Long term groundwater balance and water quality monitoring in the eastern plains of Urmia Lake, Iran: A novel GIS based low cost approach

Mehrdad Jeihounia, Ara Toomanianb, Seyed Kazem Alavipanah, Saeid Hamzehb, Petter Pilesjöb

a Dept. of Remote Sensing and GIS, Faculty of Geography, University of Tehran, Azin Alley, 50, Velayat Str., Tehran, Iran
b GIS Center, Department of Physical Geography and Ecosystem Science, Lund University, Lund, Sweden

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A B S T R A C T
Groundwater quality and quantity are two major challenges in arid and semi-arid regions, due to their critical roles in sustainable agricultural development. Irrigated lands are spread all over Urmia Lake’s surrounding plains in Iran. Due to the risk of saltwater intrusion as a result of over-exploitation from groundwater resources, it is important to monitor the groundwater quality and quantity through time and space. In this paper, the groundwater quality was assessed over 11 years applying a novel groundwater balance estimation method based on water table data and 3D modeling; groundwater quality were monitored over 10 years using GIS and geostatistics; and the saltwater intrusion were investigated through generated quality maps and regression analysis. Results indicate that the groundwater balance was negative during the study period. Furthermore, the aquifers quality decreased over the study period, which was severe in west and southwest of the study area. The saltwater intrusion into aquifers increased electrical conductivity, chloride and sodium concentrations and will cause many ecological and agricultural problems. The novel and practicable approach utilized for groundwater balance quantitative assessment is suitable for countries lacking hydrological properties databases.

1. Introduction

Groundwater is the most significant source of water in arid and semi-arid regions (Sener and Davraz, 2013) for urban, rural and irrigation demands (Uyan and Cay, 2013). Water quality assessment is crucial for agricultural water management (Tutmez et al., 2006). Irrigation with low quality water affects the soil’s physicochemical properties and leads to secondary soil salinization which reduces crop yield (Salama et al., 1999; Jeihouni et al., 2015b). This results in decrease the quantity and quality of agricultural productions (Sappa et al., 2015). Accordingly, it is important to assess and monitor the quality and quantity of groundwater in coastal aquifers supplying water for irrigation purpose.

Coastal aquifers are very important sources of freshwater, yet they are vulnerable to saltwater intrusion due to over exploitation (Sappa et al., 2015). The saltwater intrusion has long-term impacts on coastal groundwater quality, and limits their usage (Perera et al., 2009) as irrigation sources. Saltwater intrusion can arise in two major ways: decrease in the groundwater table or increase in the water level (Essink, 2001). By over use of water from coastal aquifers the freshwater level decreases and saltwater intrudes (Qahman et al., 2005). In recent years, an increasing number of studies have been conducted to investigate the intrusion of saltwater (Demirel, 2004; Carretero et al., 2013; Cobaner et al., 2012; El-Kaliouby and Abdalla, 2015; Jeihouni et al., 2015a; Ketabchi et al., 2016; Lu et al., 2015; Najib et al., 2016; Yihdego and Becht, 2013) indicating the importance of this phenomenon. Jeihouni et al. (2015a) assessed the saltwater intrusion in Tabriz plain, Iran as well.

A groundwater status reports are often based on drops or rise of groundwater table. However, these fluctuations may not be tangible. Therefore, the need for new quantitative reporting criterion arises, where one proposed solution is to report groundwater changes by volume (net balance). To estimate the net balance, all inputs and outputs of groundwater should be measured, often these measurements are difficult and costly, especially for low income countries. The lack of comprehensive datasets is tangible for these analyses and defining the groundwater balance. Many components are affecting water balance such as: precipitation, runoff percentage, soil infiltration rate, the volume of surface water (i.e. rivers) penetration, the outflow from springs, and the volume of output from wells. These components must be known

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to gain accurate results. Studies have been carried out to estimate groundwater balance, e.g., based on direct rainfall and streambed infiltration, irrigation return, artificial recharge by flood irrigation and lateral subsurface inflows (Vourdouris, 2006), flow records (Lee et al., 2006), or through satellite gravity measurements (Rodell et al., 2009; Frappart et al., 2011; Chen et al., 2016).

