Arab J Geosci (2016) 9:502
DOI 10.1007/s12517-016-2520-9

ORIGINAL PAPER

A GIS-index integration approach to groundwater suitability zoning for irrigation purposes

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Received: 6 May 2015 / Accepted: 26 May 2016
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Abstract In recent decades, the high population growth has increased the demand for agricultural lands and products. Groundwater offers reliability and flexibility in access to water for irrigation purposes, especially in arid and semi-arid areas, such as Amol-Babol Plain, Iran. However, the quality and quantity of groundwater may not be suitable for irrigation purposes in all areas due to urbanizations, and intensive agricultural and industrial activities. Groundwater suitability zoning for irrigation purposes could be useful to improve water resources and land use planning, mostly in areas with water scarcity. Therefore, a GIS-based indices method is proposed to assess suitable zones for agricultural activities, integrating the irrigation water quality (IWQ) index and hydrogeological factors. IWQ index was utilized to assess groundwater quality based on salinity hazard, infiltration hazard, specific ions, and trace elements hazards, and miscellaneous effects such as pH, bicarbonate, and nitrate. The potential of the aquifer for irrigation water abstraction was investigated using hydrogeological surveys such as slope angle of the plain, hydraulic conductivity, and aquifer thickness. The groundwater suitability index classified most of the study area (more than 90 %) as "excellent" or "good" suitability zones for irrigation purposes. A limited area of around 5.6 % of the total area has moderate suitability for irrigation purposes due to the Caspian Seawater intrusion and the presence of fossil saline water. The proposed methodology provides useful information in order to allow irrigation management to prevent water and soil deterioration.

Highlights
- Developing irrigation water quality index based on the indicators.
- We proposed new GIS-based indices approach for irrigation suitable zoning.
- Suitable zones depend on both hydrochemical and hydrogeological factors.

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Keywords Index method · GIS · Irrigation water quality · Suitability zone · Amol-Babol plain

Introduction

Agriculture is a dominant component of the global economy (FAO 1994). Population growth increases rapidly the demand for agricultural lands and products. Agriculture is well known as the largest user of fresh water and a major cause of degradation of surface and groundwater resources and quality (FAO 1994). Globally, irrigation accounts for more than 70 % of total water withdrawals and for more than 90 % of total water consumption (Adhikari et al. 2013). All the groundwater sources are not recoverable or in good quality, thus they face with limited availability. Groundwater availability is also influenced with groundwater quality, which is the physical and chemical characterization of ground water. Groundwater quality is often attributed to the natural hydrogeological setting and anthropogenic reasons. In areas with intensive agricultural activities, such as Amol-Babol Plain, Iran, the quality of irrigation water has a considerable impact on crop yields, soil physical conditions, and water infiltration. Therefore, suitability of groundwater quality for irrigation usages had to be assessed using various parameters and indicators.

Published online: 04 June 2016

Electrical conductivity (EC), sodium adsorption ratio (SAR), residual sodium carbonate (RSC), and specific ions such as Cl^- and NO_3^- are principal parameters utilized for irrigation water quality assessment (Yidana et al. 2008). Although traditional assessment of groundwater quality, based on the individual parameters, is simple yet detailed (Mohebbi et al. 2013), it is not sufficient to provide an accurate representation of water quality. Therefore, water quality indices have been developed to summarize water quality data in an easily expressible and understandable format (Saeedi et al. 2010).

Several researchers assessed the suitability of groundwater quality for irrigation purpose based on various hydrochemical parameters (Haritash et al. 2008; Jafar Ahamed et al. 2013; Neshat et al. 2014a, b; Narany et al. 2015). Haritash et al. (2008) combined suitability assessment of groundwater for drinking, irrigation, and industrial usage. They applied SAR, RSC, soluble sodium percentage (SSP), and magnesium hazard for evaluating suitability of groundwater for irrigation in north Indian villages. An et al. (2012) suggested that the construction of the index system is the core of the suitability of groundwater exploitation for groundwater management and development. They applied several parameters for evaluation index, including groundwater quality, exploitation conditions, aquifer properties, and groundwater recharge using GIS. Moreover, Jafar Ahamed et al. (2013) suggested to utilize water quality index (WQI) as a tool to convert a large dataset into a much reduce and informative form to assess the suitability for drinking and irrigation purpose in Pugalur area, India.

The first water quality index (WQI) was developed by selecting and weighting methods and introducing an aggregation function (Horton 1965). The WQI was revised by the United States National Sanitation Foundation (Ott 1978) and modified based on its utilization by different researchers (Liou et al. 2004; Vasanthavigar et al. 2010; Gazzaz et al. 2012; Mohebbi et al. 2013). Mohebbi et al. (2013) developed an innovative drinking water quality index (DWQI) using 23 water quality parameters, based on the Canadian DWQI and the Iranian standard for drinking water quality. The modified DWQI was divided into health- and acceptability-based indices and scored from 0 as a poor drinking water quality to 100 for an excellent drinking water quality. Simsek and Gunduz (2007) proposed an irrigation water quality (IWQ) index to classify irrigation water quality based on the five hazard groups: (a) salinity hazard, (b) infiltration hazard, (c) specific ion toxicity, (d) trace element toxicity, and (e) miscellaneous impacts on sensitive crops. Adhikari et al. (2013) suggested that single parameters are not sufficient for classification of water suitability for irrigation. They used EC, SAR, and RSC to transform parametric concentration into qualitative scores as a water quality indexing system.

The IWQ index is a method based on the linear combination of a group of irrigation water quality factors that have a negative influence on soil quality and crop yield (Adhikari et al. 2011). Many researchers have utilized the index since it is user-friendly and easy to understand especially for the non-technical decision maker (Debels et al. 2005; Simsek and Gunduz 2007; Narany et al. 2014; Neshat and Pradhan 2015). Simsek and Gunduz (Simsek and Gunduz 2007) mentioned that no complete assessment tool has been undertaken on the crucial aspects of irrigation water quality analysis despite the large number of studies on index techniques. The quality index is calculated based on the quality classes of parameters, which were determined using the concentrations of ions in groundwater.

Although IWQ index was widely applied for the assessment of groundwater suitability and availability for irrigation, other factors such as a hydrogeological survey were proposed to evaluate groundwater accessibility for suitable zone determination for irrigation purposes. The groundwater quality assessment could be adversely affected by application of IWQ index without consideration of hydrogeological factors. Over abstraction of groundwater can cause drawdown which increases the risk of salt water intrusion to the wells (Romanelli et al. 2012).

A Geographical Information System (GIS) is a powerful tool for storing, manipulating, analyzing, and mapping spatial data for decision making in several areas, such as environmental issues (Nampak et al. 2014). Capability of GIS is well known for mapping the spatial distribution of individual water quality parameters, visualizing suitable zones, and comparative evaluation in water quality studies had been proven (Simsek and Gunduz 2007). Several researchers have successfully utilized the GIS in showing the spatial distribution of water quality parameters for the purpose of agriculture and domestic activities (Assaf and Saadeh 2009; Ashraf et al. 2011; Narany et al. 2014; Manap et al. 2014).

The integration of GIS for locating groundwater quality zones, with groundwater quality indices, and hydrogeological factors provides a new approach, which allows a spatially distributed assessment of groundwater for irrigation purposes. Romanelli et al. (2012) introduced a new GIS-based water quality assessment by combining water quality parameters of EC, SAR, and RSC with hydrogeological factors, such as hydraulic gradient, slope angle, and aquifer thickness for delineating groundwater suitability zones for irrigation purposes in flat areas in Argentina.

The main aim of the present study is to develop a GIS-based approach to assess groundwater suitable zones for irrigation purposes in Amol-Babol Plain, using an irrigation water quality index and hydrogeological factors, which can provide a useful and easy-to-understand results for decision makers involved in groundwater management.

