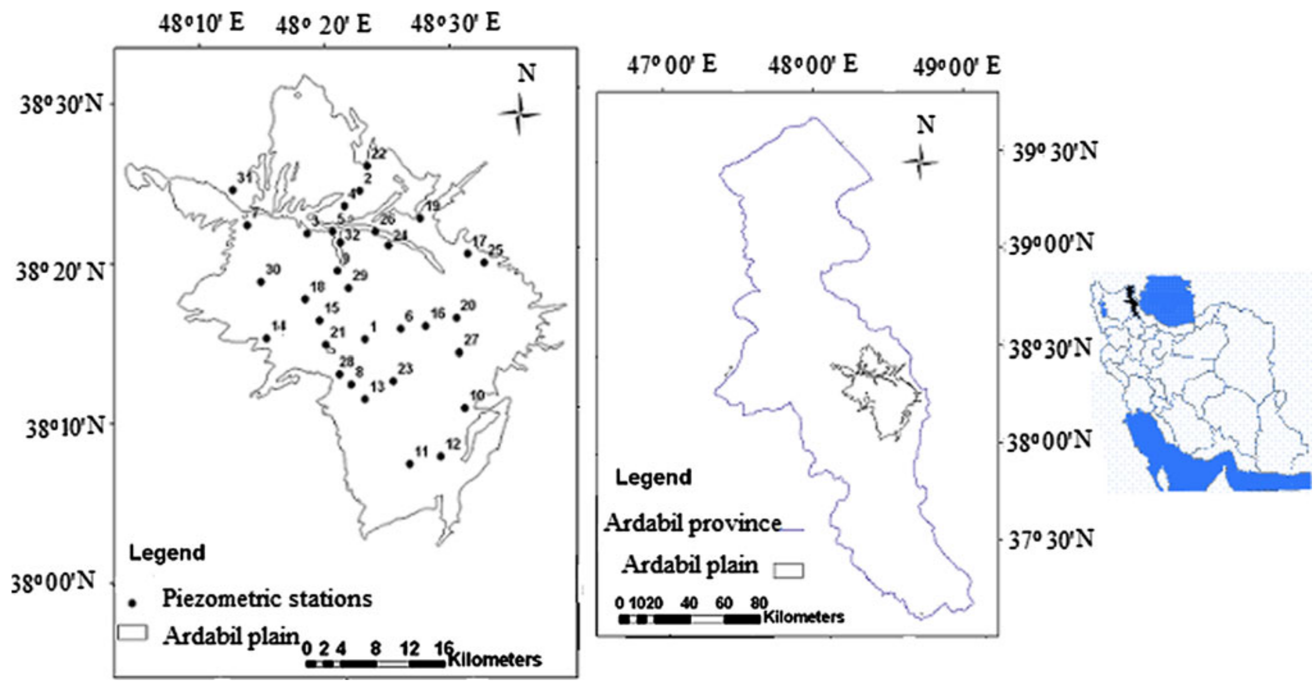

Fig. 1 Study area map, Ardabil plain, Iran

Table 1 Groundwater quality parameters used in the present study

Parameter	Unit
pH	No dimension
EC	μZIMENS/cm
SO_4^-	meq/l
HCO_3^-	meq/l
Na^+	meq/l
SAR	No dimension
TDS	mg/l
Na %	No dimension
Ca^{++}	meq/l
Mg^{++}	meq/l
K^+	meq/l
Cl^-	meq/l
TH	mg/l
Cations	meq/l
Anions	meq/l

as the wet and dry months, respectively. Figure 2 presents the locations of 32 stations at which the data of various parameters of groundwater quality are measured.

2.2 Non-parametric test for trend detection

2.2.1 MK test (MK1)

The conventional MK test given by Mann (1945) and Kendall (1975) has been extensively used to assess the significance of monotonic trends in hydro-meteorological time series such as precipitation, temperature and stream flow (Gan 1998; Zhang et al. 2001; Burn and Elnur 2002; Xu et al. 2003; Yang et al. 2004). The non-parametric statistical tests are flexible, and can handle the idiosyncrasies of data like presence of missing values, censored data, seasonality and highly skewed data. However, the MK test for trend detection assumes that the sample data are serially independent, even though a few hydrological series show significant serial correlation. The presence of positive serial correlation increases the probability that MK test detects trend even though no such trend exists. One approach to handle serial correlation is to consider a subset of data that ensures the data independence (Gan 1998). The other approach is to remove the serial correlation such as lag 1 auto regression (1) or higher order process from the time series before application of the test. This process is called the pre-whitening (Zhang et al. 2001; Burn and Elnur 2002).

Consider the time series of the groundwater level data measured through the piezometric wells for seasons in each of the n years and at t stations. Each observation may be denoted by X_{igk}, which represents the observation collected in year i (i = 1,2,…n), season g (g = 1,2,…, 12) and from station k (k = 1,2,…, t).

The series for the season g at station k may be expressed as $\{X_{1gk}, X_{2gk}, X_{3gk},\ldots,X_{ngk}\}$. The MK test statistic for the series, S_{gk}, is the sum of all signs of consecutive observation differences defined as

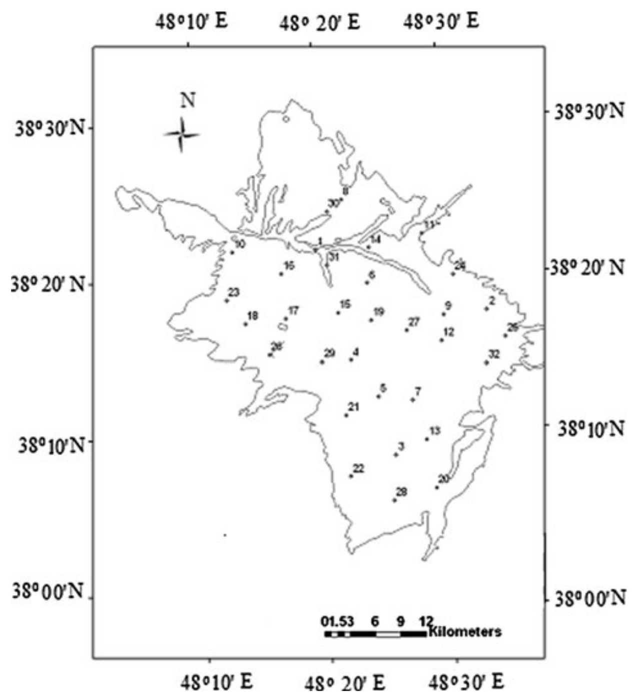

Fig. 2 Location of groundwater quality stations, Ardabil plain, Iran

$$S_{gk} = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}\left(X_{jgk} - X_{igk}\right), \quad \forall 1 \leq i < j \leq n \tag{1}$$

here

$$\operatorname{sgn}(\theta) = \begin{cases} 1 & \text{if } \theta > 0 \\ 0 & \text{if } \theta = 0 \\ -1 & \text{if } \theta < 0 \end{cases} \tag{2}$$

