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Assessment of Saltwater Pollution in Azarshahr Plain Groundwater, Iran: Conjugating GALDIT Method and Geostatistics

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ABSTRACT

Overutilization of groundwater resources can put their quality under stress. It could be base on rapid declination in groundwater level leading to salt water intrusion in the coastal aquifers. The objective of this study was to map the vulnerability of salt water intrusion of the Urmia Lake, Iran to nearby coastal aquifer (Azarshahr) using GALDIT method. The GALDIT index based on six parameters including; groundwater occurrence (*G*), Aquifer hydraulic conductivity (*A*), Level of water table above the sea level (*L*), Distance from shore (*D*), Impact of existing amplitude and extensive of saline water intrusion (*I*) and Thickness of aquifer (*T*) was computed in 21 observational points of the study area. A ranking system was developed both to give the relative importance of GALDIT factors and to differ categories within each GALDIT factor. After computing the GALDIT index for certain points, Geostatistic method was utilized instead of the layer overlaying to figure out the vulnerable zones. Results showed that except the central part of the study area and just 2 small portions in the northwest and southeast having moderate vulnerability hazards, others have a minimum vulnerability degree to the intrusion of Urmia Lake saltwater. Consequently, the GALDIT approach assisted to manage the monitoring of locations with high vulnerability risk.

Keywords

Azarshahr, Urmia Lake, GALDIT index, Geostatistics

1. Introduction

Being a primary source of freshwater, groundwater resources are often faced with challenges posed by natural processes as well as anthropogenic activities (Singh et al., 2005). Diverse climatic conditions affect the unequally Groundwater distribution throughout the world. Arid zones with scarce rainfall and resultant intermittent rivers receive less renewable recharge and groundwater constitutes the absolute predominant water resource that are often over exploited, especially in these areas, lowering the water table. Thus, it induces an intensification in pumping costs and the possibility of contamination, especially in coastal zones where overexploitation of coastal aquifers leads to saline water intrusion as a consequence of drastic lowering of water table relative to the adjoining sea level (Brehme et al., 2011, Steinich et al., 1998). Most often, these scenarios are further complicated by increasing groundwater draft and simultaneous reduction in natural recharge (Vaux, 2011).

Under natural, undisturbed conditions in a coastal aquifer, a state of equilibrium is maintained between the steady state seawater zone and flowing freshwater zone and hence a transition zone of finite thickness separates these two fluids (Bear et al., 2007). Where the lighter fresh water lies the seawater and the boundary surface between them is known as

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the freshwater-seawater interface. This distribution was attributed to a hydrostatic equilibrium existing between the two fluids of different densities. The entire seawater intrusion phenomenon is governed by Ghyben-Herzberg relation (Todd et al., 2005). When drawdown occurs, the base of the freshwater lens is adjusted at a rate of 40 m for each meter of drawdown in the well through up-coning effect. Therefore extraction of freshwater from a zone above an underlying saltwater body must be accomplished by creating very small drawdown, if saltwater is to be prevented from upcoming into the freshwater wells (McWhorter et al., 1977).

The Urmia lake coastline elongates about more than 200 km that major part of it, occupied by farms and the main portion of the water demand is answered by groundwater resources there. In recent years, groundwater consumption has amplified in this area due to rapid urbanization as well as the lack of precipitation and high evaporation. The over extraction of wells near the coastline has led to saltwater intrusion and groundwater pollution. Consequently, predisposed the aquifer vulnerability, means sensitivity of groundwater quality to an imposed groundwater pumping or sea level rise or both, which is determined by the intrinsic characteristics of the aquifer (Lobo et al., 1991). Hence, it is essential to identify the vulnerable zones to maintain the groundwater quality.

Many approaches have been developed to extract aquifer vulnerability such as process based method, statistical methods and overlay/index methods (Tesoriero et al., 1998, Zhang et al., 1996). Groundwater vulnerability maps are designed to show areas of greatest potential for groundwater contamination on the basis of hydrogeological and anthropogenic factors. Aquifer quality mapping has been successfully used to access the extent of aquifer contamination due to seawater intrusion and it was used as a tool for management of the coastal groundwater resource (Melloul et al., 2003). GIS was effectively used for the evaluation of groundwater quality by several researchers (Phukon et al., 2014, Shahid et al., 2000). The overlay/index approaches gained popularity particularly with the ease of usage of GIS technology (Bonhamcarter, 1996, Corwin et al., 1997, Fuest et al., 1998, National Research Council, 1993).