Materials and methods

Study area

Amol-Babol Plain is located in the northern region of Mazandaran Province, in the north of Iran, and covered an area of 1822 km^2. Annual precipitation is approximately 870 mm which is 3.5 times greater than the average annual precipitation of nearly 250 mm for Iran (Fakharian 2010). Agriculture is the main economic activity and covers around 80 % of the plain's areas. Rice is the main crop and nearly 62 % (1200 km^2) of land is used for rice cultivation (Fig. 1a). Citrus orchards and crops, such as wheat, barley, beans, and corn, cover 12 % (220 km^2) and 10 % (182 km^2) of the total land, respectively. The total water abstraction from Amol-Babol aquifers during the 2008 to 2009 period was approximately 507 million m^3 (Fakharian 2010). About 93.5 to 96.5 % of the groundwater abstraction is attributed to agricultural activities. There are 68,128 wells on the Amol-Babol Plain with more than 6000 wells classified as shallow wells (Fakharian 2010).

From a geomorphological perspective, the study area is a flat alluvial plain (the slope angle is mostly less than 1 %) surrounded by the Caspian Sea in the north and the Alborz Highlands in the south. The alluvial plain is divided into two parts, the southern alluvial plain which is mostly created by deposition of grain size sediment by Haraz, Babol, and Talar Rivers coming from Alborz Highlands, and the northern alluvial plain, which consists of clay, silty clay, and sand that is formed by deposition of rivers and the Caspian Sea. The thickness of alluvial fans varies from less than 30 m in the coastal area to more than 300 m in the Haraz homogenous alluvial in the western side of the plain (Fakharian 2010) (Fig. 1b). The alluvial plain is formed by Quaternary activities such as river sediment deposition, rock weathering, evaporation, and Caspian Sea level variation. The oldest geological units called Dorud, Ruteh, and Nessan consist of limestone layers, and thin layers of shale and marl of the Permian age. The late Jurassic and Cretaceous ages are represented in limestone, marl, and clay layers (Aghanabati 2004).

The alluvial aquifers consist of an unconfined aquifer, which extends to around 94 % of the plain. The aquifer thickness ranges from 10 to 200 m, as it increases towards the west and southwestern sides and decreases towards the northern coastal side (Fakharian 2010). Regional flow of groundwater is from the recharge zones in the southern side to the discharge area (Caspian Sea) in the northern area. The recharge naturally comes from the infiltration of precipitation and snow in the Alborz Highlands and discharge occurs towards rivers, water bodies, and directly into the Caspian Sea. Majority of the coastal area is not affected by seawater intrusion (Sheikhy Narany et al. 2014). The high discharge rate of Haraz and Babol Rivers had restricted the seawater intrusion to the limited section of the coastal area in the northeastern region of the plain. The high discharge rate had washed fossil saline water through sediment layers and prevented seawater intrusion into fresh aquifer water. Contrary to this, in the northeastern side, the weak discharge rate of the Talar River is not powerful enough to wash fossil saline water. Therefore, saline water still remains between sediment layers and reduces the quality of groundwater quality in this region.

Water quality parameters

Groundwater samples were collected to assess the groundwater quality for its suitability for irrigation purposes, from 94 agricultural wells during October and November (wet season), and May and June (dry season) in 2009. The water samples were collected after 10 min of pumping, transferred into acid-washed polyethylene bottles, and stored for less than 24 h at 4 °C until transferred to the laboratory. Samples were preserved according to the standard method for the examination of water and waste water (APHA 2005). The temperature, pH, electrical conductivity (EC), and total dissolved solid (TDS) were measured using a multi-parameter WP600 series meter immediately after sampling. The collected samples were analyzed for 25 chemical parameters and heavy metals including sodium (Na^+), chloride (Cl^-), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), nitrate (NO_3^- as N), sulfate (SO_4^{2-}), carbonate (CO_3^{2-}), bicarbonate (HCO_3^-), aluminum (Al), arsenic (As), beryllium (Be), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), lead (Pb), lithium (Li), manganese (Mn), molybdenum (Mo), nickel (Ni), selenium (Se), zinc (Zn), and boron (B) and were made following the American Public Health Association's standard (APHA 2005). The Ca^{2+} and Mg^{2+} were determined titrimetrically using the ethylenediaminetetraacetic acid (EDTA) method, and sodium and potassium by flame photometry. The anions and bicarbonate were determined by acid titration, the chloride concentration was determined by $AgNO_3$ titration, and the sulfate and nitrate were determined using a molecular absorption spectrophotometer. For analyzing sodium, trace elements, and metals, samples were acidified with 1 % HNO_3 to reach pH <2 and transported to the ACME laboratory in Vancouver, Canada using ICP-mass spectrometers.

QA/QC is an appropriate quality control and quality assurance on water samples to provide greater data confidence from the analytical procedure regarding bias and variability. Quality assurance includes high level activities to ensure the accuracy, precision, completeness, and effectiveness of the monitoring program. Quality control refers to the technical activities to ensure that the data collected are adequate for quality assessment purposes. Control chart and blank samples were applied to assess the analytical precision. Applications of the same laboratory equipment were advised for all collected samples for quality control from sampling irregularities. Moreover, the ionic balance error formula, accepting the relationship between the anions (Cl^-, HCO_3^-, CO_3^{2-}, and NO_3^-) and total cations (Na^+, K^+, Ca^{2+}, and Mg^{2+}) for samples, is observed to be within the range of acceptability (±5 %).

Data analysis

The proposed methodology is a GIS-integrated approach based on a linear combination of multi-parametric data for evaluating groundwater quality for irrigation purposes in the Amol-Babol Plain. In this approach, hydrochemical data and hydrogeological factors of slope angle, aquifer thickness, and hydraulic conductivity are combined to determine the suitability zones of irrigation water. The index technique is commonly used as a technique to assess water quality based on the rates that provide the composite influence of individual parameters on the overall quality of water to different usages (Sadat-Noori et al. 2013). Based on the methodological flowchart (Fig. 2), the point-data-based maps previously had to be converted to surface data sets for each parameter as Table 1. Various thematic layers of IWQ index, hydraulic conductivity, and aquifer thickness were prepared using the geostatistical method.

The geostatistical interpolation methods quantify the spatial autocorrelation among sampling points and accounts for the spatial distribution around an un-sampled location (Narany et al. 2014). Kriging is a stochastic interpolation method, which can be applied to find the best linear unbiased estimate with the minimum variance of estimation error. The slope map as a parameter which represents the topography of the ground was generated from a digital elevation model (DEM) using elevation points. The "spatial analyst" extension in ArcGIS was applied to obtain this layer. Once the thematic maps were prepared, each one was classified into specific categories to enable the zoning of groundwater quality for irrigation.

The classification of maps ranges from index 1 (excellent potential for irrigation) to index 5 (unsuitable conditions for irrigation) based on the criteria mentioned in Table 1. The groundwater suitability map for irrigation usage was obtained by combining each classified map in the GIS environment called the "Overlay method" (ESRI 2003). This approach often uses individual index maps to combine the layers and assign new index values in the output layer.

Hydrochemical data

The quality of irrigation water is highly dependent on the type and the quantity of the ions and elements dissolved in it. The combination of the five hazards, namely, salinity, infiltration, specific ion toxicity, trace element toxicity, and miscellaneous effect to sensitive crops, are used to assess the irrigation water quality index. The irrigation water quality can influence the soil characteristics and agricultural products, which should be considered as a significant tool in sustainable agricultural management (Wilcox 1955).