Under the null hypothesis of no trend, S_{gk} is asymptotically normally distributed with mean 0 and variance given as

$$(\sigma_{gg})_k = \frac{[n(n-1)(2n+5) - \sum d(d-1)(2d+5)]}{18} \tag{3}$$

here, d is the extent of any tie (i.e. length of tie), and the summation is over all the ties. The series having no repeat observations, d becomes 0. For a time series of more than equal to 10 years, i.e. $n \geq 10$, the MK1 statistics is nearly normally distributed. Applying continuity correction, the test statistic becomes $S'_{gk} = S_{gk} - \operatorname{sgn}(S_{gk})$, which follows normal distribution. For testing the null hypothesis, the Z-value associated with the test statistic can be calculated

$$Z_{gk} = \frac{S'_{gk}}{(\sigma_{gg})_k^{1/2}} \tag{4}$$

The null hypothesis is accepted when $-Z_{1-\alpha/2} \leq Z_{gk} \leq Z_{1+\alpha/2}$, where $\pm Z_{(1-\alpha/2)}$ are the $1 - \alpha/2$ standard normal distribution quantiles.

The MK test is applied to the y_i series to determine the significance of the trend.

Another very useful index to quantify the monotone trend is Kendall slope (β), initially proposed by Sen (1968), and later extended by Hirsch et al. (1982). It is defined as

$$\beta_{gk} = \text{Median}\left(\frac{X_{igk} - X_{jgk}}{i - j}\right), \quad \forall 1 \leq i < j \leq n \tag{5}$$

The estimator β is the median over all combination of record pairs for the whole data set, and is resistant to the extreme observations. A positive value of β indicates an upward trend, and the negative value indicates a downward trend with time.

2.2.2 MK1 with trend-free pre-whitening (TFPW) (MK2)

The TFPW, which we called it MK2 here after described by Yue et al. (2002) involves the following steps (Kumar et al. 2009):

1. Compute the lag-one autocorrelation coefficient (r_1) using:

$$r_k = \frac{\frac{1}{n-k}\sum_{i=1}^{n-k}(x_i - \bar{x})(x_{i+k} - \bar{x})}{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2} \tag{6}$$

2. If $\frac{-1-1.645\sqrt{n-2}}{n-2} \leq r_1 \leq \frac{-1+1.645\sqrt{n-2}}{n-2}$ then the data are assumed to be serially independent at 10 % significance level (CL = 90 %) and no pre-whitening is required. Else data are considered to be serially correlated and pre-whitening is required before applying the MK1.
3. Compute slope (β) in the sample data by using Eq. (5), and remove the trend from the series to get a detrended series by using the following equation:

$$X'_i = X_i - (\beta * i) \tag{7}$$

4. Compute the lag-1 autocorrelation of the detrended series, i.e. r_1 by using Eq. (6).
5. Remove the lag-one autoregressive component (AR (1)) from the detrended series to get a residual series as given below:

$$y'_i = X'_i - r_1 * X'_{i-1} \tag{8}$$

6. The trend (β*i) is added back to the residual series to get a new series as below:

$$y_i = y'_i + (\beta * i) \tag{9}$$

We used MK test to analyze trends of this new series.

2.2.3 Homogeneity of trends

The homogeneity test is based on partitioning the sum of square that uses the one-sided Chi-square (χ^2) test with $\alpha < 0.05$ to determine the trend homogeneity between months, sites and month-site interactions (Van Belle and Hughes 1984; Gan 1998). The normalized MK trend statistics Z_{gk} associated with month g and site k is presented in a two-way format as

months	stations 1	2	…	t	$Z_{g.}$
1	Z_{11}	Z_{12}	…	Z_{1t}	$Z_{1.}$
2	Z_{21}	Z_{22}	…	Z_{2t}	$Z_{2.}$
.					.
.					.
.					.
s	Z_{s1}	Z_{s2}	…	Z_{st}	$Z_{s.}$
$Z_{.k}$	$Z_{.1}$	$Z_{.2}$	…	$Z_{.t}$	$Z_{..}$

where $Z_{g.} = t^{-1}\sum_{k=1}^{t} Z_{gk}$ denotes the average Z value over t sites for month g; $Z_{.k} = s^{-1}\sum_{g=1}^{s} Z_{gk}$ denotes the average Z value over s months for site k; $Z_{..} = (st)^{-1}\sum_{g=1}^{s}\sum_{k=1}^{t} Z_{gk}$ denotes the overall average Z-value. Without the loss of the generality, we define the hypotheses of interest in terms of S_{gk} as

(I) $H_0 : \tau_{1.} = \tau_{2.} = \cdots = \tau_{s.}$ (i.e., is there trend homogeneity among months?)
(II) $H_0 : \tau_{.1} = \tau_{.2} = \cdots = \tau_{.t}$ (i.e., is there trend homogeneity among sites?)
(III) $H_0 : \tau_{gk} - \tau_{g.} - \tau_{.k} - \tau_{..} = \text{constant}$ (i.e., is there presence of site-month interaction?)
(IV) $H_0 : \tau_{..} = 0$ (i.e., is there presence of overall trend given the above conditions?)

