Indian Journal of Fundamental and Applied Life Sciences ISSN: 2231– 6345 (Online)
An Open Access, Online International Journal Available at www.cibtech.org/sp.ed/jls/2015/03/jls.htm
2015 Vol. 5 (S3), pp. 1228-1236/Jeihouni et al.
Research Article

ASSESSING THE SPATIO-TEMPORAL VARIATIONS OF TABRIZ PLANE AQUIFER SALINIZATION AND ITS RELATION WITH URMIA LAKE WATER LEVEL

***Mehrdad Jeihouni, Seyed Kazem Alavipanah, Ara Toomanian and Saeid Hamzeh**
Department of Remote Sensing and GIS, Faculty of Geography, University of Tehran,
Azin Alley. 50, Vesal Str., Tehran, Iran
**Author for Correspondence*

ABSTRACT
Groundwater salinity significantly causes soil salinity in irrigated lands. Considerable decrease in the quality and salinization of the groundwater not only gradually reduce the under cultivated area but also cause a sharp drop in production in these regions and eventually the destruction of these resources. Tabriz plain is one of the most important plains of Urmia Lake basin. In this study the spatio-temporal variation of Tabriz plain aquifer were assessed based on 120 wells in this plain over a period of 7 years. The geostatistical analyst was employed for the analysis of observational data, semivariogram model selection, validation, mapping the groundwater salinity, and finally the aquifer spatio-temporal salinity changes were assessed. The results of the study showed that the groundwater salinity increased from 2004 to 2010. It was also found that areas with higher salinity than 5dS.m^{-1} were in 2.65% of the total study area in 2004 and increased to 12.82% in 2010. In addition, by comparing changes between the level of the lake and the average salinity of wells in this period the coefficient of determination was 0.709 and coefficient of determination of the average water level of the lake and aquifer level average was 0.835. As a result it can be concluded that the by drop in lake level and a sharp drop in the aquifer level due to excessive withdrawal of freshwater from underground aquifer the saline aquifer pressure causes imbalance between the under lake saline aquifer and the plain aquifer. Consequently the influx of saltwater into aquifers happened and exacerbates the aquifer salinity. These processes face the region to many ecological problems, such as increase the risk of soil and water salinization, reduce the area of crop lands, and reduce the crop productivity and desertification in near future.

Keywords: *Aquifer, Geostatistics, Urmia Lake, Semi-variogram, Tabriz Plane*

INTRODUCTION
Groundwater is the main source of water for urban, rural and irrigation demands in arid and semi-arid regions (Uyan and Cay, 2013). The low quality irrigation water can change soil physicochemical properties, causing soil salinization and reducing crop productivity (Ramsis *et al.*, 1999; Tutmez *et al.*, 2006). Although at first glance it seems that the environmental factors influence groundwater less than surface water, but studies have shown that along with surface water resources, groundwater quantity and quality are influenced by environmental factors (DuNing *et al.*, 2007) and even in some cases the impact is more severe and lasting (Chandrasekharan *et al.*, 2008). Another important issue that should be considered in parallel with these issues is that the quality of groundwater is change in the large spatial scale. Consequently, it cannot assume to be changeless in the range of locations (Sun *et al.*, 2009).
Geostatistics provide efficient method for the study of spatially distributed data, such as contamination of soil and groundwater (Cemek *et al.*, 2007; Arslan, 2012; Gokalp *et al.*, 2010; Nas and Berktay, 2010). In geosatictics, the kriging is a random linear method which is developed based on probability theory and statistical tests. This method have been used by many researchers to estimate the hydrological and hydro-geological factors values at unsampled locations (Wang *et al.*, 2001; Desbarats *et al.*, 2002, Jang and Liu, 2004; Sepaskhah *et al.*, 2004; Nas and Berktay, 2010; Arslan, 2012). This method is the best unbias estimator (Lee, 2000). Geostatistical analysis can play a central role in the sustainable management of groundwater by identify the spatial patterns and interpolating values at unsanpled locations. This method can provide estimated values at any location from observations at random locations (Kumar, 2007).