Salinity hazard Accumulation of salts in the crop root zone reduces the amount of water available to the roots, which reduces plant growth and causes drought-like symptoms (Ayers and Westcot 1985). The salinity hazard is directly related to the concentration of ions in the water, which also affects soils by enriching with a sodium concentration, when sodium values are much higher than calcium in the water. It can destroy the structure of soil due to the dispersion of clay particles and decrease the osmotic activity of plants (Adhikari et al. 2013). Salinity hazard can be measured by electrical conductivity (EC) values (Ayers and Westcot 1985). In general, high electrical conductivity reduces the amount of water available to the crop. In order to assess the salinity hazard, electrical conductivity was separated into three classes (Table 2). Usually, water with EC values greater than 3000 μS/cm is considered to be an unsuitable quality for irrigation purposes.

Infiltration hazard The concentration of sodium, calcium, magnesium, and sodium in water can influence the normal infiltration rate of the water. The infiltration and permeability hazard occurs when high sodium ions decrease the rate at which irrigation water enters the soil's lower layers (Simsek and Gunduz 2007) because the high sodium in water starts to accumulate at the soil surface and deteriorates the soil characteristics. Therefore, the crop cannot extract sufficient water from the soil, which reduces agriculture production. The relative concentration of sodium, magnesium, and calcium in water is known as the sodium adsorption ratio (SAR), is used to measure the sodium hazard in irrigation water, and is computed as the following equation (Ayers and Westcot 1985):

$$\mathrm{SAR} = \frac{\mathrm{Na}^{+}}{\sqrt{\frac{(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+})}{2}}} \tag{1}$$

where all concentrations are expressed in milliequivalents per liter.

The classification of groundwater samples demonstrates that SAR values of less than 10 indicate excellent water quality; 10–18, good water; and >18, doubtful to unsuitable water for irrigation purposes (Ravi Shankar and Mohan 2006).

Specific ions Chloride is another ion from the irrigation water which may accumulate in the plants and reduce yields (FAO 1994). Chloride is a significant ion to crops at low concentration, but shows toxicity to sensitive crops in values higher than 140 mg/l (Table 2). Injury symptoms mostly develop as leaf burn or the drying of leaf tissue (Simsek and Gunduz 2007).

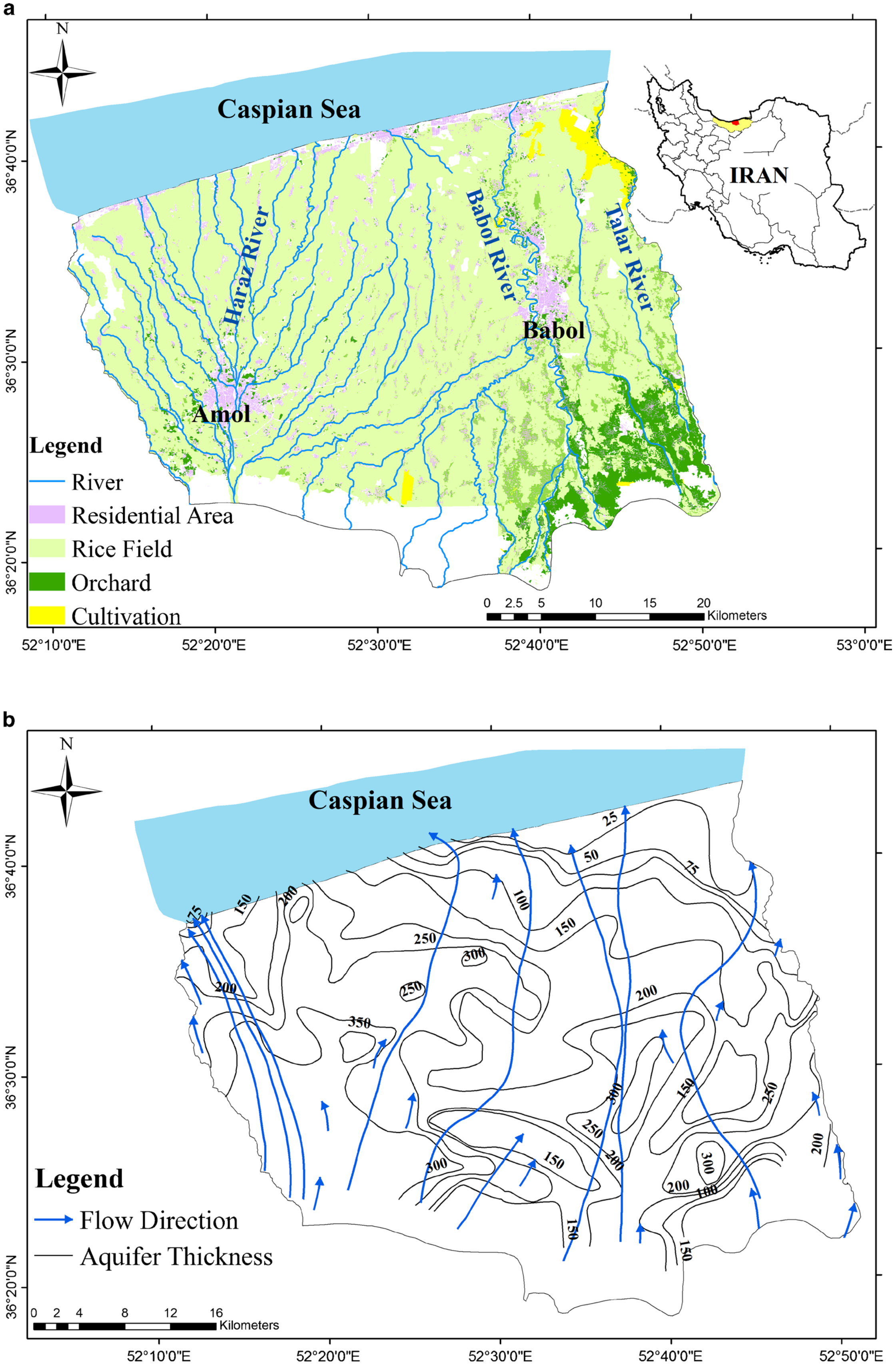


Fig. 1 Land use map of Amol-Babol Plain, Iran (**a**). Aquifer thickness contour map (**b**)