Table 2 Mann–Kendall Z statistics for groundwater level in the Ardabil plain

Number	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Aghabagher	**−4.35**	**−4.38**	**−4.85**	**−4.85**	**−4.65**	**−5.15**	**−4.73**	**−4.64**	**−4.91**	**−4.85**	**−4.55**	**−4.33**
2	Aghazaman kandi	**−3.92**	**−3.28**	**−3.37**	**−2.66**	**−2.48**	**−3.38**	**−3.66**	**−4.28**	**−4.74**	**−3.58**	**−4.16**	**−3.61**
3	Aghche kandi	0.55	0.22	−0.75	−1.21	0.46	1.05	0.75	1.37	**2.40**	0.00	0.44	0.73
4	Alibolaghi	−1.44	−1.57	**−1.90**	**−2.24**	**−1.96**	−1.59	**−2.32**	−0.91	−1.33	−1.37	**−1.66**	−1.12
5	Anzab payin	**−4.06**	**−4.35**	**−3.02**	**−3.64**	**−3.71**	**−3.54**	**−2.66**	**−3.54**	**−2.76**	**−4.19**	**−3.47**	**−3.11**
6	Arazi gharahasanlo	**−4.85**	**−5.56**	**−5.31**	**−4.97**	**−5.87**	**−6.07**	**−5.74**	**−6.00**	**−5.81**	**−6.13**	**−5.53**	**−5.09**
7	Arazi jobbedar	−1.19	−0.77	−0.44	**−2.04**	**−2.66**	**−3.34**	**−2.87**	**−3.18**	**−3.21**	**−2.95**	**−2.63**	**−1.82**
8	Arazi kami abad	**−2.95**	**−2.81**	**−2.81**	**−3.46**	**−3.39**	**−3.36**	**−3.23**	**−2.62**	**−2.84**	**−2.74**	**−2.63**	**−2.34**
9	Arazi khalilabad	**−4.91**	**−5.07**	**−5.15**	**−5.61**	**−5.94**	**−5.68**	**−5.53**	**−5.15**	**−5.23**	**−5.67**	**−5.67**	**−5.23**
10	Arazi noshahr	**−2.85**	**−1.86**	**−3.58**	**−3.50**	**−4.38**	**−4.74**	**−4.35**	**−4.27**	**−4.49**	**−4.28**	**−4.65**	**−3.11**
11	Arazy karkaragh	**−2.54**	**−3.36**	**−3.60**	**−4.39**	**−4.57**	**−4.02**	**−3.94**	**−4.76**	**−4.96**	**−4.70**	**−4.47**	**−3.02**
12	Darvaze astara	**−2.65**	**−2.30**	**−1.88**	−0.63	−1.06	−0.23	0.29	**3.09**	0.60	0.70	−0.39	−1.61
13	Ghara hasanlo	**−5.95**	**−5.56**	**−5.68**	**−5.23**	**−6.00**	**−5.61**	**−5.23**	**−5.67**	**−5.81**	**−6.07**	**−6.07**	**−5.48**
14	Hasan bari	−0.71	−1.20	0.62	**−3.30**	**−2.21**	**−1.85**	**−1.75**	−1.26	**−1.98**	**−2.04**	**−1.98**	**−2.54**
15	Kalkhoran	**−2.35**	**−2.18**	**−1.74**	−1.30	**−2.10**	−1.14	**−1.79**	0.37	−0.59	**−1.94**	**−2.45**	**−2.30**
16	Karkaragh	**−2.67**	**−3.36**	**−3.60**	**−4.39**	**−4.57**	**−4.02**	**−3.94**	**−4.76**	**−4.96**	**−4.70**	**−4.47**	**−3.09**
17	Kenazagh	**−2.84**	**−2.93**	**−4.16**	**−4.34**	**−4.92**	**−3.99**	**−3.94**	**−4.34**	**−4.25**	**−3.73**	**−4.06**	**−2.84**
18	Khalifelosheykh	**−5.76**	**−5.56**	**−5.56**	**−5.68**	**−6.07**	**−6.07**	**−5.81**	**−5.94**	**−6.00**	**−5.95**	**−5.76**	**−5.27**
19	Niar madrase	**3.65**	**3.83**	**3.83**	**3.01**	**3.64**	**3.37**	**2.02**	**2.75**	**2.63**	**4.24**	**3.71**	**3.94**
20	Noshahr korkan	**−2.92**	**−2.84**	**−1.64**	**−3.93**	**−4.12**	**−4.19**	**−5.11**	**−4.57**	**−4.44**	**−3.34**	**−3.99**	**−3.33**
21	Noshnagh	**−2.38**	**−1.78**	**−1.76**	−0.36	−0.28	−1.44	−0.63	−0.49	−1.14	**−2.39**	**−2.65**	**−2.87**
22	Piraghom	**−5.09**	**−4.91**	**−5.00**	**−5.32**	**−5.31**	**−5.67**	**−4.49**	**−5.23**	**−4.98**	**−5.00**	**−4.98**	**−4.16**
23	Razey abad	**−2.27**	**−2.60**	**−2.39**	**−3.41**	**−3.93**	**−3.42**	**−2.68**	**−2.66**	**−3.17**	**−2.87**	**−2.11**	**−2.51**
24	Roberoye forodghah	**−4.65**	**−4.05**	**−4.27**	**−3.94**	**−3.11**	**−3.83**	**−4.69**	**−4.32**	**−4.08**	**−4.65**	**−4.92**	**−3.83**
25	Said abad	**−2.96**	**−2.19**	**−2.75**	**−3.03**	**−3.26**	**−4.17**	**−4.41**	**−4.45**	**−4.09**	**−3.50**	**−2.81**	**−1.98**
26	Sakhsilo	**−4.08**	**−3.56**	**−2.93**	**−3.54**	**−3.94**	**−2.60**	**−3.42**	**−3.58**	**−3.42**	**−3.09**	**−3.58**	**−3.75**
27	Serahi marney	**−5.09**	**−5.00**	**−5.40**	**−5.53**	**−5.39**	**−5.87**	**−5.04**	**−6.00**	**−5.74**	**−5.61**	**−5.94**	**−5.40**
28	Serahi mehmandost	**−3.07**	**−3.23**	**−3.66**	**−3.74**	**−3.86**	**−4.16**	**−4.26**	**−4.06**	**−3.61**	**−3.83**	**−4.01**	**−3.94**
29	Soltan abad	**−4.69**	**−3.92**	**−3.96**	**−3.79**	**−4.64**	**−2.26**	−0.12	**−2.33**	**−3.36**	**−3.79**	**−3.92**	**−3.07**
30	Somee	−0.54	−0.41	0.00	−1.47	−1.44	**−2.80**	−1.59	−0.99	0.00	0.55	−0.14	−0.89
31	Taleb gheshlaghi	**−3.15**	**−3.02**	**−2.79**	**−3.05**	**−3.22**	**−2.58**	**−2.26**	**−2.12**	**−2.20**	**−1.04**	**−3.22**	**−2.97**
32	Yengheje	−0.15	1.09	0.09	−0.66	0.00	0.46	0.82	−0.93	−0.49	0.00	0.54	0.20