In many low-income developing countries located in arid and semi-arid regions, it's impossible to generate groundwater balance equation and estimate water balance due to the lack of hydrological properties databases. Accordingly, simple, replicable and accurate methods and techniques must be developed to overcome these problems. Expressing a quantitative criterion to indicate the state of groundwater will help to get a general knowledge about groundwater status. This knowledge could accelerate growth towards sustainable agricultural development by groundwater resource management. In this study it is assumed that Geographic Information System (GIS) can be used in this context, due to its abilities in 3D modeling and 3D spatial analysis.

GIS is a broadly used tool for assessing water quality and quantity. GISs have developed rapidly to become efficient computing tools for numerous applications such as sophisticated 3D analyses and modeling. Estimation of the groundwater vulnerability to pollution, groundwater quality assessment, and finding pollution sources are typical applications of GIS in groundwater studies (Engel and Navulur, 1999; Jeihouni et al., 2015c). Geostatistics, as a component of GIS, have been utilized to assess groundwater quality in numerous studies (Arslan, 2012; Jeihouni et al., 2015a, 2015b, 2015c; Nas and Berktay, 2010).

Geostatistical analyses have a critical role in the sustainable groundwater resources management through estimating the groundwater quality factors quantities at unsampled locations and reveal their spatial patterns (Kumar, 2007; Arslan, 2012). Geostatistics is broadly used in assessing spatio-temporal variation of spatially distributed data such as water resources studies (Adhikary et al., 2010; Ashrafzadeh et al., 2016; Agoubi et al., 2013; Arslan, 2012; Baalousha, 2010; Jeihouni et al., 2015b; Kazemi and Hosseini, 2011; Khashei-Siuki and Sarbazi, 2015; Theodossiou and Latiopoulos, 2006; Yimit et al., 2011). As an example, ordinary kriging (OK), as a geostatistical interpolation technique, has been used in groundwater quality studies (Delgado et al., 2010; Nas and Berktay, 2010; Jeihouni et al., 2015c).

Iran is mostly covered by arid and semi-arid climates (Amiraslani and Dragovich, 2011). In Iran, a large percent of irrigated fields are affected by the poor quality groundwater, resulting in secondary salinization and threaten sustainable agriculture. Irrigated lands are spread over Urmia Lake’s surrounding plains, getting their water through groundwater resources. Overexploitation of groundwater increases the risk of saltwater intrusion in this area. Urmia Lake is the largest inland lake of Iran (Hassanzadeh et al., 2012), and the world’s second hypersaline lake (Simu et al., 2013). It has a significant role in the ecosystem of the northwestern Iran (Jeihouni et al., 2017). During last decade the water level of the lake has a descending trend and decreased about 8 m since 1994, mainly due to droughts, overuse of surface waters and dams (Hassanzadeh et al., 2012). Urmia Lake is classified as oceanic, the hydrochemistry type is the sodium-chloride-sulfate (Eugster and Hardie, 1978), and the sodium (Na⁺) and chloride (Cl⁻) concentration in the lake is generally 4 times the concentration of natural seawater (Sorgeloos, 1997). Under normal condition the groundwater charges the lake and the drop in Urmia Lake water level would positively impacts groundwater quality by preventing saltwater intrusion. However due to the unique conditions of Urmia Lake and over exploration of groundwater resources surrounding the lake, it is possible that saltwater intrusion occurring in the region. If the concentrations of Na⁺ and Cl⁻ are increasing in surrounding aquifers it may be concluded that the saltwater is intruding. Tabriz, Azarshahr, Sofian, Shiramin and Shabestar are the five most important agricultural plains east of Urmia Lake. These plains are highly dependent on groundwater for irrigation. Excessive withdrawal of freshwater from underground and using it for inefficient irrigation have cause a decrease in groundwater quantity and quality, leading to reduction in crop yield and soil fertility.

Referring to the importance of agricultural practices in the region, the specific conditions of the lake and the potential threat of saltwater intrusion in to surrounding freshwater aquifers’ it is of high interest to assess the qualitative and quantitative groundwater status.

The main objective of this study is to apply a novel and simple approach to estimate groundwater balance using 3D modeling techniques, suitable for low income countries lacking hydrological properties databases. It will be applied on a time-series dataset spanning over 11 years (2001–2012). The study area consists of five eastern plains of Urmia Lake in northwestern Iran. Second objectives of the study are: (1) to monitor the spatio-temporal distribution of groundwater quality factors such as electrical conductivity (EC), sodium, and chloride using GIS and geostatistics to generate groundwater quality maps over a period of 10 years (2003–2012); (2) to provide a general assessment of saltwater intrusion into Urmia Lake’s eastern plains aquifers over a period of 10 years based on interpretation of groundwater quality distribution maps and regression analysis.