Kriging is one of the geostatistical interpolation techniques that have different types including: simple kriging, ordinary kriging, co-kriging, and universal kriging. The difference between kriging and other interpolation methods like inverse distance weighted (IDW) is that kriging uses the variance of the estimated values (Buttner *et al.*, 1998). Kriging has been broadly used in geology, hydrology, environmental studies, atmospheric sciences and pedology for interpolation of spatial data (McBratney *et al.*, 1982; Stein, 1999; Poon *et al.*, 2000; Gringarten and Deutsch, 2001; Oliver and Webester, 2014). Ordinary kriging has been employed to estimate the groundwater total dissolved solids in india (Ahmed, 2002). Theodossiou and Latinopoulos (2007) used kriging to estimate the level of groundwater in Greece. Yemit *et al.*, (2011) used ordinary kriging for mapping the groundwater salinity in China. Jeihouni *et al.*, (2015) employed ordinary kriging to interpolate the groundwater quality factors such as chloride, electrical conductivity, sulfate, hardness and pH.

Intrusions of saltwater into fresh water aquifers can pollute drinking water sources and cause other consequences. Due to hydraulic connection between groundwater and under sea saltwater, saltwater intrusion occurs in many coastal aquifers. Because saltwater has a higher mineral content than fresh water, it has a higher density and higher water pressure. As a result, salty water can push coastal freshwater aquifer and push it back (Johnson, 2007).

The saltwater and freshwater zones within coastal aquifers are separated by dispersion zone where there is mixing between saltwater and freshwater (Barlow, 2003).

The excessive extraction of groundwater by pumping in coastal freshwater can exacerbate the intrusion of saltwater in coastal areas, because freshwater pressure decrease and saltwater penetrate easily in fresh water aquifer. The temporal pattern of groundwater discharge to estuary was closely related to the tidal cycle within the estuary because in tide cycle sea level changes (Barlow, 2003). Permanent changes in water level are the same thing but more lasting effect. For example, a reduction in sea level is expected to lower the salinity of groundwater in the coastal regions.

In Iran, the large areas affected by groundwater problems, especially groundwater salinity, and the use of this low quality water for irrigation. Urmia Lake as Iran largest inland lake and the world second hyper-saline lake has an important role in the ecosystem of the north-west Iran. In recent years the water level of this lake shows a descending trend.

Thereby reducing the water level of the lake could negatively impact groundwater quality status through the imbalance of groundwater aquifers resources around this lake. Tabriz plain is one of the most important plains of the country and also one of the great sub-basins of Urmia Lake. Reduction of aquifers water quality and excessive use of underground water in inefficient irrigation methods causes the decrease in groundwater level, reducing crop productivity and reduce soil fertility.

The purpose of this study is to assess the spatio- temporal changes of Tabriz plain aquifer salinity by employing ordinary kriging technique as a geostatistical approach and its relation to the annual drop in the water level of Urmia Lake over a period of 7 years.

MATERIALS AND METHODS

Study Area

Tabriz plain is located in north-west of Iran, with an approximate area of 1900 km^2 and its part of East Azarbaijan province. This plain lies between Latitude 37° 53´ to 38° 12´ N and Longitude 45° 55´ to 46° 45´ E, This plain limited by Urmia Lake from west (Figure 1). The climate of the area is semi arid and average annual precipitation is 228 mm. Geological formation of Tabriz plain is alluvial. The water supply for agriculture, industry and drinking demands in this plain is highly depends on groundwater quality and piezometric data of 120 observation wells in this aquifer (Figure 1), which have been collected by the Iranian Ministry of Energy (IMOE) from 10th August 2004 to 29th September 2010, were used in the current research.