The GALDIT model has been established as a mapping system that is simple enough to apply using the available data, contains hydrogeological, topographical, and other aquifer characteristics. Most of the assessment of seawater intrusion is based on the computation of some indices, discussed later, some of them are purely based on geochemical and geophysical methods. GALDIT as an indicator-based model that evaluates and quantifies the vulnerability magnitude of the coastal aquifers to saltwater intrusion. GALDIT-based investigations have been performed in several coastal belts of Portugal (Chachadi et al., 2001), India (Chachadi, 2005, Mahesha et al., 2011), and Greece (Kallioras, 2011) as it has been used for Urmia coastal aquifer with the objective of groundwater vulnerability map preparation.

2. Materials and Methods

2.1. Study area

The Azarshahr Plain is one of the Urmia Lake subbasins that is located in Azarbaijan province, northwest of Iran. The plain is bordered from east and southeast by Sahand volcanic mountain, from south by Ghezeldagh travertine, and also north and west by Aji Chay and Urmia Lake salty flat plains, respectively (Fig. 1). The study area is a densely populated area of Iran, with 100 percent of its drinking, domestic and industrial water and 80 percent of agricultural water supplied from groundwater resources (Asghari Moghaddam, 1991). The total area of the Azarshahr basin and Plain are about 580 km^2 and 136 km^2, respectively.

Average annual precipitation values of study area is about 221.2 mm for a 30 years period and mean daily temperature varies from 0.14ºC in January up to 25.8ºC in July with a yearly average of 13º C (ARWA, 2009).

Azarshahr Chay is the main stream flow in the study area, which originates from Sahand Mountain and rarely discharges into the Lake due to percolation and evaporation losses, as well as diversion of water for irrigations.

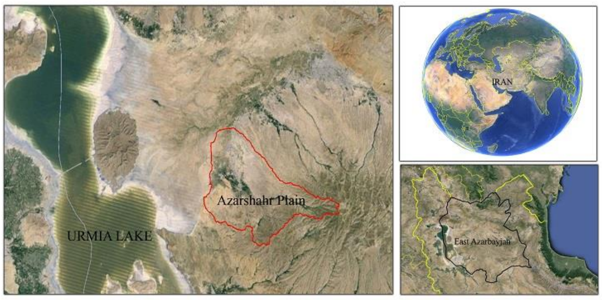

Fig. 1. The study area location

2.2. Geological and Structural Settings

The study area lies in the East Azarbaijan province, which is part of Central Iran unit structurally. It is wedged between the Zagros and Alborz mountain systems. The area includes representatives of Jurassic to Quaternary age with various movements affecting it, most strongly those of Alpine origin.

Pliocene time involved a marine regression and a change to continental conditions, mainly lacustrine, coupled with the deposition of clay and clastic. Then, the Plio-Pleistocene was marked by significant volcanic activity, with lava flows and pyroclastic masses associated with the continental conditions of that epoch.

Hence, the eastern part of the Azarshahr area is occupied by the extinct Sahand volcano, which is built up from a volcanic series of rocks. This mass is surrounded by volcanic sediments called “alluvial tuff”, which were deposited around the andesitic core (Moinvaziri et al., 1978). The Sahand alluvial tuff conformably overlies Pliocene marls, sand-stones and fish-bed layers (the bedrock of the study area). The southwestern part of study area includes Jurassic and Cretaceous limestone with Pliocene travertine, which is believed to be connected to the thermal mineral issuing from the Cretaceous limestone as well as from alluvial tuff (Issar, 1969).

The alluvial water course and plain deposits of the study area are derived from the erosion of Sahand pyroclastic materials, which have transported by water and other transporting agents and deposited in the Azarshahr Plain. They are coarse and poorly sorted in the highest parts of the plain and become progressively finer and more clayey towards the Urmia Lake, which is flanked by a salty loam and huge clay plug. From geological point of view, the Quaternary alluvial deposits including water course and plain deposits form the main water bearing layers in the study area. Figure 2 depicts a schematic geological plot of study area.