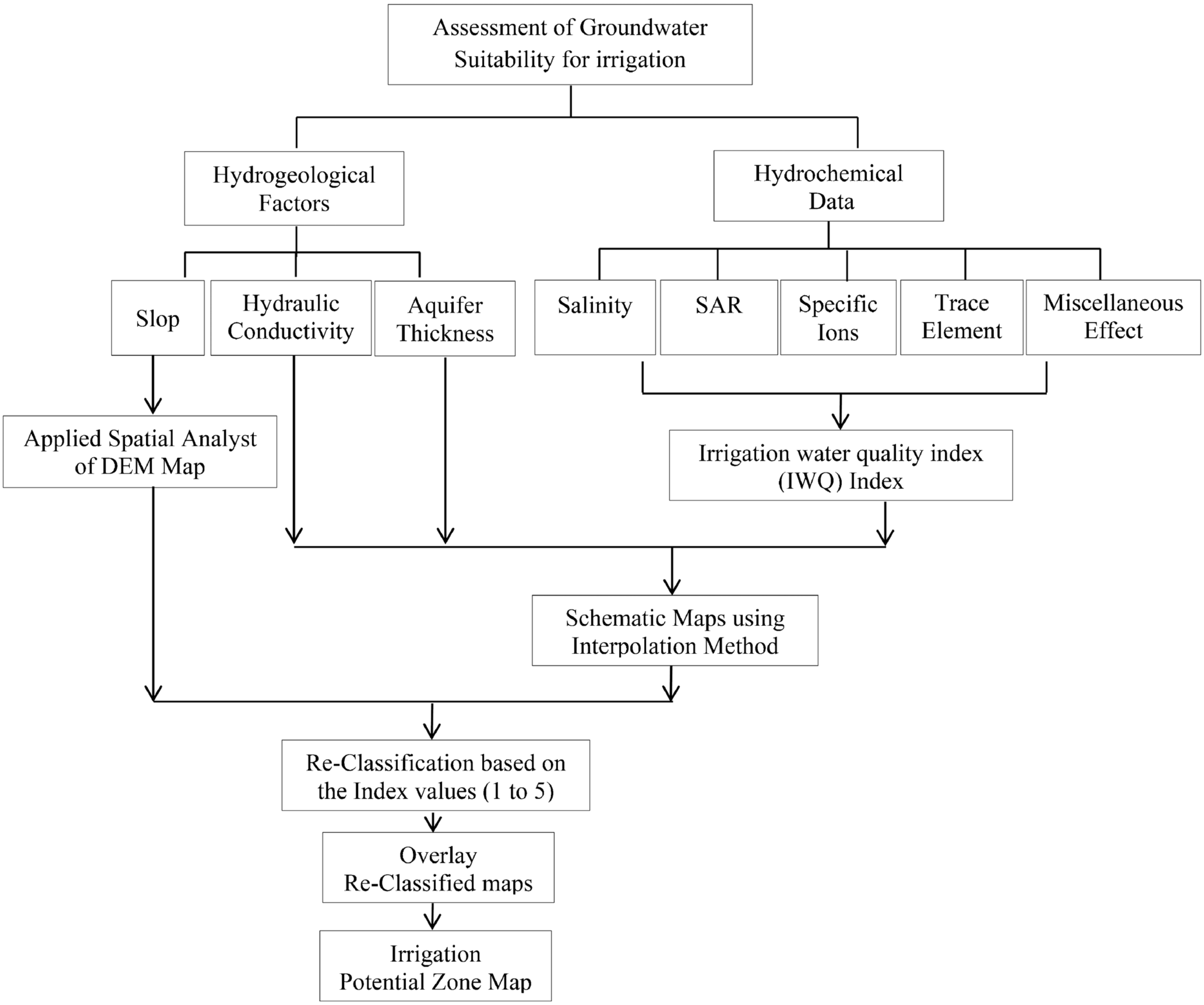


Fig. 2 Schematic flowchart of the proposed methodology

Boron is present in water as boric acid and in low concentration is an essential element for plant growth, but is considered to be toxic in excess values (Eaton 1950). Sensitive crops are mostly affected by boron toxicity in 0.7 mg/l (Table 2). Therefore, the classification indicates that boron <0.7 mg/l is suitable for irrigation water.

RSC has been recognized as able to identify the hazardous effect of carbonate and bicarbonate on the irrigation water quality (Eaton 1950). High concentration of carbonate and sodium bicarbonate is considered to be detrimental to the physical properties of soils, as it causes dissolution of organic matter in the soil, which in turn leaves a black stain on the soil surface upon drying (Ravikumar and Somashekar 2011). RSC is calculated from the following equation (Eaton 1950):

$$\mathrm{RSC} = \left(\mathrm{CO}_3^{-2} + \mathrm{HCO}_3^{-1}\right) - \left(\mathrm{Ca}^{+2} + \mathrm{Mg}^{+2}\right) \qquad (2)$$

Table 1 Classification of irrigation water suitability parameters (modified from Romanelli et al. (2012))

Index	Classification	IWQ index	Aquifer thickness	Hydraulic conductivity	Slope (°)
1	Excellent	<21	–	<4	>6
2	Good	21–27	>30	4–12	2–6
3	Moderate	27–33	10–30	12–28	1–2
4	Doubtful	33–39	<10	28–41	<1
5	Unsuitable	39<	–	41<	–

Table 2 Modified classification for IWQ index parameters (modified from Simsek and Gunduz 2007)

Hazard	Parameter	Range			Weight (w)
		High suitable (1)	Moderately suitable (2)	Low suitable (3)	
Salinity	EC (μS/cm)	$EC < 700$	$700 \leq EC \leq 3000$	$EC > 3000$	5
Infiltration	SAR	$SAR < 10$	$10 \leq SAR \leq 18$	$SAR > 18$	4
Specific ion	RSC	$RSC < 1.25$	$1.25 \leq RSC \leq 2.5$	$RSC > 2.5$	3
	Boron (mg/l)	$B < 0.7$	$0.7 \leq B \leq 3.0$	$B > 3.0$	
	Chloride (mg/l)	$Cl < 140$	$140 \leq Cl \leq 350$	$Cl > 350$	
Trace element	Aluminum (mg/l)	$Al < 5.0$	$5.0 \leq Al \leq 20.0$	$Al > 20.0$	2
	Arsenic (mg/l)	$As < 0.1$	$0.1 \leq As \leq 2.0$	$As > 2.0$	
	Beryllium (mg/l)	$Be < 0.1$	$0.1 \leq Be \leq 0.5$	$Be > 0.5$	
	Cadmium (mg/l)	$Cd < 0.01$	$0.01 \leq Cd \leq 0.05$	$Cd > 0.05$	
	Chromium (mg/l)	$Cr < 0.1$	$0.1 \leq Cr \leq 1.0$	$Cr > 1.0$	
	Cobalt (mg/l)	$Co < 0.05$	$0.05 \leq Co \leq 5.0$	$Co > 5.0$	
	Copper (mg/l)	$Cu < 0.2$	$0.2 \leq Cu \leq 5.0$	$Cu > 5.0$	
	Iron (mg/l)	$Fe < 5.0$	$5.0 \leq Fe \leq 20.0$	$Fe > 20.0$	
	Lead (mg/l)	$Pb < 5.0$	$5.0 \leq Pb \leq 10.0$	$Pb > 10.0$	
	Lithium (mg/l)	$Li < 2.5$	$2.5 \leq Li \leq 5.0$	$Li > 5.0$	
	Manganese (mg/l)	$Mn < 0.2$	$0.2 \leq Mn \leq 10.0$	$Mn > 10.0$	
	Molybdenum (mg/l)	$Mo < 0.01$	$0.01 \leq Mo \leq 0.05$	$Mo > 0.05$	
	Nickel (mg/l)	$Ni < 0.2$	$0.2 \leq Ni \leq 2.0$	$Ni > 2.0$	
	Selenium (mg/l)	$Se < 0.01$	$0.01 \leq Se \leq 0.02$	$Se > 0.02$	
	Zinc (mg/l)	$Zn < 2.0$	$2.0 \leq Zn \leq 10.0$	$Zn > 10.0$	
Miscellaneous effect	Nitrate-nitrogen (mg/l)	$NO_3\text{-}N < 5.0$	$5.0 \leq NO_3\text{-}N \leq 30.0$	$NO_3\text{-}N > 30.0$	1
	Bicarbonate (mg/l)	$HCO_3 < 90$	$90.0 \leq HCO_3 \leq 500$	$HCO_3 > 500$	
	pH	$7.0 \leq pH \leq 8.0$	$6.5 \leq pH \leq 7.0$ and $8.0 \leq pH \leq 8.5$	$pH < 6.5$ or $pH > 8.5$	

Where the concentration for the ions are in milliequivalents per liter.

RSC varies from −6.1 to 12.39 with a mean of 2.5. The positive value of RSC indicates that the cumulative concentration of CO_3^{-2} and HCO_3^- is higher than the combined Ca^{+2} and Mg^{+2} concentration, and a negative value indicates no residual carbonate (Romanelli et al. 2012).

Trace element Although the presence of trace elements in low concentration is essential for plants and animals, higher values are considered to be toxic even for humans. Trace elements, such as arsenic, selenium, lead, cadmium, chromium, and barium, pose serious threats to groundwater supplies because the increased concentrations of these elements in the upper layer of the soil could be transported to the lower layer and eventually to the groundwater with the infiltrating water.

Miscellaneous effects Nitrate is the most available form of nitrogen, which occurs frequently in irrigation water. Anthropogenic activities such as agricultural processes, application of nitrogen-rich fertilizers, and septic tanks increase the nitrate concentration especially in groundwater. Sensitive crops may be affected by nitrate-nitrogen above 5 mg/l, but most other crops are not affected even by nitrogen content of up to 30 mg/l (FAO 1994).