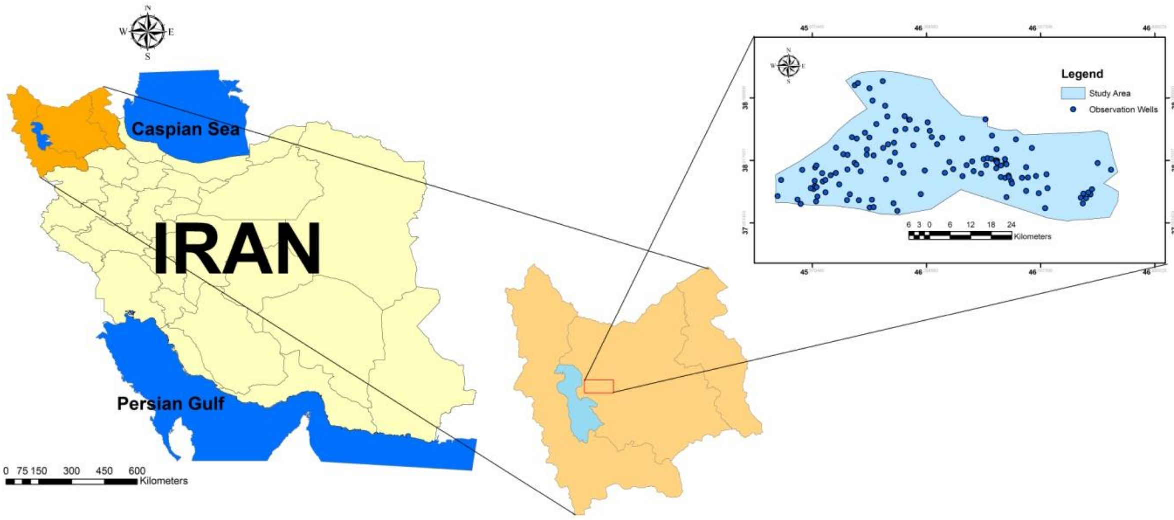

Figure 1: The study area and distribution of sampling locations

Geostatistical Methods

Geostatistics is a branch of statistics focusing on spatial or spatiotemporal datasets. Geostatistical theory is based on a stochastic model which allows the derivation of finest predictions at random locations in the considered area. In this technique spatial correlations between neighbouring observations take into account (Wameling, 2003; Castrignano *et al.,* 2008). Advantage of geostatistics is the use of quantitative measures of spatial correlation, commonly expressed by variograms (Diodato and Ceccarelli, 2005; Uyan and Cay, 2013). The core of geostatistics is the variogram, which expresses the spatial dependence between near observations (Isaaks and Srivastava, 1989). The variogram can be defined as one-half the variance of the difference between the attribute values at all points separated by lag distance (h) as follows (1):

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x_i) - Z(x_i + h)]^2 \quad (1)$$

Where N represents the number of pairs of observations separated by the distance h, where $Z(x_i)$ is the water quality value at point i; $Z(x_i +h)$ is the water quality value of other points separated from xi, by a discrete distance h; x_i are the georeferenced positions where the $Z(x_i)$ values were measured; and γ (h) is the estimated or "experimental" semi-variance value for all pairs at a lag distance h (Isaaks and Srivastava, 1989).

The histograms of each year dataset were first checked to see whether the parameter showed a normal distribution pattern. Then, we used 120 sampling points to develop an interpolation map of the spatial distribution electrical conductivity (EC) as an index of salinity for each year by the geostatistical method of ordinary kriging employing ordinary kriging over the study area. A trend analysis was conducted, and the 11 different semivariogram models were tested for each parameter. Then, performances were assessed by cross-validation. For this porpuse spatial patterns and spatial dependency of variables γ (h) were evaluated through semi-variogram and experimental semi-variogram was calculated by equation (1) for each year.

Kriging method is an exact interpolation technique which the best unbias linear estimator. The general equation of the kriging method is as follows (2) (Uyan and Cay, 2013):

$$Z(x_0) = \sum_{i=1}^{N} \lambda Z(x_i) \quad (2)$$

Where $Z(x_0)$ is the estimated value at allocation x0, $Z(x_i)$ is the known value at location x_i, λ_i is the weight associated with the data.

In kriging method the variables weight (λ_i) were defined by components of semi-variogram function to estimate Z value at unsampled locations based on observed data at known locations through eaquation (2). Then in order to achieve unbias estimation in ordinary kriging the following set of set of equations (3) were solved simultaneously.

$$\begin{cases} \sum_{i=1}^{N} \lambda i \gamma(x_i, x_j) - \mu = \gamma(x_i, x) \\ \sum_{i=1}^{N} \lambda i = 1 \end{cases} \quad (3)$$

where Z (x_0) is the estimated value at location x0, Z(x_i) is the known value at location xi, λ_i is the weight associated with the data, μ is the Lagrange coefficient, and $\gamma(x_i, x_j)$ is the value of variogram corresponding to a vector with origin in xi and extremity in x_j.

RESULTS AND DISCUSSION

In order to generate the EC distribution maps and determine nugget, sill and range, it is necessary to verify the appropriate theoretical variogram model.

In this study, 11 semivariogram models (Circular, Spherical, Tetraspherical, Pentaspherical, Exponential, Gaussian, Rational Quadratic, Hole effect, K-Bessel, J-Bessel, and Stable) were tested for each year dataset. As an example, Figure 2 shows the Tetraspherical semivariogoram model that fitted the 2004 EC dataset. The semivariogram model parameters for each year are summarized in Table 1. As indicated in Table 1, Tetraspherical, Exponential, Rational Quadratic and Stable models have the best fits with the datasets and the year 2007 has the minimum range, which shows its high spatial variability.