2. Materials and methods

2.1. Study area

The study area is a part of the Urmia Lake drainage basin situated east of Urmia Lake (see Fig. 1). This area is located in northwestern of Iran between latitudes 37° 28′ and 38° 23′ N and longitudes 45° 24′ and 46° 39′ E. It has an approximate area of 6723 km² (672,300 ha) (Fig. 1). The area contains the Shabestar, Sofian, Tabriz, Azarshahr, and Shiramin plains located from north to south. The climate of the area is semi-arid with an average annual precipitation of 310 mm. The Geological map of the study area is showed in Fig. 2. The Urmia basin topographic and geomorphologic characteristics presented with digital elevation model (DEM) in Fig. 3. The highest point of Urmia basin is 3746 m above sea level and due to the mountainous nature of the area the drainage system is dense (Fig. 3). The groundwater resources are charged by infiltration of surface water from rainfall and snowmelt of mountain peaks and glaciers. The water demand for agriculture is almost completely dependent on groundwater resources in the study area, making the quality and quantity of groundwater extremely important factors influencing crop and soil productivity.

2.2. Data and data collection

Time-series of groundwater quality and piezometric data for 285 wells in the study area are used in this study (Fig. 1). Groundwater quality data (EC, sodium and chloride) were measured over a period of 10 years (2003–2012) which have been taken in May and October, and piezometric (water table) data were measured over a period of 12 years (2001–2012) which collected in all months of the year. The dataset was collected by the Iranian Ministry of Energy (IMOE).

Fig. 1. Study area location and distribution of the observed wells.
2.3. Geostatistics

Geostatistics, as a branch of statistics, is focusing on spatially distributed or spatio-temporal datasets (Jeihouni et al., 2015c). The geostatistics fundamentals and theories are described in Isaaks and Srivastava (1989). The fundamental tool in geostatistics is the semi-variogram, which indicates the spatial dependence between surrounding observations (Isaaks and Srivastava, 1989). The semi-variogram $\gamma(h)$ is calculated as follows (1):

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

Where $N$ represents the total number of the variable pairs separated by the distance $h$, $Z(x_i)$ means the value of water quality at point $i$; $Z(x_i + h)$ is the variable value of other points separated from $x_i$, by a discrete distance $h$, $x_i$ are the georeferenced sampling points where the $z(x_i)$ values were measured; and $\gamma(h)$ is the experimental semi-variance value for all pairs at the distance $h$ (Isaaks and Srivastava, 1989). An explanation of geostatistics and its applications in groundwater studies can be found in (Gringarten and Deutsch, 2001; Isaaks and Srivastava, 1989; Gaus et al., 2003; Goovaerts et al., 2005 and Uyan and Cay, 2013).

2.4. 3D modeling

3D modeling is broadly used for modeling and displaying the Earth’s surface or subsurface. It can be based on vector based and raster based data (Li et al., 2005; Longley et al., 2005). A triangulated irregular network (TIN) is a digital vector-based surface model (De Floriani, 1987) that generally utilized to surface modeling in GIS (Li et al., 2005). TINs are generated based on irregularly-distributed nodes and lines with three-dimensional coordinates (x, y, and z) that are positioned in a network of non-overlapping triangles. TIN is appropriate for managing randomly located data points, and can be easily updated by point insertion or deletion (De Floriani, 1987). A Digital elevation model (DEM) is a digital raster-based data model and 3D representation of the terrain’s surface or any surface with elevation changes. DEM is a regular arrays of height values. This data model is grid based, and every grid cell, has a value that indicates the height at that point.

In order to generate the DEM, here the digital water table model (DWTM), the TIN model is used referring to Hu et al. (2011). They claiming that to obtain high quality and precise DEM it should be generate from TIN.

2.5. Estimation of groundwater balance volume

The proposed method estimating the groundwater balance is based on two assumptions:

1) All groundwater balance components such as precipitation, runoff percentage, soil infiltration rate, the volume of surface water (i.e. rivers) penetration, the outflow from springs, and the volume of pumping from wells are manifested in the water table.

2) The aquifer properties affecting the water storage are assumed homogeneous all over the study area.