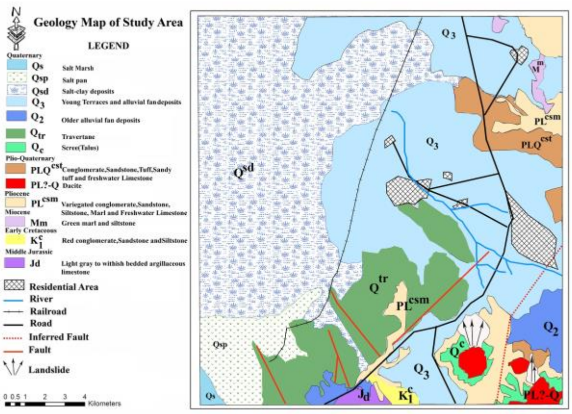

Fig. 2. Geology map of the study area

The alluvial aquifer of the study area has been known for many years as a good aquifer. It has been extensively developed for public and agriculture water supply and investigated hydrogeological setting, particularly in connection with groundwater development. 233 deep and 500 shallow pumping wells, 162 Qanats and 6 springs operate in the alluvial aquifer of the plain (ARWA, 2009) imposing stress on aquifer quantity and quality.

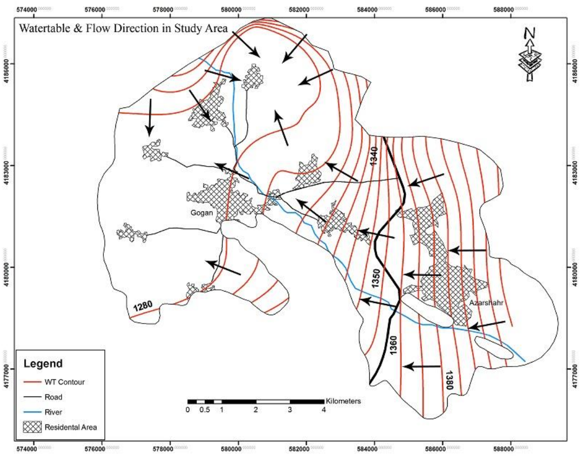

Fig. 3. Water table and Flow direction of the study area

2.3. Vulnerability evaluation and ranking

The GALDIT method is a weightage driven approach, which is figured out from hydrogeological, morphological and other aquifer characteristics in a distinct way.

Computing the final GALDIT index, six important physical parameters that control the seawater intrusion in different hydrogeological settings were utilized.

Inherent in each hydrogeological setting is the physical characteristics that affect the seawater intrusion potential. Groundwater occurrence (aquifer type), Aquifer hydraulic conductivity, Level of the groundwater above the mean sea level, Distance from the Shore (distance inland perpendicular from shoreline), Impact of existing status of seawater intrusion in the area and Thickness of the aquifer, are the most important factors that control the seawater intrusion which is being mapped.

The bolded letters constitute the acronym GALDIT, from the parameters for ease of reference. The system incorporates a weight range and importance rating that defines the relative importance of each factor under varied hydrogeological settings. These factors, in combination, are determined to include the basic requirements needed to assess the general seawater intrusion potential of each hydrogeological setting. GALDIT factors represent measurable parameters for which data are generally available from a variety of sources without detailed reconnaissance [18]. The system contains three significant parts: weights, ranges and importance ratings.

The indicator weights depict the relative importance of the indicator to the process of saltwater intrusion. The most significant indicators for saltwater intrusion have a maximum weight of 4 and the least have a minimum weight of 1. The indicator weights are decided based on results from the studies related to saltwater intrusion from the peers in the field (Chachadi et al., 2001).

After recognition of all indices, every index gets a specific weight considering its importance in saltwater intrusion that is shown in Table 1. The most important index gets the weight 4 and the least gets 1.

Indices importance rating is done, using a scale between 2.5 to 10. Considering the relative importance of each index, its rank is determined. The importance rating ranges between 2.5, 5, 7.5 and 10. Higher the values of importance ratings of the variable, more vulnerable are the aquifer to saltwater intrusion. At last, the decision criterion is the total sum of the individual indicator scores obtained by multiplication of values of importance rating with the corresponding indicator weights.