The bold numbers indicate significant at $\alpha = 0.1$

Table 3 Sen's slope values for groundwater level in Ardabil plain

Number	Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Aghabagher	−1.10	−1.16	−1.17	−1.15	−1.14	−1.21	−1.26	−1.26	−1.26	−1.24	−1.24	−1.31
2	Aghazaman kandi	−0.17	−0.23	−0.20	−0.13	−0.10	−0.08	−0.09	−0.11	−0.12	−0.15	−0.13	−0.23
3	Aghche kandi	0.04	0.02	−0.02	0.00	0.00	0.03	0.02	0.09	0.10	0.00	0.04	0.06
4	Alibolaghi	−0.02	−0.02	−0.04	−0.04	−0.04	−0.03	−0.03	−0.01	−0.02	−0.01	−0.01	−0.02
5	Anzab payin	−0.05	−0.06	−0.08	−0.08	−0.08	−0.06	−0.07	−0.08	−0.06	−0.05	−0.06	−0.07
6	Arazi gharahasanlo	−0.96	−0.99	−1.03	−0.95	−0.96	−0.96	−1.01	−0.94	−0.98	−0.88	−0.92	−1.03
7	Arazi jobbedar	−0.14	−0.14	−0.12	−0.16	−0.19	−0.15	−0.19	−0.22	−0.19	−0.18	−0.19	−0.14
8	Arazi kami abad	−0.81	−0.80	−0.79	−0.53	−0.54	−0.53	−0.50	−0.47	−0.44	−0.56	−0.55	−0.87
9	Arazi khalilabad	−1.43	−1.36	−1.66	−1.57	−1.42	−1.58	−1.51	−1.61	−1.43	−1.32	−1.34	−1.44
10	Arazi noshahr	−0.35	−0.33	−0.37	−0.32	−0.34	−0.23	−0.29	−0.33	−0.25	−0.26	−0.30	−0.35
11	Arazy karkaragh	−0.17	−0.26	−0.21	−0.14	−0.16	−0.14	−0.19	−0.18	−0.16	−0.16	−0.18	−0.21
12	Darvaze astara	−0.04	−0.06	−0.04	0.00	−0.02	−0.01	0.02	0.15	0.06	0.03	−0.01	−0.04
13	Ghara hasanlo	−1.12	−1.25	−1.26	−1.20	−1.15	−1.24	−1.35	−1.20	−1.17	−1.11	−1.09	−1.26
14	Hasan bari	−0.01	−0.03	−0.01	−0.02	−0.03	−0.03	−0.04	−0.03	−0.04	−0.04	−0.04	−0.03
15	Kalkhoran	−0.09	−0.10	−0.07	−0.05	−0.06	−0.05	−0.28	0.07	−0.09	−0.14	−0.13	−0.10
16	Karkaragh	−0.09	−0.05	−0.06	−0.05	−0.06	−0.04	−0.05	−0.06	−0.04	−0.07	−0.07	−0.06
17	Kenazagh	−0.05	−0.06	−0.08	−0.05	−0.05	−0.04	−0.04	−0.05	−0.04	−0.04	−0.05	−0.05
18	Khalifelosheykh	−1.64	−1.71	−1.75	−1.57	−1.53	−1.59	−1.65	−1.60	−1.56	−1.61	−1.70	−1.93
19	Niar madrase	0.20	0.16	0.19	0.16	0.14	0.19	0.13	0.11	0.17	0.18	0.13	0.23
20	Noshahr korkan	−0.25	−0.26	−0.15	−0.27	−0.32	−0.31	−0.34	−0.31	−0.31	−0.28	−0.50	−0.25
21	Noshnagh	−0.06	−0.04	−0.05	−0.01	−0.01	−0.05	−0.02	−0.02	−0.03	−0.06	−0.05	−0.06
22	Piraghom	−1.36	−1.34	−1.45	−1.32	−1.59	−1.44	−1.59	−1.52	−1.52	−1.41	−1.36	−1.43
23	Razey abad	−0.29	−0.25	−0.29	−0.43	−0.47	−0.65	−0.66	−0.46	−0.75	−0.42	−0.30	−0.32
24	Roberoye forodghah	−0.19	−0.21	−0.24	−0.15	−0.15	−0.15	−0.17	−0.20	−0.21	−0.20	−0.20	−0.21
25	Said abad	−0.36	−0.47	−0.35	−0.20	−0.21	−0.23	−0.27	−0.28	−0.28	−0.29	−0.39	−0.33
26	Sakhsilo	−0.11	−0.10	−0.09	−0.08	−0.09	−0.07	−0.13	−0.12	−0.12	−0.08	−0.11	−0.11
27	Serahi marney	−1.80	−1.77	−1.89	−1.69	−1.74	−1.65	−1.65	−1.52	−1.66	−1.51	−1.55	−1.75
28	Serahi mehmandost	−0.83	−0.75	−0.75	−0.78	−0.88	−0.92	−1.03	−1.16	−1.17	−0.93	−0.98	−0.97
29	Soltan abad	−0.18	−0.17	−0.25	−0.15	−0.13	−0.10	−0.06	−0.12	−0.21	−0.18	−0.16	−0.16
30	Somee	−0.13	−0.09	0.00	−0.15	−0.18	−0.17	−0.17	−0.19	0.01	−0.04	−0.09	−0.18
31	Taleb gheshlaghi	−0.14	−0.13	−0.16	−0.15	−0.15	−0.10	−0.12	−0.12	−0.08	−0.06	−0.13	−0.18
32	Yengheje	0.00	0.04	0.00	−0.01	0.00	0.02	0.04	−0.04	−0.02	0.00	0.02	0.02

Under the null hypothesis that there is no trend for a particular month in a given station, i.e. $H_0 : \tau_{gk} = 0, \sum_{g=1}^{s} \sum_{k=1}^{t} Z_{gk}^2$ has a χ^2 (total) distribution with st degrees of freedom. Subsequently, the total χ^2 is partitioned into respective sources of variations as

(I) $X^2_{\text{total, st}} = \sum_{g=1}^{s} \sum_{k=1}^{t} Z_{gk}^2$ i.e. the total χ^2 with st degrees of freedom (d.f.).

(II) $X^2_{\text{homogeneity,st}-1} = \sum_{g=1}^{s} \sum_{k=1}^{t} \left(Z_{gk} - Z_{..}\right)^2$ i.e. the homogeneity χ^2 with (st − 1) d.f.

(III) $X^2_{\text{months}-1} = t \sum_{g=1}^{s} \left(Z_{g.} - Z_{..}\right)^2$ i.e. the χ^2 due to month with (s − 1) d.f.

(IV) $X^2_{\text{site},t-1} = s \sum_{k=1}^{t} (Z_{.k} - Z_{..})^2$ i.e. the χ^2 due to site with (t − 1) d.f.

(V) $X^2_{\text{site-month},(t-1)(s-1)} = \sum_{g=1}^{s} \sum_{k=1}^{t} \left(Z_{gk} - Z_{.k} - Z_{g.} - Z_{..}\right)^2$ i.e. the χ^2 due to site-month interaction with (t − 1)(s − 1) d.f.

(VI) $X^2_{\text{trend},1} = stZ^2_{..}$ i.e. the χ^2 due to trend with 1 d.f.

The following steps are used for testing the null hypothesis:

(1) Under the null hypotheses, the χ^2 statistics presented above are used for testing site homogeneity (χ^2_{site}), month homogeneity (χ^2_{month}), and site-month homogeneity $\left(\chi^2_{\text{site-month}}\right)$.

(2) If site, season and site-season homogeneity are not found to be significant, then the test for overall trend is carried out using the $\left(\chi^2_{\text{trend}}\right)$.