The method estimates the groundwater balance between measured occasions in this case years. In order to estimate the groundwater balance volume, it is necessary to have the DWTM of each year, as well as the specific yield of the aquifer. As an example we assume that the aquifer’s water level states are available in years 2000 and 2001(Fig. 4a). To calculate the volume changes between the two states of water table, first two raster layers should be created and stacked with identical cell size, therefore changed cells and the amount of changes (water table in meters) between two years cells can be identified. Then
Where CA is cell area in m², and \( \sum \) is the difference between before and after water table in meter. Calculated volume from equation (2) is not the volume of the water, but contains solid materials as well. Therefore, the aquifer’s particle size, porosity, void ratio, and other characteristics must be taken into account. These properties can be expressed as specific yield, which reports how much water is available for use (Heath, 1983). Accordingly, equation (2) is modified as follows:

\[
\text{Volume} = (CA) \times \Delta l \\
\text{(2)}
\]

Where \( CA \) is cell area in m², and \( \Delta l \) is the difference between before and after water table in meter.

The volume change can be positive, negative, or zero. A simple representation of the volume calculation is showed in Fig. 4b.

**2.6. Methodology**

In this study, first the distribution pattern of each water quality datasets for each year was checked for normality through histogram analysis. Then the time-series data for 285 observation wells were used to calculate the groundwater balance. In the proposed method, it is necessary to have DWTM and specific yield map could be generated by employing interpolation methods. The generated maps can be inserted in the model to apply specific yield value in each cell.

**3. Results and discussion**

**3.1. Spatio-temporal groundwater quality mapping**

Saltwater intrusion is a main problem in arid and semi-arid regions that supply irrigation demands from groundwater. In order to monitor the quality it is necessary to generate spatiotemporal maps to assess the groundwater quality through time and space. In this study the EC, sodium and chloride datasets were not normally distributed, but the OK method works the best for normally distributed data. Accordingly, all datasets distributions were log-transformed.

To obtain an accurate estimation of the variables in unsampled locations, it is necessary to find the best fitted semi-variogram model. 11 Different semi-variogram models were evaluated for each parameter and each yearly dataset to find the best fitted semi-variogram. As an example, for the EC datasets the Stable model has the best fit for the majority of datasets. The year 2012 has the maximum range, which demonstrates its low spatial variability. The differences between the semi-variogram models and parameters may represent the each year conditions such as climatic conditions, irrigation and drainage (Arslan, 2012; Caro et al., 2013; Jeihouni et al., 2015b). According to this criteria the groundwater EC, sodium and chloride have strong spatial dependence from 2003 to 2007, and that they from 2008 to 2012 have moderate spatial dependence. This change in spatial dependency indicates the local changes in water quality during 2008–2012.

The estimation performances of the models were evaluated by cross-validation technique. This technique allows determining which model can be investigated through the nugget to sill ratio (%) (Arslan, 2012; Caro et al., 2013; Jeihouni et al., 2015b). According to this criteria the groundwater EC, sodium and chloride have strong spatial dependence from 2003 to 2007, and that they from 2008 to 2012 have moderate spatial dependence. This change in spatial dependency indicates the local changes in water quality during 2008–2012.

The methodology flow chart.
supplying fresh water by collecting surface water and in rivers. Accordingly, it has a recharging role in groundwater resources which collects rainfalls and snow melt water and formed permanent South-East of the study area and generated a dense drainage system snow melts water and glaciers therefore, the groundwater quality presented in Figs. 2 and 3, the Sahand Mountain is located in East and of the study area) and reduces the groundwater quality. However as In other words, saltwater spread from the lake side (west and southwest the aquifers in areas close to lake may be caused by saltwater intrusion. [38x252]type, the increasing trend in concentration of sodium and chloride of the Urmia Lake chemical properties which are sodium-chloride-sulfate type, the increasing trend in concentration of sodium and chloride of the aquifers in areas close to lake may be caused by saltwater intrusion. In other words, saltwater spread from the lake side (west and southwest of the study area) and reduces the groundwater quality. However as presented in Figs. 2 and 3, the Sahand Mountain is located in East and South-East of the study area and generated a dense drainage system which collects rainfalls and snow melt water and formed permanent rivers. Accordingly, it has a recharging role in groundwater resources and supplying fresh water by collecting surface water and infiltrating of snow melts water and glaciers therefore, the groundwater quality reduction in this area is not severe as the other areas. In the other words, the Sahand Mountain has an undeniable role as charging source of the groundwater resources in the study area.