Table1. Indicators (Chachadi, 2005)

Factors	Weights
1. Groundwater occurrence (Aquifer Type)	1
2. Aquifer hydraulic conductivity	3
3. Height of groundwater level above sea level	4
4. Distance from the shore	4
5. Impact of existing status of seawater intrusion	1
6. Thickness of aquifer being mapped	2

2.4. Indicator Description

2.4.1. Groundwater occurrence (aquifer type)

The extent of seawater intrusion is primarily dependent on the nature of the groundwater occurrence (Sherif et al., 2001). Saltwater intrusion depends on aquifer type, for example the confined aquifer due to larger cone of depression and instantaneous release of water to wells during pumping (Chachadi, 2005). For allotting the importance rate to parameter *G*, disposition and type of aquifer in the study area were inspected cautiously. Table 2 gives the rating for different aquifer types. Field observations and pumping tests analyzing revealed that the aquifer is shallow and unconfined in nature and hence a rating of 7.5 was adopted as per the specifications.

2.4.2. Aquifer Hydraulic Conductivity

Water transmitting ability among the soil or rock due to hydraulic gradient is explained as Hydraulic conductivity (Castany, 1982). The magnitude of saltwater front movement is influenced by the aquifer hydraulic conductivity. For a given hydraulic head, higher the rating of parameter A (aquifer hydraulic conductivity) greater will be the extent of seawater intrusion (Andersen et al., 1988, Ebraheem et al., 1997, Elewa et al., 2012).

The extent of intrusion is directly related to the hydraulic conductivity and nature of aquifer as specified in Bear et al. (1987). Figure 4 shows the relationship between saltwater intrusion length (*L*) and groundwater flux to the sea (*Q*). For unconfined aquifers, the length of saltwater intrusion is expressed by Eq. (1):

$$q = [KB^2 / 2L] * [(1+\delta)/\delta^2] - WL/2 \quad (1)$$

where *W* is the natural recharge. Hydraulic conductivity rating is shown in Table 2.

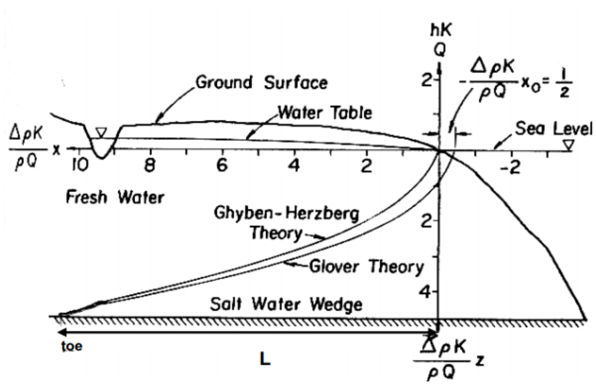

Fig. 4. Saltwater intrusion length front (Bear et al., 1987)

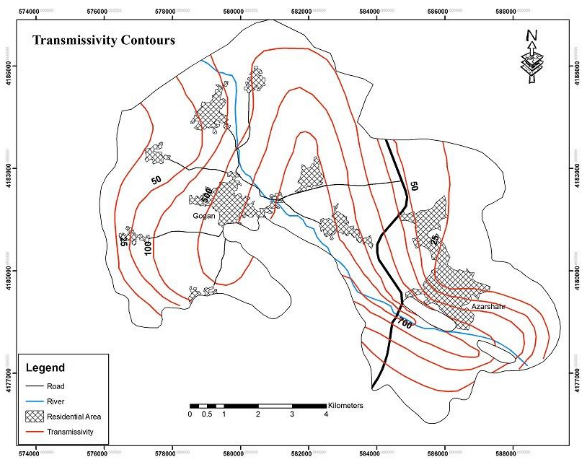

Fig. 5. Groundwater transmisivity of the study area

2.4.3. Groundwater level above the mean sea level

The groundwater level plays a crucial role in maintaining the hydraulic pressure along the coast to push saltwater back. Regarding the long period observations of the average water table fluctuations, the rating for the parameter *L* was given.

According to Gheyben-Herzberg, for every meter rise of fresh water above the mean sea elevation, a freshwater column of 40 meters is needed to interface remains balanced (Todd et al., 2005). Therefore, when the freshwater level decreases, saltwater intrusion front penetrates more than before and aquifer vulnerability risk boosts. Groundwater hydraulic conductivity began from about 20 m per day in the center of the study area and decreased to about 30 cm per day in the western border of the plain near the salt pans. Table 2 depicts the rating of the water table height.