(3) If sites are heterogeneous but not months then the trend test for individual site is obtained from $sZ_{.k}^2 (k = 1, 2, \ldots, t)$, which is distributed as χ^2 variate under the null hypothesis $H_0 = \tau_{.k} = 0$.
(4) If months are heterogeneous but not sites, then trend test for individual month is obtained from $tZ_{g.}^2 (g = 1, 2, \ldots, s)$, which is distributed as χ^2 variate under the null hypothesis $H_0 = \tau_{g.} = 0$.
(5) If both sites and months are heterogeneous or there is significant site-month interaction, then the individual entries in the site-month two way table, i.e. Z_{gk}, (g = 1, 2,…, s; k = 1,2,…, t) are tested for significance of trends. The null hypothesis of no trend is accepted if $-Z_{\alpha/2} < Z_{gk} < Z_{\alpha/2}$, where $\pm Z_{\alpha/2}$ is the standard normal deviate at the significance level α.

3 Results

3.1 Non-parametric test results

The application of MK test statistics using Eq. (4) has resulted in the identification of trend direction in the groundwater levels and groundwater quality parameters in the Ardabil plain. A negative trend indicates the decline of groundwater levels and a positive trend indicates the rise of groundwater levels over the years. As each monitoring well reflects the groundwater dynamics of the surrounding area, each trend value gives an idea about the water table fluctuations of that area over the time period.

3.2 Trends in the groundwater level

The values of the Z statistics obtained through the MK test for the groundwater levels in the Ardabil plain are shown in Table 2. Significant declining trends, at 10 % significance level, in the groundwater levels were witnessed in most of the stations across the plain. Trend analysis through the MK test and Sen's slope estimator indicates drastic decline in the groundwater levels. Most of the time series showed negative trends indicating the decline in the ground water levels in most of the area under study. About 79 % of the negative trends were statistically significant ($\alpha < 0.10$). Results showed that about 303 cases witnessed significant negative trends, while only 14 cases witnessed significant positive trends. Groundwater levels declined extremely in 5 sampling stations, i.e. 6, 9, 13, 18, 22 and 27 (See Table 2) that witnessed the strongest significant negative trend. On the other hand, three stations, namely 3, 19 and 32, witnessed positive trends. In the wet month, the negative trends were observed in about 30 (94 %) stations out of the total 32 monitoring stations. All months exhibited significant negative trends in the case of groundwater level at $\alpha = 0.1$. This implies that water table declined significantly during the period of analysis in the study plain. This declination of groundwater level may affect the most of the water dependent activities especially agricultural water management in the Ardabil plain.

Table 3 presents the trend line slopes of groundwater level in the study area. One can observe from the table that the median of slopes vary from −0.14 to −0.19 m/year.

This implies that water table has declined in the Ardabil Plain in the range of 1.4 and 1.9 m per decade. The most negative slope occurred at the site 18, located in the east of the Ardabil plain, at the rate of about −1.93 m/year. The most positive slope (0.23 m/year) occurred at the site number 19, which is located in the west of Ardabil plain.

Figure 3 showed the box-whisker diagram of groundwater levels that indicate the variations in the trend line slopes of groundwater levels in Ardabil plain. The line in the inside of the rectangles indicates the median of slopes. The lines in the bottom and upper of the rectangles represent the 25th and 75th percentiles, respectively. The lowest part of the vertical lines in the lower part of rectangles indicate the minimum value of trend slope, and the corresponding upper part of the vertical lines in the top of rectangles represent the maximum slope.

3.3 Homogeneity test (groundwater level)

Table 4 represents the results of homogeneity trend test for groundwater levels in Ardabil plain. All of the sites and site-month interaction components exhibited significant trend heterogeneity in Ardabil plain since $\chi^2_{site,31} < \left(\chi^2_{site,31}\right)_{calulated}$, $\chi^2_{site-month,(t-1)(s-1)} < \left(\chi^2_{site-month,(t-1)(s-1)}\right)_{calculated}$ respectively. The overall trend heterogeneity was found to be significant since $\left(X^2_{trend,1}\right) = stZ^2_{..} > X^2_{trend,1} = 3.84$. The average value of MK1 statistics Z_{gk} over months (g = 1, 2,…, 12) and sites (k = 1, 2,…, 32) was found to be negative ($Z_{..} = -2.98$) indicating the decline in groundwater levels over the Ardabil plain in Iran.

The sites only exhibited trend heterogeneity in groundwater levels as the $\chi^2_{site,31} < \left(\chi^2_{site,31}\right)_{calulated}$. But, the months witnessed homogeneous trends. Hence, the test of significance of trend homogeneity for each site was conducted using the average MK1 statistics for each site ($Z_{.k}$). Here, $sZ^2_{.k}$ is obtained to test the overall spatial trend homogeneity, which under the null hypothesis follows a χ^2 distribution with 1 degree of freedom.

3.4 Analysis of hydro-geochemical Trends

Fifteen chemical parameters of the collected groundwater samples in two months time period from the Ardabil region over a period of 13 years were analyzed. The concentrations of cations and anions, i.e., Ca^{+2}, Mg^{+2}, Na^{+}, K, Cl^{-}, SO_4^{-2}, bicarbonate (HCO_3^{-}) electrical conductivity (EC), TH, total dissolved solids (TDS), Na% and pH generally have witnessed rising trends in the Ardabil region in 2 months during last 13 years.

Table 5 shows the results of MK test in the wet month. For the SO_4^{-2} value, almost 28 percent of stations witnessed statistically significant rising trends with Sen's slopes varying from −0.5 to 0.66 (meq/l)/year. For the case of Cl^{-} value, about 35 percent of stations had witnessed significant rising trends with Sen's slopes varying from −0.07 to 0.68 (meq/l)/year. Similarly, HCO_3^{-} (21.9 % of total 32 stations), anions (40.6 %), pH (6.2 %), TDS (65.6 %), TH (25 %), SAR (18.75 %), EC (46.9 %), Na % (12.5 %), K (9.4 %), Na (31.25 %), Mg (18.75 %), Ca (37.5 %) and cations (50 %) have witnessed significant rising trends at $\alpha = 0.1$ significance level.

We also conducted similar tests for all the geochemical elements for the dry month. It was found that most of them exhibited significant rising trends at $\alpha = 0.1$.

The results of the significant trends in these two months are almost similar. For the detected rising trends, the most significant parameters are cations, EC, Ca and TDS. However, the pH and Na% are two parameters that witnessed the least significant trend throughout the study period over the Ardabil plain. The most declining trends in water quality parameters are found in stations 8, 3, 13, 24, 25 and 30, mostly located in the north, the east and the south of Ardabil plain in the dry month. For wet month, declining trends in water quality parameters are found in stations 18, 20, 21, 23, 24, 28 and 30, mostly located in the north, west and south of the plain. An increase in concentration can be clearly observed over time in all points. Dry month had the least negative trend in comparison to the wet month. This upward trend may be due to the developing urbanization in Ardabil city, intrusion of agricultural, industrial and urban sewage water into the Ardabil plain groundwater.