As presented in Fig. 3 the lake area has the minimum elevation and all surface and underground water flow to the lake. The Sahand Mountain is the highest point of the study area and located in eastern part of the study area therefore, a gradient of freshwater is from east to west and groundwater resources charged by mountainous areas.

### 3.2. Saltwater intrusion

To prove the saltwater intrusion, the relation between Urmia Lake's water level and the surrounding plains water table and quality were assessed (Jeihouni et al., 2015a). Accordingly, to assess the interactions of Urmia Lake and surrounding plain's aquifers, the correlations between the Lake's average water level with the aquifer's average water table and salinity were analyzed (Figs. 9 and 10). It is vital that these relations are not immediate, but a lag time is evident (Jeihouni et al., 2015a). Consequently, the relations between the variables were assessed during the twelve month before and after the lake water level status with the lag time of one month. The highest correlation between the average lake water level and the average water table was reached when the average water level was related to the average water table six month before (Fig. 9). The highest correlation between the average lake water level and the average EC was reached when the average water level was related to the average EC six month after (Fig. 10).

If the Urmia Lake and surrounding aquifers were in the normal condition, meaning that just the lake level changed, it is supposed to find a direct positive relation between aquifers' EC and lake level, caused by the saltwater pressure reduction. Regarding to water level drop of Urmia Lake during the last decade, it is expected to see an EC

#### Table 1

<table>
<thead>
<tr>
<th>Years</th>
<th>Mean</th>
<th>Root-Mean-Square</th>
<th>Average Standard Error</th>
<th>Mean Standardized</th>
<th>Root-Mean-Square Standardized</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>−0.036</td>
<td>1.797</td>
<td>1.791</td>
<td>−0.019</td>
<td>1.183</td>
</tr>
<tr>
<td>2004</td>
<td>0</td>
<td>1.938</td>
<td>1.854</td>
<td>0</td>
<td>1.062</td>
</tr>
<tr>
<td>2005</td>
<td>0.040</td>
<td>2.210</td>
<td>1.978</td>
<td>−0.010</td>
<td>1.194</td>
</tr>
<tr>
<td>2006</td>
<td>−0.016</td>
<td>1.963</td>
<td>1.984</td>
<td>0</td>
<td>1.052</td>
</tr>
<tr>
<td>2007</td>
<td>0</td>
<td>2.185</td>
<td>2.401</td>
<td>0</td>
<td>0.964</td>
</tr>
<tr>
<td>2008</td>
<td>−0.062</td>
<td>3.945</td>
<td>4.277</td>
<td>−0.020</td>
<td>4.277</td>
</tr>
<tr>
<td>2009</td>
<td>−0.031</td>
<td>3.007</td>
<td>3.574</td>
<td>0</td>
<td>0.852</td>
</tr>
<tr>
<td>2010</td>
<td>−0.004</td>
<td>2.880</td>
<td>3.279</td>
<td>−0.002</td>
<td>0.899</td>
</tr>
<tr>
<td>2011</td>
<td>−0.014</td>
<td>2.755</td>
<td>3.171</td>
<td>−0.005</td>
<td>0.891</td>
</tr>
<tr>
<td>2012</td>
<td>0.009</td>
<td>3.274</td>
<td>3.341</td>
<td>0.002</td>
<td>1.009</td>
</tr>
</tbody>
</table>

The spatial distributions of EC, sodium, and chloride in the study area are presented in Figs. 6–8 respectively. The area and percentage of classes for EC, sodium, and chloride are calculated for each year. The classification class selections were based on the literature. Based on Richards (1954) the ideal value for EC is less than 0.75 ds/m, and higher values than 2.25 ds/m is not appropriate for irrigation (Delgado et al., 2010). Chloride levels in unpolluted waters are often less than 10 mg/L and sometimes below 1 mg/L (WHO, 2003).

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reduction in areas close to the lake. In other words, the aquifers’ quality must be improved in the west and south west of the study area. But Urmia lake’s condition is completely different. Here, the lake level dropped but due to high pumping from groundwater the aquifers’ water table decreased as well. Accordingly, the both saltwater and freshwater pressure reduced in transition zone. The aquifers’ water table has a downward trend during the last decade and it directly related to the fall in the lake level (Fig. 9). Considering the direct relation between them, the important point is the drop rate. Referring to Fig. 10, EC increased in aquifers by drop in the lake level. Accordingly, it could be concluded that the water table drop rate is higher than lake level drop. This sharp drop can be caused by the high number of legal and illegal wells in the region, and their over exploitation. A high drop rate in the water table leads to reduction of freshwater pressure in the transition zone, and accordingly the saltwater penetrates into the surrounding plains aquifers. Finally, the saltwater intrusion into the freshwater aquifers increases the aquifers’ EC and decreases the quality. The invasion of salty water from the west and southwest of the study area is clearly observable in Figs. 6–8.