2.4.4. Distance of point in question from coastline

The magnitude of saltwater intrusion is directly related to the perpendicular distance from the coast. The rating value for the parameter *D* generally declines in accordance with an increase in the perpendicular distance from the shoreline. It is obvious that saltwater intrusion reaches to its maximum amount when the aquifer closes to the shore and of course, hydrogeological conditions are proper for transmission. Table 2 provides the general rating for index *D*.

2.4.5. Impact of existing saltwater intrusion

Usually, chloride is the dominant ion in the seawater and its concentration is much less in fresh groundwater and its threshold concentration in the range of 40 to 300 mg/l is specified as indicative of saltwater invasion. Simultaneously, bicarbonate is found in large quantities in fresh groundwater. The [CL/ (HCO3+CO3)] ratio was introduced as a criteria by Revelle (1941), explaining the magnitude of contamination by the intrusion of seawater in coastal aquifers (Bowen, 1986, Revelle, 1941). [Cl / (HCO3+CO3)] values above 1.5 may be considered to be affected by saltwater intrusion and is used to assign a rating value for the parameter I (Table 2 and Fig. 6).

2.4.6. Thickness of Aquifer

It can be clearly seen that, the thickness of the aquifer is directly affecting the extent of saltwater intrusion. Larger the aquifer thickness, larger will be the volume of seawater intrusion. Rating for the parameter *T* increases when the aquifer thickness value exceeds. Electrical resistivity survey has determined the thickness of the aquifer in the study area indicating that the area consists of shallow, unconfined aquifer with the thickness ranging from 22 m to 102 m. Rating of aquifer thickness and Aquifer Thickness of the study are has depicted in Table 2 and Fig. 7, respectively.

Once the GALDIT index has been figured out, identifying the areas that are more likely to be susceptible to saltwater intrusion than others is possible. The higher the index, greater is the seawater intrusion potential. Finally, computing the individual indicator scores and summing them and dividing by the total weight as per the following expression gives the GALDIT index:

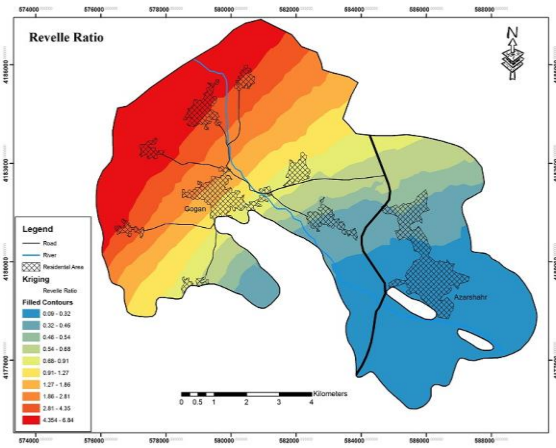

Fig. 6. Revelle Ratio Distribution in the study area

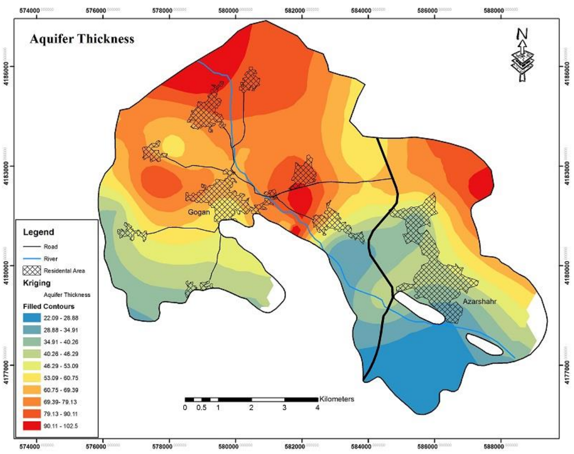

Fig. 7. Aquifer Thickness of the study area

Table 2. Rating the GALDIT Indicators

Indicator	Weight	Indicator Variables: Class	Indicator Variables: Range	Importance Rating
Groundwater occurrence/ Aquifer type (G)	1	Confined aquifer		10
		Unconfined aquifer		7.5
		Leaky confined aquifer		5
		Bounded aquifer		2.5
Aquifer hydraulic conductivity (m/day)(A)	3	High	>40	10
		Medium	40-10	7.5
		Low	10-5	5
		Very low	<5	2.5
Level of groundwater above mean lake level (m)(L)	4	High	<1.0	10
		Medium	1.0-1.5	7.5
		Low	1.5-2	5
		Very low	>2.0	2.5
Distance of the point in question from shore / Height tide (m) (D)	4	Very small	<500	10
		Small	500-750	7.5
		Medium	750-1000	5
		far	>1000	2.5
Impact status of existing seawater intrusion (I)	1	High	>2	10
		Medium	1.5-2.0	7.5
		Low	1-1.5	5
		Very low	<1	2.5
Thickness of Aquifer (saturated) (m)(T)	2	Large	>10	10
		Medium	7.5-10	7.5
		Small	5-7.5	5
		Very Small	<5	2.5

$$GALDIT\ Index = \sum_{i=1}^{6} \{(W_i)R_i\} / \sum_{i=1}^{6} W_i \qquad (2)$$

where W_i is weight of the i^{th} indicator and R_i is importance rating of the i^{th} indicator. Generally, higher index score indicates increase of vulnerability to saltwater intrusion.

3. Results and Discussion

Maximum and Minimum of GALDIT index for Azarshahr coastal Aquifer derived as below:

Maximum GALDIT Index:

$$\frac{\{(1\times10)+(3\times10)+(4\times10)+(4\times10)+(1\times10)+(2\times10)\}}{15}=10$$

Minimum GALDIT Index:

$$\frac{\{(1\times2.5)+(3\times2.5)+(4\times2.5)+(4\times2.5)+(1\times2.5)+(2\times2.5)\}}{15}=2.5$$

Therefore, the maximum and minimum of GALDIT index changed from 10 to 2.5. The vulnerability of the area to saltwater intrusion was evaluated upon the magnitude of the GALDIT index. The lower the index, less vulnerable is the area to the saltwater intrusion. After the GALDIT index were computed, actually it was possible to classify the vulnerable areas to the saltwater intrusion. The GALDIT index scores were divided in 3 groups. The GALDIT index amounts were derived from rate summation divided to sum of parameters weights. Tables 3 and 4 show the computation of GALDIT index and vulnerability classes in study area, respectively.

Table 3. Rating and computing the GALDIT index

Indicator	Weight	Importance Rating Range: Minimum	Importance Rating Range: Moderate	Importance Rating Range: Maximum	Range of Scores: Minimum	Range of Scores: Moderate	Range of Scores: Maximum
Aquifer type	1	2.5	5-7.5	10	2.5	5-7.5	10
Hydraulic Conductivity	3	2.5	5-7.5	10	7.5	15-22.5	30
Groundwater level above the Lake	4	2.5	5-7.5	10	10	20-30	40
Distance to Shore	4	2.5	5-7.5	10	10	20-30	40
Impact of existing Saltwater	1	2.5	5-7.5	10	2.5	5-7.5	10
Thickness of Aquifer	2	2.5	5-7.5	10	5	10-15	20
Total Score					37.5	75-112.5	150
GALDIT Index					2.5	5-7.5	10

Table 4. GALDIT index & Vulnerability in the study area

Row	X	Y	Score	GALDIT Index	Vulnerability
1	582700	4186000	67.5	4.50	Minimum
2	583880	4183600	52.5	3.50	Minimum
3	580500	4187100	65.0	4.33	Minimum
4	579500	4184600	65.0	4.33	Minimum
5	584500	4183550	52.5	3.50	Minimum
6	578045	4180332	82.5	5.50	Moderate
7	588050	4179750	52.5	3.50	Minimum
8	583350	4179450	62.5	4.17	Minimum
9	586250	4177400	47.5	3.17	Minimum
10	582120	4184390	72.5	4.83	Moderate
11	582193	4184229	72.5	4.83	Moderate
12	576400	4183950	60.0	4.00	Minimum
13	581100	4183400	72.5	4.83	Moderate
14	586950	4182960	57.5	3.83	Minimum
15	576740	4178990	52.5	3.50	Minimum
16	576301	4180303	55.0	3.67	Minimum
17	580304	4179897	47.5	3.17	Minimum
18	577372	4183785	60.0	4.00	Minimum
19	586027	4181791	52.5	3.50	Minimum
20	581770	4181832	72.5	4.83	Moderate
21	579638	4185482	80.0	5.33	Moderate

The results from the application of GALDIT vulnerability index were linked with GIS in order to derive vulnerability maps for the study area with respect to the potential of aquifer contamination due to seawater intrusion and finally map of vulnerability degree of Azarshahr plain was drawn. Computed GALDIT index and vulnerability zones are shown in Figs. 8 and 9, respectively.