Table 1: Semivariogram model parameters for each year's datasets

Years	**Models**	**Nugget(C_0)**	**Sill(C_0+C)**	**Range(m)**	**Nugget /Sill ratio**
2004	Tetraspherical	0.1154	1.420	52181.6	8.15
2005	Exponential	0	1.539	52064.3	0
2006	Rational Quadratic	0.1361	1.277	52777.9	10.66
2007	Stable	0	1.355	38739.9	0
2008	Rational Quadratic	0.3022	1.230	52069	24.55
2009	Stable	0.2622	1.236	41274.8	21.20
2010	Rational Quadratic	0.2390	1.193	51736	20.02

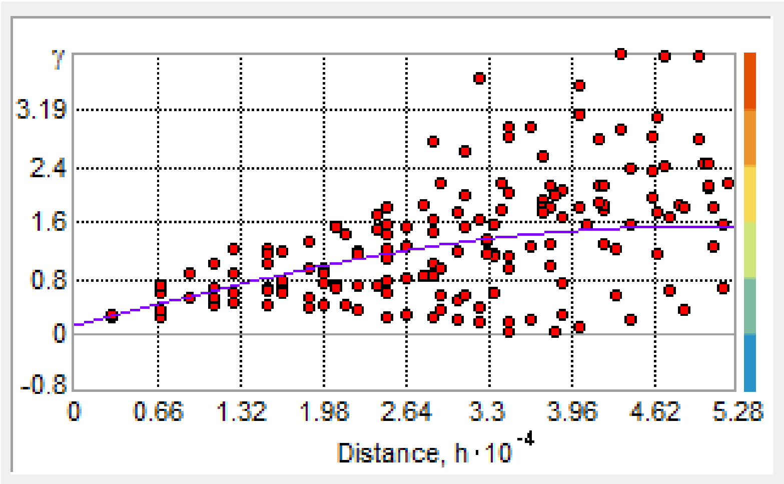

Figure 2: Fitted Tetraspherical Semivariogram model to 2004 EC dataset

The best fitted variograms were used to obtain the most accurate estimations, it should be noted that the differences between variogram models and results may be attributed to differences in climactic conditions, drainage and irrigation regimes (Arslan, 2012).

The nugget to sill ratio can be used to classify the spatial dependence of groundwater EC. If the ratio is less than 25%, the variable has a strong spatial dependence. Between 25 and 75%, the variable has moderate spatial dependence, and greater than 75% the variable shows only weak spatial dependence (Caro *et al.*, 2013). According to nugget-to-sill ratio from Table 1, it can be concluded that the spatial dependence of groundwater EC has strong spatial dependency for all investigated years.

The prediction performances were assessed by cross-validation, which allows the determination of which model provides the best predictions. The results are shown in Table 2. A model has the precise predictions that has the mean standard error (mean prediction error) is close to 0, root-mean-square error and average standard error values should be close, mean standardized should be small as possible and root-mean-square Standardized should be close to 1 (Johnston *et al.*, 2001). The results indicate that the utilized models have the high accuracy.