Alkalinity is the measure of the acid-neutralizing capacity of water and occurs due to the presence of carbonate and bicarbonate in water. A high level of carbonate causes the calcium and magnesium ions to form insoluble minerals, leaving sodium as the main ion in the solution. Thus, it is possible to develop both salinity and alkalinity conditions in the soil. Moreover, Zn deficiencies are usually associated with alkaline soils and occur in soils with pH greater than 7.0, a low level of Zn, and a high amount of bicarbonate (Hajiboland and Salehi 2006). It causes some symptoms in rice; leaves develop brown blotches and streaks that may fuse to cover older leaves entirely, plants remain stunted and in severe cases may die, while those that recover will show substantial delay in maturity and a reduction in yield (Wissuwa et al. 2006). Zinc deficiency in rice is widespread throughout Asia in natural to alkaline calcareous soils, which contain more than 1 % organic matter (Forno et al. 1975). Acidity or alkalinity of water is dependent on pH levels. Soil quality, plant productivity, and growth could be influenced by the role of pH values on the carbonate equilibrium, heavy metal content, and the ratio of nitrogen components.

Irrigation groundwater quality index (IWQ index) A linear combination of hydrochemical groups (Table 2) is utilized as an index method to classify irrigation waters with respect to irrigation water quality. The hydrochemical parameters are chosen based on the Ayers and Westcot (1985) and Simsek and Gunduz (2007) methods, and modified based on the groundwater condition in the study area. In the index methodology, each of the hazard groups (Table 2) is given a specific weight from 1 (least significant group in irrigation water quality) to 5 (most significant group in irrigation water quality).

$$W_i = \frac{w}{N} \sum_{i:1}^{N} R_i \tag{3}$$

$$\text{IWQ Index} = \sum W_i \tag{4}$$

The maximum weight of 5 has been assigned to EC in the salinity hazard class due to its important role in irrigation water quality assessment. Nitrate, bicarbonate, and pH are given the minimum weight of 1 as they are considered the least important influences on irrigation water quality. The other hazard classes were assigned a weight between 1 and 5 depending on their importance in the overall irrigation water quality. The quality rating scales are ranged from 1, high suitability for irrigation, to 3, low suitability for irrigation, for each parameter as in Table 1. The proposed IWQ index, to assess the combined impact of irrigation water quality parameters, is calculated as in Eqs. 3 and 4; where *i* is an incremental index, *W* is the contribution of each one of the five hazard categories that are important to assess the quality of irrigation water, *w* is the weight value of each hazard category, *N* is the total number of water quality parameters in each hazard category, and *R* is the rating value of each parameter as given in Table 2. Computed IWQ index values are usually classified based on the suitability for irrigation consumption (Table 1). The minimum possible IWQ index is 14.94, which represents excellent suitability for irrigation, and the maximum possible index is 44.97, which indicates unsuitable conditions for irrigation, based on the irrigation water quality parameters in Table 1.

Hydrogeological data

Although the IWQ index is an important factor to assess groundwater potential for irrigation, it is not sufficient for delineating groundwater suitability zones for irrigation purposes. Therefore, hydrogeological factors, namely, slope angle, aquifer thickness, and hydraulic conductivity, are applied to determine water availability and local extraction of groundwater resources.

Hydraulic conductivity is the ability of the aquifer formation to transmit water, which depends on the intrinsic permeability of the material and on the degree of saturation (Rahman 2008). The aquifer with higher conductivity is vulnerable to substantial contamination, due to the rate of groundwater flow which controls the rate of contaminant movements into groundwater. Hydraulic conductivity was measured after dividing transmissibility from aquifer pumping test data into the thickness of the saturated zone (Eq. 5).

$$K = \frac{T}{b} \tag{5}$$

K is the hydraulic conductivity of the aquifer (m/day), *T* is the transmissivity (m^2/day), and *b* is the thickness of the aquifer (m). The hydraulic conductivity map was classified into five categories from the values less than 4 m/day to greater than 41 m/day.

The aquifer thickness is an indirect estimation of groundwater quantity assuming homogenous hydraulic conditions (Romanelli et al. 2012). In the sedimentary rocks, the saturated thickness of the aquifer can be determined from the borehole data and water table level of the study area. The aquifer thickness values are classified from thin layers (less than 10 m) to thick layers (greater than 30 m) (Table 1).

Slope influences the potential of groundwater contamination by increasing runoff or infiltration. Infiltration increases in lower slope angles where a slope angle of less than 1° has been shown to reduce water drainage and increase the probability of soil salinity and alkalinity, which leads to an agricultural productivity problem (Romanelli et al. 2012). Agricultural lands, residential areas, and industrial activities are usually developed in flat zones and are always exposed to polluted runoff to the groundwater. Generally, the best quality of groundwater may be found in areas of higher elevation where the slopes are characterized by well-developed drainage features known as recharge zones. Therefore, following this assumption, the slope categorize into four classes in terms of suitability for agricultural purposes (Table 1).

Results and discussion

Assessment of hazard groups

Generally, water quality index aims to reduce the large amount of water quality data to a single numerical value. Water samples may have hundreds of constituents. WQI becomes complicated if all the constituents are applied in the index. Therefore, it is significant to select the appropriate parameters which reflect the accurate overall water quality, based on the research purposes. In the present study, the irrigation groundwater quality (IWQ) index covered 23 hydrochemical variables, which are classified into five hazard groups (Table 2), for assessing groundwater quality for irrigation purposes. Each hazard group was assigned a weight between 1 and 5 based on its effect on water quality. A maximum weight of 5 was assigned to salinity hazard, which is measured by electrical conductivity.

Electrical conductivity ranges between 659 and 3120 μS/cm, with a mean of 1238.2 μS/cm in the Amol-Babol Plain (Table 3). Just 3.1 % of the sampling wells show EC values <700 μS/cm, which falls within the good category. Moderate salinity waters (700–3000 μS/cm) are the dominant feature, corresponding to 94.6 % of the total agriculture sampling wells. The samples with limited salinity (less than 2.3 %) were followed by high salinity water (>3000 μS/cm). The groundwater quality could be influenced by Caspian Sea water intrusion in the northern side or fossil saline water in the northeast side of the plain.

Although water mostly contains calcium, magnesium, and bicarbonate, the concentrations of sodium, magnesium, and bicarbonate increase gradually when the water flows across alluvial sediments from highlands to the coastal area. Lower concentrations of EC in the groundwater are expected in the west and southwestern parts (near the Amol City), where fossil saline water had been washed through Haraz's homogenous alluvial sediments by the Haraz River. Moreover, the high discharge rate of the Haraz River (near 34 m^3/s) prevents the Caspian Sea water intrusion into fresh groundwater in the northeastern part of the study area. Based on the geophysical investigation, fossil saline water was still trapped between the sediment layers in the eastern and northeastern parts due to the weak discharge of the Talar River and the heterogeneous structure of alluvial fan in this part of the plain (Fakharian 2010).