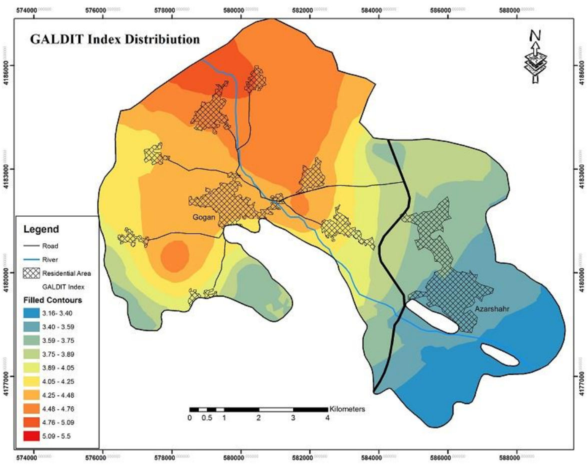

Fig. 8. Computed GALDIT index in the study area

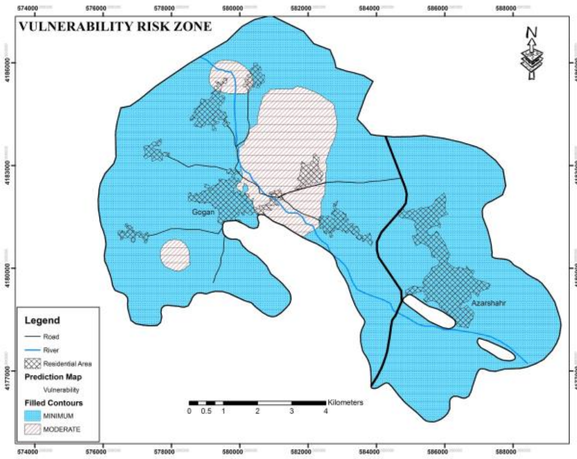

Fig. 9. Vulnerability zones of the study area

4. Conclusions

The vulnerability map of Urmia Lake has been provided to show the impact of saltwater intrusion along the coastal zone. However, the vulnerability degree is high at the borders near the shore and it becomes lower in areas far from that generally, but it was not true for the study area. Results represented that vulnerability in the center, northeast and southeast of the study area was moderate and in other portions was low. This methodology can be systematically done in any selected coastal area where the hydrogeological information is available. Due to hazardous situation of the groundwater quality in the study area, quality mapping should be periodically carried out as this aquifer is bounded by inferior quality of water on all the sides and withdrawal is intensifying by the time. The quality index map of the region can be used as a tool for proper and efficient management of groundwater by regulating pumping from the poor quality zone. The results from the study may be useful for further investigations related to groundwater potential and saltwater intrusion.

References

Andersen, F., Mercer, J. W. and White H. O. J., (1988), Numerical modeling of salt-water intrusion at Hallandale, Florida. Groundwater.

ARWA, (2009), Detailed data collection from discharges of pumping wells and Qanats in the Azarshahr Plain. Report in Persian.

Asghari Moghaddam, A., (1991), The hydrogeology of the Tabriz area, Iran. Ph.D. Dissertation Tabriz University.

Bear, J. and Verruijt, A., (1987), Modeling groundwater flow and pollution. Dordrecht, Holland.

Bear, J. and Zhou, Q., (2007), Seawater intrusion into coastal aquifer. London.

Bonhamcarter, G. F., (1996), Geographic information systems for geoscientists: modeling with GIS computer methods in the geosciences. Elsevier Science Ltd.

Bowen, R., (1986), Groundwater. Elsevier Applied Science, London.

Brehme, M., Scheytt, T. C., Elik, M., Dokuz, U., (2011), Hydrochemical characterization of ground and surface water at Dortyol/Hatay/Turkey. Environmental Earth Science.

Castany, G., (1982), Primcipes Methods de l'hydrogeologie. Dunod, Paris.