Table 6 shows the Sen's slope values of hydro-geochemical parameters in wet months. For example, the estimated Sen's slopes for SO_4^{-2} vary within a range of −0.50 and 1.12 (meq/l/year). The Cl^{-} varied in the range of −0.07 to 0.68 (meq/l/year). The HCO_3^{-} varied in the range of −0.29 and 0.54 (meq/l/year). The anions varied between −0.15 and 1.38 (meq/l/year). We also conducted similar analysis for dry month. Result indicated that the Sen's slopes obtained for Cl^{-}, anions, pH, TDS, EC and cations is varied widely throughout the studied period in dry month.

To better understand the variation of Sen's slope in the groundwater quality parameters box-whisker plots were drawn for the fifteen groundwater quality parameters, and four of these fifteen parameters (EC, SAR, TH and TDS) are shown in Fig. 4. In both wet and dry months, the Sen's slope of groundwater quality parameters were found to be positive, i.e. the quality of the groundwater declined during the time period over the Ardabil region. SO_4^{-2}, HCO_3^{-}, anions, pH, TDS, SAR, EC, Na%, K, Na, Ca and cations had great length of vertical line for dry month than wet month. Furthermore, SO_4^{-2}, HCO_3^{-}, SAR, Na%, K^{+}, Na^{+} and Ca^{2+} had small length of vertical line below median for both dry and wet months. All of the hydro-geochemical parameters had positive median of slopes in both months.

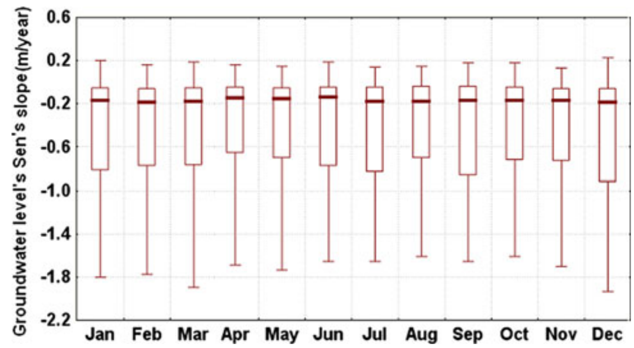

Fig. 3 *Box-whisker* plots of trend magnitudes of groundwater level in Ardabil plain

Table 4 Significance test of trend homogeneity for groundwater level parameter

Source	d.f.	X^2 − value	Sig.
X^2-total	384	5133.80	Sig.
X^2-homog	383	1730.74	Sig.
X^2-month	11	10.08	Ns
X^2-site	31	1545.07	Sig.
X^2site-month	341	13787.81	Sig.
X^2-trend	1	3403.06	–

NS not significant, *Sig* significant, *d.f.* degrees of freedom

Significance tested at $\alpha = 0.05$

4 Discussions

In this paper an attempt has been made to estimate the trends in the groundwater levels and the hydro-geochemical concentrations in Ardabil plain aquifer. Significant ($P < 0.10$) declining trends are witnessed in the groundwater levels during the period from 1988 to 2009 in the Ardabil region. Similar results, i.e., decline in the groundwater level, were reported in Poland (Gehrels et al. 1994), in the watersheds of Pearl river in China (Zhang et al. 2009), in the northwest of Bangladesh (Shahid and Hazarika 2009), Neishabour plain in northeast Iran (Beizai

Table 5 Trend analysis of 15 groundwater quality parameters for wet month in Ardabil plain (1996–2009)

Number	Stations	SO_4^{2-}	Cl^-	HCO_3^-	Anion	PH	TDS	TH	SAR	EC	Na%	K^+	Na^+	Mg^{2+}	Ca^{2+}	Cation
1	Anzabepain	**2.13**	0.24	**2.13**	**3.22**	−0.73	**3.77**	**2.54**	1.04	**3.22**	−0.43	**2.57**	**2.67**	1.41	**2.95**	**3.63**
2	Abibeyglo	−0.18	**2.40**	0.98	**2.54**	1.34	**2.95**	**2.26**	−0.92	**2.81**	−1.40	0.00	0.06	**2.26**	1.22	**3.09**
3	Aralloyebozorgh	1.43	**2.15**	0.62	**2.10**	0.00	**1.97**	**2.65**	−0.47	**2.02**	−0.78	−0.18	0.86	**2.10**	**2.72**	**2.18**
4	Agabgh	**1.71**	**1.71**	**−2.06**	1.44	−0.62	**2.02**	**1.99**	0.00	1.44	-1.58	0.00	0.89	1.51	**1.85**	1.44
5	Piraghom	**3.04**	**2.57**	1.48	**2.68**	0.78	1.56	1.41	1.09	**2.86**	0.62	−1.18	**1.97**	0.47	1.63	**3.22**
6	Tazekandrezaabad	**2.65**	**2.02**	**2.80**	**3.43**	0.27	**3.74**	**3.11**	**1.99**	**3.43**	0.89	−0.14	**3.58**	1.30	**1.87**	**3.58**
7	Topraghlo	1.12	0.87	1.25	1.53	0.00	1.36	**1.73**	−0.12	1.36	−0.62	−0.12	0.12	0.99	**2.24**	1.36
8	Tappekandi	−0.60	**1.67**	0.00	0.30	0.60	0.30	1.20	−0.90	0.30	−0.90	**1.69**	0.00	0.15	1.50	0.30
9	Jaberlo	−0.52	1.44	1.26	1.58	**1.97**	**3.23**	1.26	−0.18	**1.97**	−0.18	−0.45	0.27	0.81	0.72	**1.88**
10	Jobbedar	**2.35**	**2.10**	−1.36	**1.88**	0.31	**2.19**	0.37	1.36	**1.88**	0.31	−0.85	**1.98**	0.94	−0.10	1.25
11	Jegarkandi	0.63	0.31	0.52	0.52	0.94	0.31	1.11	0.00	0.31	−0.52	−1.22	0.11	−0.11	1.15	0.52
12	Khalifelo sheykh	0.00	**1.97**	0.98	**2.00**	0.89	**2.19**	1.15	−0.54	**2.15**	−0.52	−0.93	0.18	0.45	1.56	**2.41**
13	Khalilabad	0.16	1.32	0.31	1.25	1.64	**1.97**	0.16	0.31	1.40	0.31	−0.76	0.08	0.14	1.07	1.40
14	Sarband	1.56	**1.67**	−0.10	**2.10**	0.00	**2.61**	1.56	1.36	**2.85**	−0.10	0.52	**2.10**	**1.67**	**1.99**	**2.85**
15	Soltanabad	**2.02**	0.48	−1.10	**2.13**	−0.34	**2.34**	0.48	1.44	**2.13**	0.16	0.82	**2.33**	−0.62	**1.65**	**2.26**
16	Sharifabad	1.36	0.10	**1.88**	1.61	0.00	1.36	1.04	**1.77**	**1.98**	0.63	0.84	1.61	1.46	0.11	**1.86**
17	Sheykhkalkhoran	0.21	0.87	−0.31	1.36	−0.18	**1.56**	−1.15	1.61	1.61	**2.61**	−0.84	**2.81**	0.21	−1.77	**1.77**
18	Somee	−0.09	1.16	−0.09	1.15	**1.79**	**1.98**	1.16	−1.61	1.15	−1.61	0.27	−0.89	1.43	1.61	0.72
19	Gharalar	0.38	0.96	0.57	0.75	0.00	**2.20**	**2.20**	**−1.88**	**1.71**	−1.22	0.00	−0.57	**2.20**	**2.20**	**2.20**
20	Korgan	**1.86**	**2.10**	**−1.75**	**1.73**	0.99	**1.86**	**1.98**	**−2.10**	1.36	**−2.10**	1.52	−0.87	0.62	0.99	1.11
21	Kamiabad	**1.71**	1.32	**2.15**	**2.34**	−0.08	1.56	−0.62	**1.97**	**2.18**	**2.65**	0.54	**1.79**	−0.62	−0.62	**2.18**
22	Kozetopraghi	−0.30	0.37	1.37	0.90	−0.12	**1.80**	0.25	**1.86**	1.11	1.36	0.00	1.61	0.00	0.00	1.11
23	Ghorjan	1.53	1.17	−0.61	1.22	0.55	**2.40**	−1.28	**2.40**	1.40	**3.11**	−0.83	**1.99**	**−1.77**	−0.67	0.92
24	Golighadim	−0.09	1.08	1.70	1.61	0.54	1.56	1.15	−0.72	1.61	−1.07	−0.12	−0.18	1.17	**2.24**	**1.79**
25	Mahmodabad	0.76	1.13	**1.97**	0.75	0.60	1.13	1.13	0.60	1.13	0.60	0.20	1.06	−0.78	**1.88**	1.13
26	Mollayosef	0.00	1.22	0.00	0.00	0.73	**1.71**	1.02	−0.73	0.24	−1.22	0.24	−0.73	1.22	1.22	0.24
27	Mirzarahimlo	0.90	0.15	0.00	0.60	−0.60	0.90	0.00	0.90	0.60	0.60	1.20	0.30	−0.91	0.46	0.60
28	Noshahr	1.36	0.21	0.00	**1.98**	−0.10	1.11	0.42	−0.31	**2.40**	−0.31	0.31	0.52	−0.31	1.15	**2.61**
29	Niar	0.52	0.10	0.90	0.10	0.36	0.94	1.56	0.18	0.10	0.00	0.90	0.72	**1.71**	**2.40**	0.10
30	Yezenabad	0.27	−0.27	1.10	0.07	0.00	**2.02**	**−2.80**	**2.54**	−0.55	**2.26**	**1.86**	**2.26**	**−2.40**	−1.24	0.75
31	Yengejeh molla mohammad reza	0.21	1.61	**2.40**	1.11	0.94	**2.19**	1.56	0.52	1.11	−0.10	−0.31	0.73	0.73	1.61	1.15
32	Yonjalo	**2.49**	**2.02**	**2.68**	**3.11**	0.54	**2.68**	1.63	0.89	**2.33**	0.62	0.78	1.07	**1.95**	**1.79**	**2.33**