Table 3 Statistical summary of hydrochemical parameters

Parameter	Minimum	Maximum	Mean	Standard deviation
EC	659.70	3120.00	1238.16	468.213
SAR	0.21	10.70	2.12	1.860
RSC	−6.09	12.39	2.51	2.674
B	0.02	0.40	0.13	0.080
Cl	33.00	475.00	193.00	111.614
Al	0.05	4.18	0.65	0.936
As	0.00	0.04	0.00	0.006
Br	0.00	0.00	0.00	0.000
Cd	0.00	0.00	0.00	0.000
Cr	0.01	0.02	0.01	0.002
Co	0.00	0.03	0.00	0.003
Cd	0.00	0.00	0.00	0.000
Fe	0.01	8.21	1.54	2.074
Pb	0.00	0.02	0.00	0.003
Li	0.00	0.03	0.01	0.006
Mn	0.03	3.52	0.58	0.596
Mo	0.00	0.02	0.00	0.003
Ni	0.00	0.08	0.01	0.011
Se	0.00	0.01	0.00	0.002
Zn	0.00	0.66	0.04	0.071
NO3	0.02	17.80	2.84	3.696
HCO3	230.00	928.00	465.84	138.343
Ph	6.41	7.48	6.80	0.175

Infiltration hazard is measured by sodium absorption ratio (SAR) and was given the weight of 4 as it plays an important role in irrigation water quality. The SAR values change from 0.21 to 10.7, with a mean value of 2.12 in the plain (Table 3). Approximately 97.8 % of samples have SAR values of less than 10, representing an excellent quality of water. Just two sampling wells in the northeastern side have SAR ranges from 10 to 18, which is classified in the good category. Doubtful and unsuitable concentrations of SAR were not detected in the study area.

Residual sodium carbonate (RSC), chloride, and boron are defined as the features of specific ion toxicity (Table 2). This third hazard group was given the weight 3. Based on Eq. 3, the specific parameter's weight in this group was computed from the divided group weight to the number of group parameters, which indicates the corresponding weight value would be 1 for each parameter in the third group. RSC varies from −6.1 to 12.39 with a mean of 2.5 (Table 3). The positive value of RSC indicates that the cumulative concentration of CO_3^{-2} and HCO_3^- is higher than the combined Ca^{+2} and Mg^{+2} concentration, and a negative value indicates no residual carbonate (Romanelli et al. 2012). Approximately 48 % of the samples fall within the unsuitable water quality for irrigation due to the extent of calcite and dolomite rocks in the recharge area.

About 37.3 and 14.7 % of samples correspond to good and moderate categories, respectively. The boron concentrations in groundwater vary from 0.02 to 0.41 mg/l, with a mean value of 0.13 mg/l (Table 3). All the groundwater samples fall within the suitable categories (<0.7 mg/l). Therefore, all the samples were found to be excellent for sensitive, tolerant, and semi-tolerant crops in the study area. Chloride values range from 33 to 475 mg/l with a mean value of 193 mg/l in the groundwater of the study area (Table 3).

About 49 % of the samples have chloride values ranging from 140 to 350 mg/l corresponding to moderate categories. Approximately 38 % of the total samples showed a suitable concentration of chloride (less than 140 mg/l). Just 12.7 % of samples fall within the unsuitable concentration of chloride (>350 mg/l) in groundwater, mostly observed in the east and northeastern side of the plain, because of the existence of fossil saline water between sediment layers.

The weight of 2 was assigned to the trace element toxicity group. The corresponding weight of each trace element is

0.13, which is calculated from the division of group weight (2) to the number of trace elements (15). Trace elements analysis indicates that manganese and iron contain concentrations of more than the FAO (1994) standard (Table 2). Manganese concentrations range from 0.03 to 3.51 mg/l with a mean of 0.58 mg/l. Approximately 62.7 % of the sampling wells had moderate (0.2–10 mg/l) magnesium concentration. Magnesium concentration higher than 10 mg/l (unsuitable category) was not detected in the sampling points. About 10.6 % of sampling wells show iron concentration ranging from 5 to 20 mg/l; this corresponds to moderate categories, similar to the magnesium concentration in the study area. Manganese and iron are metals that occur naturally in soils, rocks, and minerals. Natural processes, such as seawater intrusion and dolomite rock weathering, and human activities, such as mining and agricultural activities, are possible sources of manganese in groundwater. The highest concentrations of manganese are mostly found in the north side of the plain, which can be related to sources from saline intrusion of seawater in this area. Based on this consideration, the other trace elements concentrations fall within the good category and the values higher than limited standards (Table 2) were not detected in the sampling wells.

Nitrate, bicarbonate, and pH are classified as miscellaneous effects and specified by weight of 0.33 for each group parameter. The nitrate concentrations were in the range 0.02 to 17.9 mg/l, with 19.2 % of samples having nitrate concentrations above the 5 mg/l, and classified as moderate. Although high nitrate values in water ($NO_3^- > 30$) were not found in the sampling wells, excessive agricultural activities in the plain and the existence of shallow wells (less than 30 m) increases the risk of water pollution by nitrate in the study area. The bicarbonate concentrations vary from 230 to 928 mg/l, with a mean value of 465.8 mg/l in the study area. Moderate bicarbonate values (90–500 mg/l) are predominant, corresponding to 62.8 % of the total sampling wells, followed by high bicarbonate concentration (greater than 500 mg/l) occupying 35.2 % of the samples. Dissolution of all minerals results in the increase of HCO_3^- concentration in groundwater, thus increasing the soluble sodium percentage in irrigation water, which poses a sodium hazard to the soil of the plain. The normal pH values of irrigation water ranges from 6.5 to 8.4 (FAO 1994), but the ideal values lie between 7.0 and 8.0 (Simsek and Gunduz 2007). Water or soil solution with a pH higher than 8.5 can result in nutrient deficiencies, whereas low pH might result in micronutrient toxicities and damage to the plant's root system.

Irrigation water quality index

Irrigation water quality index was developed from 23 thematic layers using overlay and index methods. IWQ index was classified into five categories, from excellent (<21) to unsuitable (>39) irrigation water quality (Table 1). The computed index values range from 17.9 (excellent quality) to 34.1 (doubtful quality) for the groundwater of Amol-Babol Plain. The spatial distribution map of the IWQ Index reveals that the majority of the study area (82.7 %) has a good index value (21–27) (Fig. 3 and Table 4).

About 85.1 km^2 (4.7 %) shows an excellent index (<21) for irrigation water quality. It is observed that the excellent and good IWQ Indices covered mostly the eastern, western, south-

Fig. 3 IWQ index map of Amol-Babol Plain

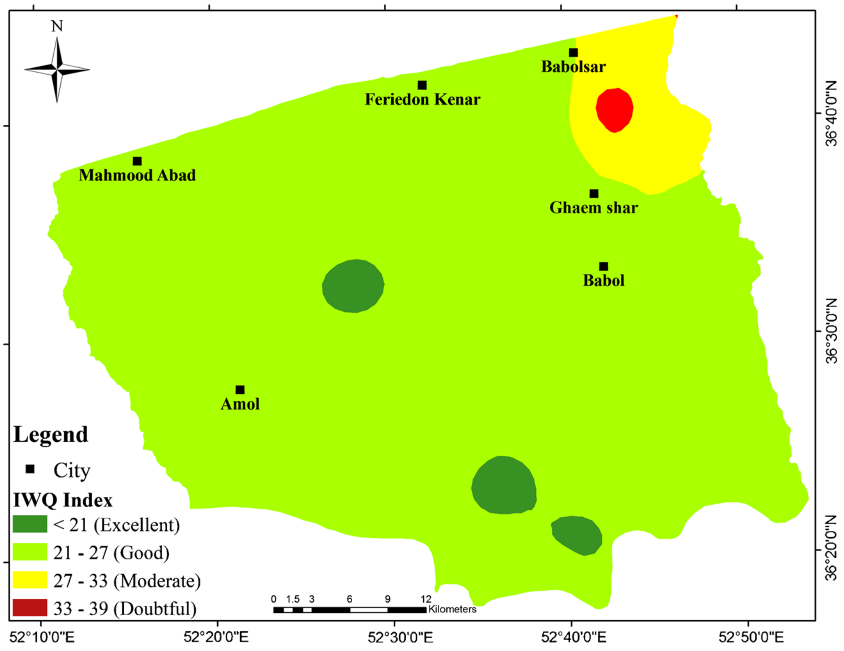


Table 4 Obtained area and percentage of the different IWQ index and hydrogeological factors

Index	Classification	IWQ index		Slope		Hydraulic conductivity		Aquifer thickness	
		Area	%	Area	%	Area	%	Area	%
1	Excellent	85.1	4.7	69.43	3.8	702.01	38.52	–	–
2	Good	1506.7	82.7	102.07	5.6	1050.6	57.7	1811	99.39
3	Moderate	210.2	11.5	156.2	8.57	69.39	3.78	10.6	0.58
4	Doubtful	20	1.1	1515.5	82.03	–	–	0.4	0.021
5	Unsuitable	–	–	–	–	–	–	–	–

eastern, and central sides of the plain (Fig. 3). Approximately 11.5 % of the total area (210.2 km^2) shows a moderate IQW index (27–33). Just 1.1 % of the total area (20 km^2) has doubtful IQW Index. The doubtful and moderate IWO indices were located in the northeastern section where the seawater intrusion, fossil saline water, and land use activities frequently influenced the groundwater quality. Based on the index map, it could be concluded that the groundwater quality is generally in a good condition to be used for irrigation in the plain (Fig. 3).