Chachadi, A. G. and Lobo Ferreira, J. P., (2001), Sea water intrusion vulnerability mapping of aquifers issuing GALDIT method. In: Proc. Workshop on Modeling in Hydrogeology, Anna University. Chennai.

Chachadi, A. G., (2005), Seawater intrusion mapping using modified GALDIT indicator model- Case study in Goa. Jalvigyan Sameek.

Corwin, D. L., Vaughan, P. J. and Loague, K., (1997), Modeling nonpoint source pollutants in the vadose zone with GIS. Environmental Science Technology.

Ebraheem, A. M., Sensosy, M. M., Dahab, K. A., (1997), Geo-electrical and hydro-geochemical studies for delineating groundwater contamination due to saltwater intrusion in the northern part of the Nile Delta Egypt. Groundwater.

Elewa, H. H., Shohaib, R. E., Quaddah, A. A. and Nousir, A. M., (2012), Determining groundwater protection zones for the Quaternary aquifer of northeastern Nile Delta using GIS-based vulnerability mapping. Environmental Earth Science.

Fuest, S., Berlekamp, J., Klein, M. and Matthies, M., (1998), Risk hazard mapping of groundwater contaminations using long-term monitoring data of shallow drinking water wells. Journal of Hazardous Material.

Issar, A., (1969), The groundwater provinces of Iran. Bulletin International Association Science Hydrology. XIV.

Kallioras, A., Pliakas, F., Skias, S. and Gkiougkis, I., (2011), Groundwater vulnerability assessment at SW Rhodope aquifer system in NE Greece. Environmental Earth Science.

Lobo Ferreira, J. P. and Cabral, M., (1991), Proposal for an Operational Definition of Vulnerability for the European Community's Atlas Groundwater Resource. Meeting of the European Institute for Water. Groundwater Work Group, Brussels.

Mahesha, A., Vysh, A., Lathashri U. A. and Ramesh, H., (2011), Parameter estimation and vulnerability assessment of coastal unconfined aquifer to saltwater intrusion. Journal of Hydrology Engineering.

McWhorter, D. B., Sunada, D. K., (1977), Groundwater hydrology and hydraulics. Water Resources, Fort Collins.

Melloul, A. J. and Wollman, S. H., (2003), Qualitative hydrological and landuse planning tool for the Israel Coastal aquifer. Science of Total Environment.

Moinvaziri, H. and Aminsobhani, I., (1978), Volcanological and volcano-sedimentological study of Sahand Mountain. University of Tarbyat Moallim. Tehran. Report in Persian.

National Research Council, (1993), Groundwater vulnerability assessment: Contamination potential under conditions of uncertainties. National Academy Press, Washington D.C.

Phukon, P., Phukan, S., Das, P. and Sarma, B., (2004), Multi criteria evaluation in GIS environment for groundwater resource mapping in Guwahati City Areas, Assam. GIS development. Natural Resource Management.

Revelle, R., (1941), Criteria for recognition of sea water in groundwater. Translation of American Geophysics Union.

Shahid, S. and Nath, S. K., (2000), GIS integration of remote sensing and electrical sounding data for hydrogeological exploration. Journal of Spatial. Hydrology.

Sherif, M. M. and Hamza, K. I., (2001), Mitigation of seawater intrusion by pumping brackish water. Transportation in Porous Media.

Singh, K. P., Malik, A., Singh, V. K., Mohan, D. and Sinha, S., (2005), Chemo metric analysis of groundwater quality data of alluvial aquifer of Gangetic plain, North India. Analytica Chimica Acta.

Steinich, B., Escolero, O. and Marin, L. E., (1998), Salt-water intrusion and nitrate contamination in the valley of Hermosillo and EI Sahuaral coast aquifers, Sonora, Mexico. Hydrogeology Journal.

Tesoriero, A. J., Inkpet, E. L. and Voss, F. D., (1998), Assessing groundwater vulnerability using logistic regression. Source Water Assess. 98th Conference Dallas.

Todd, K. D., Mays, L. W., (2005), Groundwater hydrology. John Wiley and Sons, New York.

Vaux, H., (2011), Groundwater under stress: the importance of management. Environmental Earth Science.

Zhang, R., Hamerlinck, J. D., Gloss, S. P. and Munn, L., (1996), Determination of nonpoint-source pollution using GIS and numerical models. Journal of Environmental Quality.