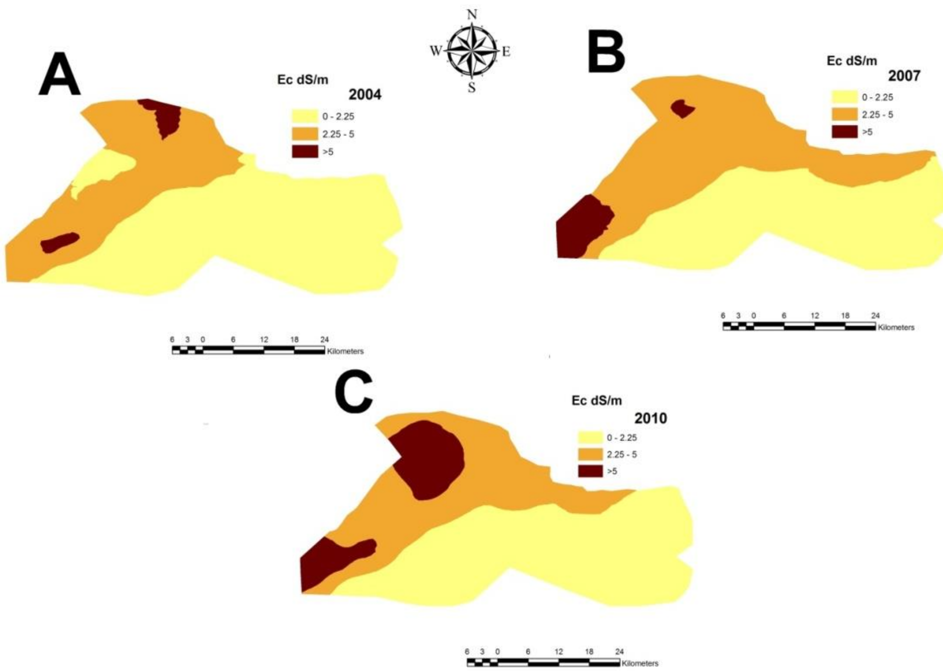

Figure 3: Spatial distribution of groundwater salinity (EC) during seven years in the study area A) 2004, B) 2007, C) 2010

Table 2: Cross-validation results between measured and estimated values for groundwater salinity (EC)

Years	Mean	Root-Mean-Square	Average Standard Error	Mean Standardized	Root-Mean-Square Standardized
2004	0.007	1.431	1.439	0.0479	0.868
2005	0.049	1.392	1.395	0.0214	1.069
2006	0.0263	1.284	1.270	0.0063	0.930
2007	0.0368	2.035	2.373	0.0161	0.912
2008	0.0608	1.904	2.358	0.0309	1.078
2009	0.0520	2.051	2.397	0.0320	1.076
2010	0.0105	1.916	2.011	0.0124	0.997

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In this study, spatial variability of salinity, as represented by EC, was classified into 3 thematic classes; 0 - 2.25 dS.m^{-1}, 2.25–5.0 dS.m^{-1} and >5.0–7.5 dS.m^{-1}. The distribution maps of these groundwater salinity maps were generate. Figure 3 shows the EC distribution maps for years of 2004, 2007 and 2010. Then the area of each respective class separated base on studied year which shown in Table 3.

Table 3: Differences in groundwater salinity values within the study area, 2004–2010 (Km^2, %)

Years	**0 - 2.25 dSm^{-1}**		**2.25 - 5 dSm^{-1}**		**> 5 dSm^{-1}**	
	Area (Km^2)	**%**	**Area (Km^2)**	**%**	**Area (Km^2)**	**%**
2004	1224.17	64.45	624.75	32.89	50.35	2.65
2005	1141.84	60.12	696.27	36.66	61.15	3.22
2006	1040.42	54.78	782.69	41.21	76.16	4.01
2007	953.42	50.19	843.93	44.43	101.92	5.36
2008	990.84	52.17	766.35	40.35	142.06	7.48
2009	1002.05	52.76	695.32	36.61	201.89	10.63
2010	1022.38	53.83	633.35	33.34	243.54	12.82

As indicated in Table 3 the groundwater salinity increased in the study area between 2004 and 2010. In this period the area of the regions where the underground water has low salinity had been reduced from 64.45% to 53.83% of study area conversely the area of the regions where the groundwater is saline had been increased from 2.65% to 12.82% of study area. Accordingly, in order to evaluate the effects of Urmia Lake water level on environs plains groundwater quality the correlation between the average salinity of the groundwater in the study area and also average water level of the lake were assessed. The results are shown in Figure 4. Figure 4 clearly shows that the lower the water level in the Urmia Lake, Tabriz plain groundwater salinity has been increased.

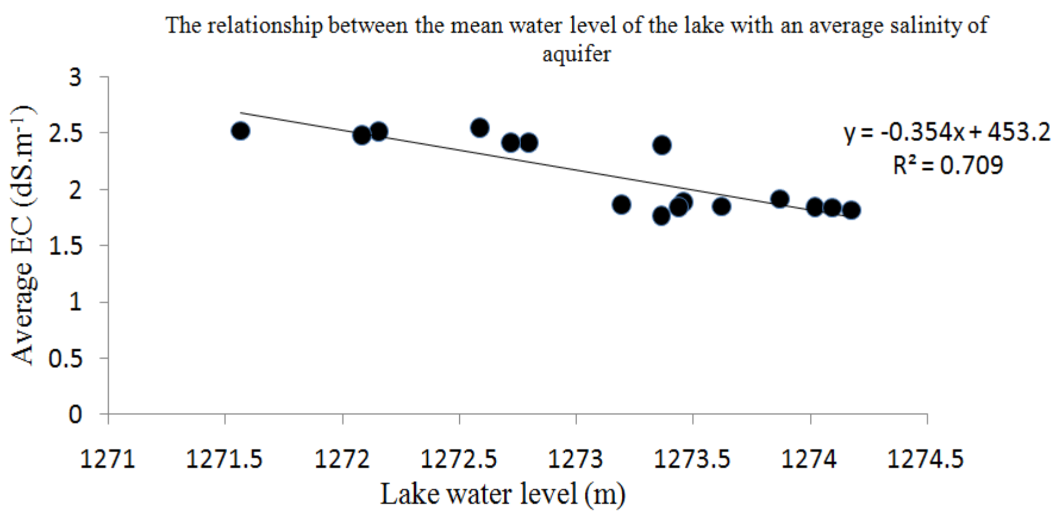

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Figure 4: Correlations between mean water level of the lake with an average salinity aquifers (with 7 months time lag)