Hydrogeological factors

Slope

The Amol-Babol Plain extends between the Alborz Highlands on the southern side to the Caspian Sea in the north. The slope angle ranges from 0 to 82°. Nearly 1515.5 km^2 (82.03 % of the total area) exhibits a "Doubtful" (<1°) range, which indicates that flat alluvial plain covers most parts of the study area (Fig. 4). Less than 4 % of the total area (around 69 km^2) has the steepest slope, which is classified as an excellent water suitability for agricultural usage and covers areas near the highlands in the southern side of the plain (Fig. 4).

Hydraulic conductivity

In general, hydraulic conductivity ranges from 0.04 to 16.4 m/day in the plain and increases gradually from the north side to the southern side (Fig. 5). The raster map was classified into five stratifications (Table 1), which shows that the class of good suitability for irrigation covers 57.7 % (near 1051 km^2) of the plain (Fig. 5 and Table 4).

In the northern area, about 38.5 % of the total area (702 km^2) can be categorized as excellent with the hydraulic conductivity lower than 4 m/day. Similar to flat and smooth topography, the hydraulic conductivity shows insignificant variations. The higher values (28–41 m/day) correspond to the "doubtful" and higher than 41 m/day instances, as the "unsuitable" category was not observed in the study area (Fig. 5).

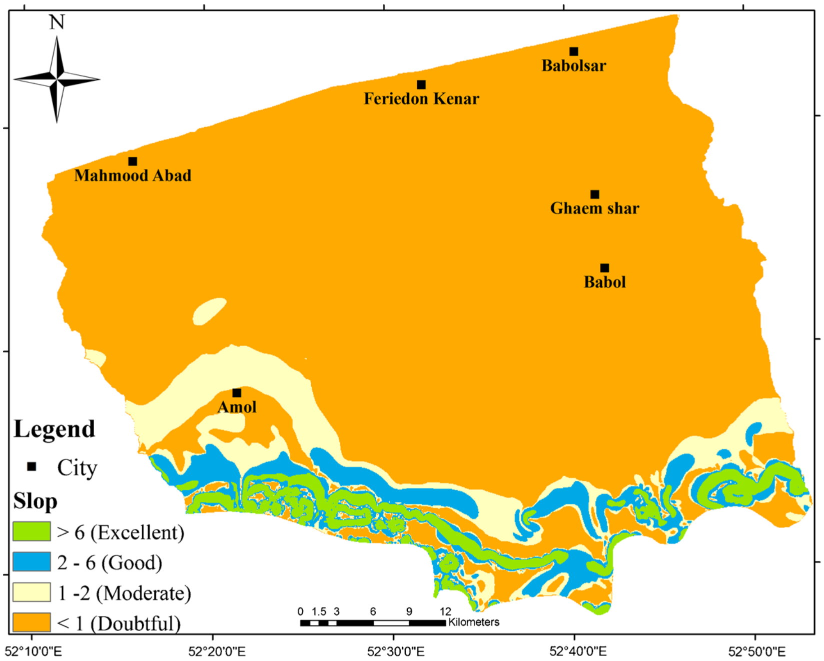


Fig. 4 Slope angle map of Amol-Babol Plain

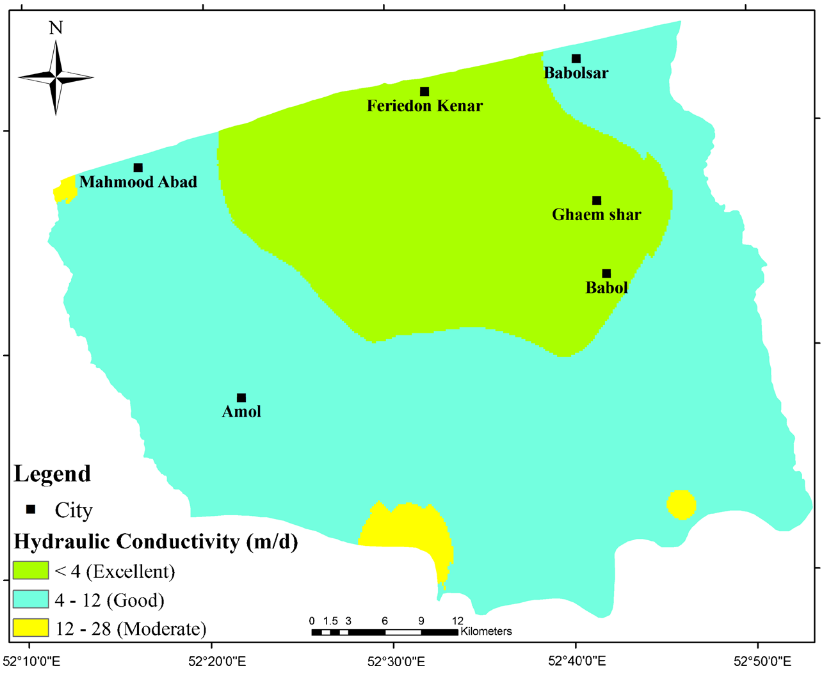


Fig. 5 Hydraulic conductivity of Amol-Babol Plain

Aquifer thickness

The aquifer thickness ranges from less than 10 m in the north coastal area to more than 200 m for the Haraz alluvial fan on the western side. Based on the irrigation water suitability classification (Table 1), an aquifer with higher thickness values (more than 30 m) indicates good to excellent potential for irrigation purposes. The map shows that nearly 99 % of the total area (around 1811 km^2) is classified in good category (Fig. 6).

The aquifer alluvial have been formed mostly by the weathering of rocks and river sedimentation, which made homogenous alluvial fans in the western side (around Haraz City) and heterogeneous alluvial fans in the eastern side, between Babol River and Talar River (Fig. 6). A limited area (around 10.6 km^2) on the coastline shows the aquifer thickness varying between 10 and 30 m, which is falling within the "moderate" category for irrigation purposes (Table 4).