3.3. Groundwater balance

Unfortunately it is difficult to calculate the precise net balance of aquifers in the study area owing to the lack of accurate statistics of withdrawals and inputs. To quantify the groundwater resources change in the study area and make it more tangible, instead of utilizing the annual changes in the water table, the approximation of net groundwater balance was estimated through the proposed method. Fig. 11 shows the water balances of the study area over a period of 12 years (2001–2012). Note that each calculation was made based on 2 years data. Fig. 11 reveals the areas with negative and positive balance. The areas and the volumes of negative and positive balances are calculated, and the chart of annual water balance is presented in Fig. 12.

According to Fig. 11 and calculated areas, the regions with negative balance are more in number than the regions with positive balance. This can be attributed to the over exploitation of groundwater resources. The high number of legal and illegal wells in the region is the main cause of this situation. The areas with negative balance are located in the west and south west of the study area, which are close to the lake. The areas with positive balance are located in the east and north east of the study area. The regions with zero balance are located in the center of the study area. The areas with negative balance have a downward trend during the last decade and it directly related to the fall in the lake level (Fig. 9). Considering the direct relation between them, the important point is the drop rate. Referring to Fig. 10, EC increased in aquifers by drop in the lake level. Accordingly, it could be concluded that the water table drop rate is higher than lake level drop. This sharp drop can be caused by the high number of legal and illegal wells in the region, and their over exploitation. A high drop rate in the water table leads to reduction of freshwater pressure in the transition zone, and accordingly the saltwater penetrates into the surrounding plains aquifers. Finally, the saltwater intrusion into the freshwater aquifers increases the aquifers’ EC and decreases the quality. The invasion of salty water from the west and southwest of the study area is clearly observable in Figs. 6–8.

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and positive balance varied each year. For instance, 2002–2003 the area of locations with negative balance is smaller than the area of locations with positive balance, but the net balance is negative which indicates the amount of withdrawal in negative balance areas overcomes the charge in the positive balance area. According to Fig. 12, the groundwater balance in the study area has a descending trend and the storage of the groundwater resources decrease each year. The net balance of the groundwater during the period of the 12 years is about −18 billion cubic meters, which is a huge volume of freshwater. It can be stated from the results that the groundwater resources are destroyed.

As mentioned above, the proposed method calculates the groundwater net balance without employing the balance components such as penetrated runoff, rainfall, withdrawals and output volumes of groundwater. Based on this simplification, the results of all components effects reflected in the groundwater table and the proposed method uses water table data as an input. Therefore, the precision of the estimation will be increased by including more piezometric sampling points.

3.4. Comprehensive discussion

Regarding the results of this study, the groundwater table in the study area has a downward trend. However, the water level of Urmia Lake has a descending trend during the study period, but the downward trend of water table is more expressed than the one for the lake’s water level. With respect to Figs. 9 and 10, the reduction occurred in the water table, and then affected the transition zone by reducing the freshwater pressure after 6 months. This pressure change caused saltwater intrusion from saltwater aquifers beneath the lake to surrounding plains freshwater aquifers. The intrusion during the next 6 months (12 months after the drop of the water table) reduced the quality of groundwater. As indicated in Figs. 6–8 the flux of saltwater is evident from the lake area (west and southwest of the study area).

Based on the discussion above, in recent years, with the lake water evaporation, saltwater intrusion into surrounding plains aquifers can also cause a drop in the water level, meaning the lake water leaks into the plains aquifers and the Urmia Lake water level drops.

In recent years, environmental organizations such as the Iranian department of environment have a particular focus on reviving and increasing water level of Urmia Lake. However, they did not consider the groundwater level changes during the last decade. Based on the results of this study, excessive attention to raising water level will increase saltwater pressure in the transition zone and exacerbate saltwater intrusion into surrounding plains aquifers. This intrusion may also affect other zones in the study area. Accordingly, the revival of groundwater situation through the water spreading has prior to the restoration of the lake level, and in case of lack of attention to this, issue irreparable environmental effects can be seen. For instance, one of the consequences could be the loss of agricultural fields using groundwater for irrigation which is typical threat in irrigated fields.