The bold numbers indicate significant at $\alpha = 0.1$

Table 6 Sen's slope values for groundwater quality for wet month in the Ardabil plain

Number	SO_4^{2-}	Cl^-	HCO_3^-	Anion	PH	TDS	TH	SAR	EC	Na%	K^+	Na^+	Mg^{2+}	Ca^{2+}	Cation
1	0.48	0.08	0.22	0.82	−0.02	87.13	13.87	0.08	81.21	−0.22	0.02	0.50	0.07	0.25	0.90
2	0.00	0.07	0.00	0.09	0.00	13.50	0.00	0.00	10.90	0.00	0.00	0.00	0.00	0.00	0.10
3	0.25	0.15	−0.09	0.25	−0.01	72.17	14.00	−0.13	25.00	−1.39	0.00	−0.03	0.08	0.44	0.31
4	0.19	0.18	−0.16	0.39	−0.01	57.18	12.08	0.00	36.81	−1.06	0.00	0.16	0.05	0.21	0.39
5	0.10	0.10	0.06	0.28	0.04	29.25	5.00	0.08	27.43	0.22	0.00	0.16	0.01	0.07	0.26
6	0.66	0.36	0.16	1.38	0.01	120.13	24.17	0.38	137.71	0.99	0.00	1.15	0.20	0.15	1.50
7	0.10	0.08	0.10	0.22	0.00	34.30	10.36	−0.08	28.75	−1.09	0.00	0.05	0.06	0.13	0.25
8	−0.50	0.68	0.00	0.20	0.04	31.00	13.00	−0.11	19.20	−1.61	0.01	−0.01	0.03	0.22	0.22
9	−0.02	0.04	0.03	0.07	0.06	16.00	1.67	−0.01	8.00	−0.26	0.00	0.01	0.02	0.03	0.10
10	0.40	0.20	−0.29	0.33	0.03	46.60	1.67	0.17	32.25	1.89	0.00	0.32	0.10	−0.01	0.26
11	0.03	0.07	0.15	0.17	0.03	27.33	12.32	−0.04	16.15	−0.96	−0.01	0.01	0.00	0.25	0.16
12	−0.01	0.06	0.03	0.09	0.04	16.80	5.00	−0.03	9.00	−1.09	0.00	0.00	0.02	0.10	0.11
13	0.02	0.03	0.01	0.05	0.04	14.25	0.00	0.04	6.10	0.62	−0.01	0.02	0.00	0.00	0.05
14	0.46	0.25	0.00	0.85	0.02	104.23	16.94	0.14	90.42	−0.03	0.01	0.57	0.18	0.13	0.96
15	0.52	0.04	−0.08	0.52	−0.02	68.41	1.83	0.20	51.50	0.64	0.01	0.45	−0.05	0.12	0.56
16	0.42	0.01	0.09	0.49	0.00	57.38	10.63	0.19	50.63	1.33	0.01	0.35	0.15	0.01	0.53
17	0.05	0.25	−0.05	0.22	−0.02	45.60	−6.19	0.31	23.33	2.57	0.00	0.39	0.02	−0.14	0.24
18	−0.01	0.10	0.00	0.20	0.05	43.00	11.25	−0.12	16.40	−1.81	0.00	−0.11	0.05	0.20	0.14
19	0.09	0.25	0.10	0.50	−0.01	75.75	35.00	−0.80	61.00	−5.89	−0.05	−0.11	0.27	0.40	0.75
20	0.22	0.09	−0.20	0.23	0.04	23.19	8.79	−0.25	18.67	−5.04	0.02	−0.08	0.05	0.11	0.15
21	1.12	0.22	0.04	1.30	0.00	161.00	−30.00	0.97	126.67	2.81	0.03	2.28	−0.27	−0.16	1.29
22	−0.10	0.09	0.54	0.56	−0.01	133.08	2.08	0.30	55.00	0.93	0.00	0.69	−0.02	−0.01	0.64
23	0.15	0.03	−0.07	0.08	0.05	19.19	−5.00	0.16	10.81	1.49	0.00	0.21	−0.06	−0.03	0.10
24	−0.02	0.08	0.16	0.21	0.02	27.40	7.50	−0.14	19.50	−1.71	0.00	−0.07	0.05	0.13	0.19
25	0.03	0.18	0.17	0.40	0.06	38.33	5.00	0.13	40.75	0.69	0.00	0.23	−0.03	0.17	0.42
26	0.38	0.30	0.00	−0.15	0.07	141.75	76.88	−0.85	36.92	−6.66	0.01	−1.16	0.68	1.00	0.48
27	0.30	0.00	0.08	0.41	−0.04	48.67	0.00	0.54	41.00	2.39	0.03	0.61	−0.05	0.06	0.33
28	0.10	0.04	−0.01	0.22	0.00	38.07	3.75	−0.10	22.11	−1.13	0.00	0.09	−0.02	0.07	0.22
29	0.36	0.24	0.26	0.91	0.01	87.00	25.00	0.16	91.86	−0.05	0.01	0.40	0.20	0.33	0.92
30	0.08	−0.07	0.11	0.07	0.00	59.00	−17.00	0.43	−13.33	1.61	0.02	0.47	−0.20	−0.07	0.17
31	0.13	0.53	0.25	0.87	0.07	166.75	20.94	0.14	87.75	−0.10	−0.01	0.58	0.07	0.35	0.82
32	0.25	0.10	0.23	0.57	0.01	47.00	15.00	0.13	59.00	0.56	0.01	0.34	0.07	0.21	0.60