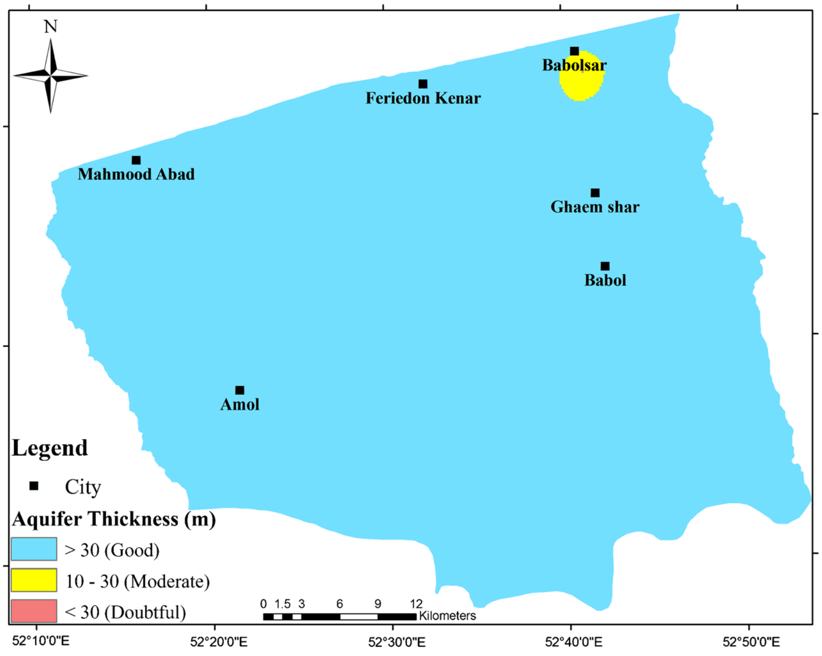


Fig. 6 Aquifer thickness of Amol-Babol Plain

Table 5 Classification and abundance of groundwater suitability index

Groundwater suitability for irrigation	Excellent	Good	Moderate	Doubtful	Unsuitable
Suitability index	<7	8–10	11–13	14–16	16<
Area (km^2)	59.1	1662	101.9	–	–

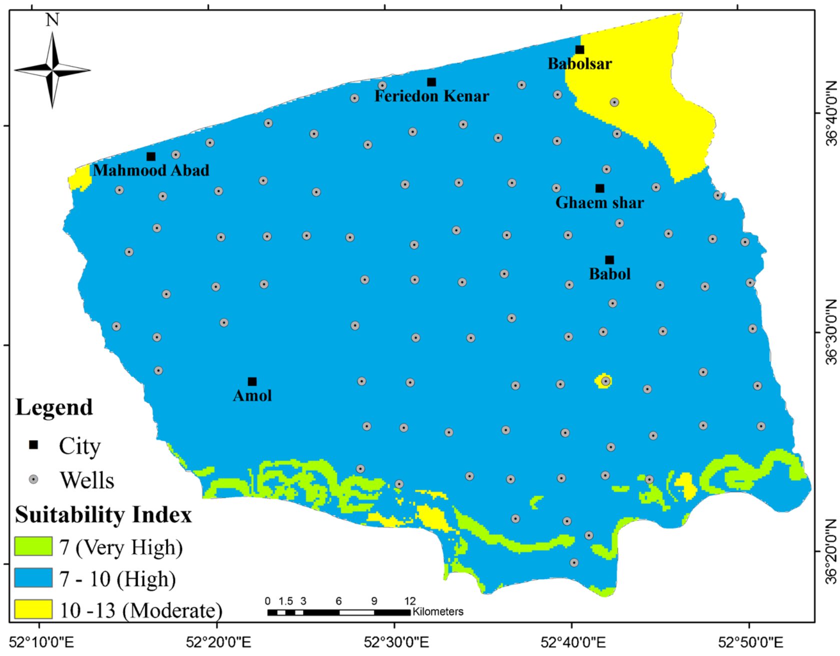
Groundwater suitability zoning

The computed suitability index value, by applying the IWQ index map and hydrogeology indices maps, varies from 7 to 13 in the study area, which are classified as having very high, high, and moderate suitability for irrigation purposes (Table 5). About 59.1 km^2 (3.2 %) of the total area has very high suitability for irrigation (Table 5). The corresponding area is considered to have the minimum level of problems and damaging effects with respect to irrigation quality. Moreover, the wells were drilled in a good hydrogeological area for water exploitation. This highly suitable area lies on the southern side in the Alborz hillside, where the groundwater quality is mostly influenced by the recharge zone in the Alborz Highlands and far away from the Caspian Sea on the north side of the plain (Fig. 7). In this area, the aquifer thickness is mostly higher than 100 m, and deep wells were drilled for irrigation purposes, which have less risk of pollution from runoff from agricultural and residential lands.

The majority of the study area (1622 km^2) is classified as a high suitability zone for irrigation purposes. These areas are mostly located in the central, western, and eastern parts of the plain where the alluvial fans of Haraz, Babol, and Talar have developed high potential and fertile soils for agricultural activities (Fig. 7). Generally, all the areas are agriculture-intensive activity lands with proximity to residential areas. Rice cultivation by traditional methods is the dominant agricultural activity in these areas, which uses vast amounts of water resources. Long-term farming activities at the current level can increase the harmful impact to water quality. Moreover, the amount of pollution could be significant because of the shallowness between the water table and surface land in the northern side of the study area.

Extensive exploitation of groundwater by farmers has resulted in the decline of the water table during recent years (Shahbazi and Esmaeili-Sari 2009) and can increase the risk of Caspian Sea water intrusion into the coastal aquifer in the plain. Approximately 5.6 % of the total area (101.9 km^2) shows moderate suitability for irrigation purposes. The soil and groundwater quality could be threatened by anthropogenic contamination and salinity problems. Moreover, the quality and quantity of groundwater resources could be negatively influenced by the hydrogeological conditions. This area corresponds to the Talar river alluvial in the northeast where saline water intrudes into coastal fresh water due to minor elevation differences between the Caspian Seawater and groundwater (Mahab 2004). In this area, over abstraction of freshwater has decreased the groundwater level and led to fossil saline water contaminating the fresh water. Groundwater utilization and management policies should be implemented to avoid the increase of salinity in the

Fig. 7 Groundwater suitable zones for irrigation purpose



groundwater and soil in this area. Effective drainage networks and proper irrigation systems are required to limit or prevent the salinity problem.

Conclusions

In this study, a GIS-index method is introduced to assess the suitability zones of groundwater for irrigation purposes, using the irrigation water quality parameters and hydrogeological factors. The proposed methodology considers water quality and accessibility together with regards to the potential soil and crop problems. Irrigation water quality (IWQ) index was computed using a linearly combined method based on the physiochemical quality parameters, as well as some significant trace elements, instead of applying individual parameters. The IWQ index map clearly demonstrates the spatial distribution of the quality patterns of the study area in a fairly simple method even for the non-technical decision maker. A proper irrigation management framework should be considered for the significant role of the intensive abstraction and utilization of freshwater to decline the aquifer water table, which mostly increases the risk of salt water intrusion to the wells.

Therefore, the aquifer thicknesses, groundwater hydraulic conductivity, and slope of the plain were applied to investigate the potential aquifer's water for irrigation extraction in the study area. The GIS-Index technique integrated different proposed indices for assessing and mapping the groundwater suitability for irrigation purposes. Although the IWQ index map shows that more than 87 % of the study area contains excellent and good quality groundwater for irrigation, approximately 12 % of the total area has only a moderate to doubtful quality for irrigation purposes in the north eastern side of the plain. Based on the hydrogeological investigation results in the northeastern side, saline seawater and fossil water are intruding to the aquifer fresh water due to minor elevation differences between the sea and groundwater, and the unsustainable extraction of groundwater.

Due to these circumstances, the northeastern side of the plain is classified as having “moderate” suitability for irrigation based on the groundwater suitability index map, and the rest of the area (more than 94 % of the total area) is classified as having excellent and good groundwater suitability for irrigation usage. However, groundwater management policies are required to prevent soil and water deterioration due to intensive agricultural activities and over extraction of groundwater in the study area.

Acknowledgments The authors acknowledge the Soil and Water Pollution Bureau of Department of Environment (DOE) in Iran for their financial support through a contract with Amirkabir University of Technology (AUT), Tehran, Iran. The financial support by DOE and the laboratory data and analyses provided by AUT are gratefully acknowledged. Special thanks are due to Mr. A. S. Mohammadlou for his sincere cooperation in providing the data.

Compliance with ethical standards

Conflict of interest We certify that there is no actual or potential conflict of interest in relation to this article.

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