In arid and semi-arid regions, the low quality irrigation water is the main cause of the secondary soil salinization. All irrigation groundwater contains salts which will remain in the soil after evaporation. Regarding to low rainfall and limited quantity of groundwater resources the conditions for leaching were not provided in these regions which leads to secondary soil salinization. But this is far more complicated in areas that use coastal aquifers due to the high risk of saltwater intrusion. Groundwater salinization accelerates and exacerbates secondary soil salinization. Controlling soil salinization in the arid and semi-arid lands is critical. These lands are vulnerable to the damage associated with low quality irrigation water owing to their limited adaptive capacities. Soil salinization has negative socio-economic effects as well. It decreases the quality of agricultural lands and covert those to barren lands. This adversely affects the livelihood of agriculturally-based communities that rely entirely on agriculture. Soil quality reduction leads to desertification and increase desertified areas in arid and semi-arid regions. These desertified areas have the potential to become dust storm hotspots. Agricultural activities in arid and semi-arid regions highly depend on groundwater resources and this study highlights the importance of groundwater quantity and quality as the most important component of the sustainable agriculture development. Moreover, the current study presents a novel, simple and applicable method of water balance estimation for water resources management and assessing groundwater resource quantity. In developing countries, where lack of datasets and groundwater quantity evaluation is a major challenge, this method can be taken into account to diminish the lack of data in decision makings and support decision makers.

4. Conclusion

In the current study, the spatio-temporal distributions of water quality factors in Urmia Lake’s surrounding plains aquifers were monitored and the groundwater balance was investigated by a proposed method. Also, the relation between Urmia Lake’s water level and aquifers’ average EC and water table were assessed to investigate the saltwater intrusion into the lake surrounding plains’ aquifers. Due to the revival of the Urmia Lake, and excessive and unauthorized withdrawals of groundwater, the knowledge of saltwater intrusion is very critical to predict the future of agricultural sustainability in the region. To reach

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Fig. 12. Changes in groundwater balance in the study area on an annual, medium term (2001–2008), and long term (2001–2012) basis.
these goals; time-series datasets of groundwater quality and piezometric data were used, GIS, geostatistical techniques and 3D modeling techniques were employed. The results indicate that (1) the groundwater quality decreased in west and southwest of the study area over the period of 10 years, (2) the groundwater average EC and water table have a high correlation with lake's water level, and (3) the groundwater balance was negative from 2001 to 2012, regarding to excessive withdrawal of groundwater. Based on the obtained results and the groundwater negative balance, water table seems to drop sharper than the water level. Accordingly, this leads to imbalance between the saltwater aquifer beneath the lake and the surrounding plains’ freshwater aquifers, and causes saltwater intrusion which exacerbate the aquifers salinization. The same result may be observed by restoring the Urmia Lake water level without reviving the critical status of groundwater.

Saltwater intrusion is a serious threat for agricultural activities in arid and semi-arid regions that use coastal aquifers for irrigation. The aquifers salinization leads to serious environmental and ecological crises. In this situation, the excessive withdrawals from unauthorized wells should be stopped and water spreading should be prioritized to restore the water table. Due to the groundwater critical rule in supplying water demand for agriculture, saltwater intrusion can result in many ecological problems that are e.g., increasing the risk of secondary soil salinization, reducing crop yield and crop lands area, and finally lead to desertification in near future. In vulnerable regions the groundwater quality and quantity should be regularly monitored, and generated quality and quantity maps can be utilized by Ministry of Agriculture for appropriate decision making. Finally, the proposed groundwater balance estimation method can be employed by the ministry of agriculture and environmental organization in developing countries, to facilitate their growth toward development and achieving sustainable agriculture by sound management of groundwater resources.

To improve the method, there are a number of effective factors such as basin drainage factors, land use/land cover, relationships between aquifers and hydrogeological properties of the aquifers like hydrogeologic cross-section and hydraulic parameters can be taken into account as future work. Moreover, some other significant factors as flash flood and pumping rates can be programmed and inserted into the method to modify and develop more complex GIS-based model. Such additional parameters might not be applicable for developing countries due to lack of existing heterogeneous data collections, but are suitable for developed countries with comprehensive references.

References
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