and Mohammadi 2003), the Lanjan state located in Esfahan province of Iran (Yazdani and Khodagholi 2009) and urban and peri-urban areas of GBM delta of Bangladesh (Shamsudduha et al. 2009). Such decline in groundwater levels may be attributed mainly to the over exploitation of water in most of regions of the Ardabil plain caused due to the increase in population in the Ardabil region and increase in standards of living inclusive of higher sanitation levels in recent times in the Ardabil plain.

The trends in hydro-geochemical parameters were also investigated for the period 1996–2009 in the region. Results showed that most of the hydro-geochemical parameters witnessed statistically significant upward trends at 10 % significance level through the MK1. This result implies that the quality of the groundwater decreased in the Ardabil plain during the study period. However, a few parameters of groundwater quality witnessed statistically significant downward trends, which were in total agreement with the findings reported for various places. For example, increases in chloride ion in groundwater of Glafkos basin (Lambrakis et al. 1997); SO_4^{-2} in surrounding Lake Texoma's groundwater (Kampbell et al. 2003); in EC and TDS in groundwater of the Kabul basin, Afghanistan (Houben et al. 2009); in pH in Sweden (Wahlin and Grimvall 2009); Mg^{+2}, Ca^{+2}, Cl^- and SO_4^{-2} in Izmir of Turkey (Elci and Polat 2010); EC in groundwater in the Sarab plain of Iran (Karami and Bayatie Khatibi 2009); and in 12 different parameters in the Bam plain (Malakutian and Karami 2004); salinity in the coastal area of Yun-Lin, Taiwan (Liu et al. 2003); pH in the Ebro Basin (Bouza-

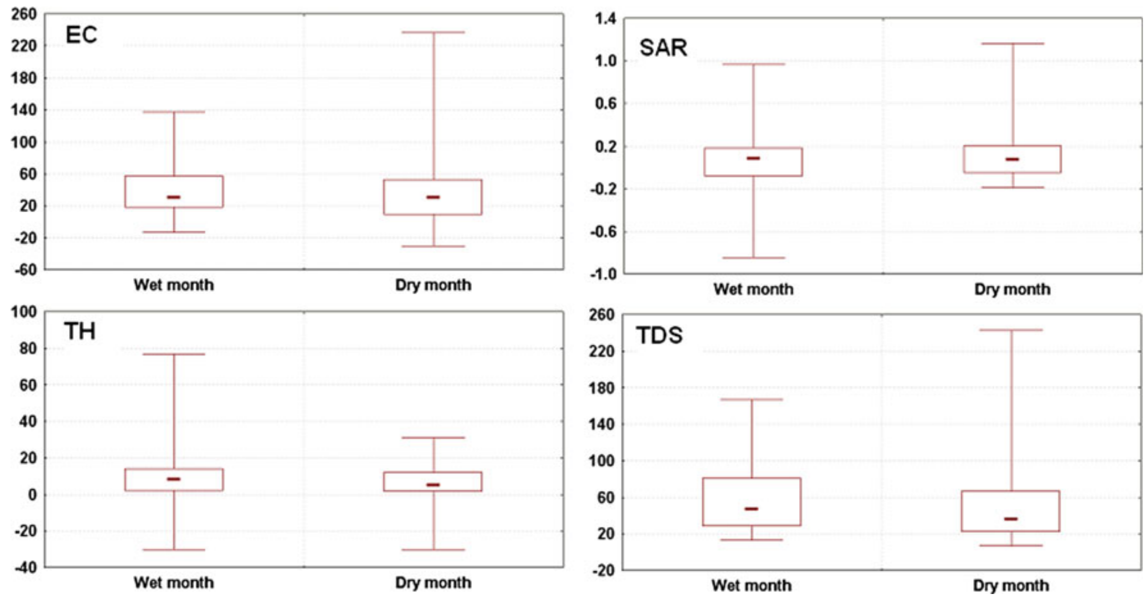

Fig. 4 *Box-whisker* plots of trend magnitudes of the four water quality parameters in Ardabil groundwater (ES, SAR, TH and TDS)

Dean et al. 2008); and salinity in the Keta basin (Yidana et al. 2010).

The results of this research may ring the alarms of starting the water crisis in the Ardabil region. On the other hand, our findings would be useful in the future groundwater resources planning, and hydrological response could be considered in the subsequent control, because of groundwater resources shortage if the quality of groundwater and its level decline excessively, the groundwater resources demand will be in danger in the Ardabil region. Data of other very important hydro-geochemical parameters such as nitrate and heavy metals (like arsenic) were not available for the Ardabil region. Detecting trends of these parameters which directly relate with the health of people in the Ardabil plain is strongly recommended for future studies.

Acknowledgments Authors are grateful to the Water Organization of the Ardabil province, Iran for providing the data. Also special thanks to the anonymous reviewers, the editor and the associate editor for their useful comments.

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