Also the correlation between the mean water level of the lake and aquifer water table was analyzed and the results are shown in Figure 5.

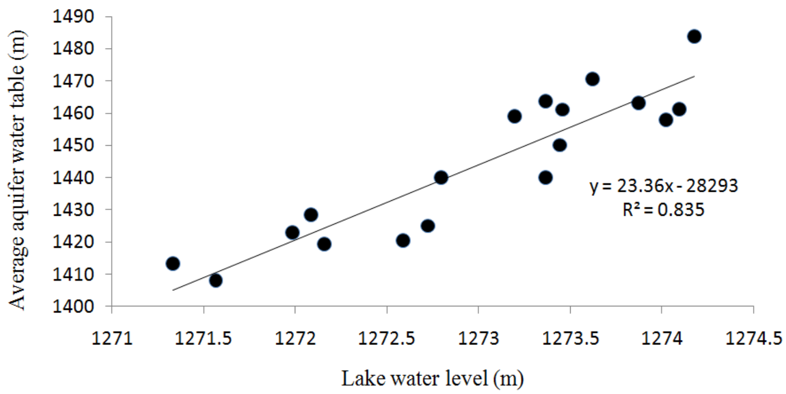

Figure 5: Correlations between the aquifer water table and water level of the lake (with 3 months time lag)

It expected to see a direct relationship between electrical conductivity of aquifer and lake level. Therefore due to water level reduction of Urmia Lake during the past few years that is expected that to face EC reduction in plain aquifer on the other word the quality of aquifer must be increased. But according to Figure 4 and the relationship between water level and EC, the aquifer EC was increase during recent years. The reason for this could be the excessive groundwater pumping from the plain aquifer. As shown in Figure 5 aquifer water table has been decreased in recent years, which is directly related to the drop in the lake level. Regarding to this direct relation, the important point is that the rate of decline in aquifer water table is more than a drop in lake level. Due to salinity increase in aquifer by drop in lake levels it can be conclude that the drop rate in aquifer water table was higher than the drop rate of Lake water level. This is due to the large number of illegal wells in the area and their excessive pumping. Unfortunately it's not possible to estimate the exact amount of groundwater withdrawals from the aquifer due to the lack of precise statistics of withdrawals. Accordingly, this causes relatively higher level of lake water than the aquifer water table. In the other word as result of aquifer water table drop and reduction of fresh water pressure in transition zone, the salty water enters in the plain fresh water aquifer. Accordingly, the intrusion of saltwater into the plain aquifer increases its electrical conductivity. The influx of saltwater from the western part of the study area is clearly showed in Figure 3.

Conclusion

In this study the spatio-temporal trend analysis of Tabriz plain aquifer salinity at eastern coast of Urmia Lake and its relation to the annual drop in the water level of the lake was assessed. The temporal changes in groundwater salinity indicate an increasing trend over a period of 7 years. The area of the regions where the underground water has a higher salinity than 5dS.m^{-1} has increased from 2.65% in 2004 to 12.86% in 2010. This represents that 190 km^2 of study area were affected by groundwater salinization. This trend can be a result of the excessive withdrawals of groundwater. On the other hand plain water table drops with more intensity than the lake water level, consequently, the result is imbalance between lake underground saltwater and the Tabriz plain aquifer's fresh water and exacerbate the aquifer salinization. The relation between lake water level and aquifer salinity can be justified according to the high coefficient of determination (R^2=0.709). The trend of groundwater salinization in the study area causes many serious environmental and ecological problems. Because of the groundwater of this plain is used for irrigation of crop lands, this can face the region to many ecological problems, such as increase the risk of soil and water salinization, reduce the area of crop lands, reduce crop productivity and desertification in near future. In this situation the withdrawals reduction from the wells can recover water level from the crisis as well as entering freshwater from feeding areas can improve water quality and push transition zone to its right place.

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