Arab J Geosci
DOI 10.1007/s12517-014-1668-4

ORIGINAL PAPER

Groundwater potential mapping at Kurdistan region of Iran using analytic hierarchy process and GIS

Omid Rahmati · Aliakbar Nazari Samani · Mohamad Mahdavi · Hamid Reza Pourghasemi · Hossein Zeinivand

Received: 8 April 2014 / Accepted: 7 October 2014

Abstract Multi-criteria decision analysis (MCDA) as an advantageous tool has been applied by various researchers to improve their management ability. Management of groundwater resource, especially under data-scarce and arid areas, encountered a lot of problems and issues which drives the planers to use of MCDA. In this research, a standard methodology has been applied to delineate groundwater resource potential zonation based on integrated analytical hierarchy process (AHP), geographic information system (GIS), and remote sensing (RS) techniques in Kurdistan plain, Iran. At first, the effective thematic layers on the groundwater potential such as rainfall, lithology, drainage density, lineament density, and slope percent were derived from the spatial geodatabase. Then, the assigned weights of thematic layers based on expert knowledge were normalized by eigenvector technique of AHP. To prepare the groundwater potential index, the weighted linear combination (WLC) method was applied in GIS. Finally, the receiver operating characteristic (ROC) curve was drawn for groundwater potential map, and the area under curve (AUC) was computed. Results indicated that the rainfall and slope percent factors have taken the highest and lowest weights, respectively. Validation of results showed that the AHP method (AUC=73.66 %) performed fairly good predication accuracy. Such findings revealed that in the regions suffering from data scarcity through the MCDM methodology, the planners would be able to having accurate knowledge on groundwater resources based on geospatial data analysis. Therefore, the developing scenario for future planning of groundwater exploration can be achieved in an efficient manner.

Keywords Groundwater potential mapping · AHP · Remote sensing · Geographic information systems · Iran

O. Rahmati (✉) · A. Nazari Samani · M. Mahdavi
Faculty of Natural Resources, University of Tehran, Tehran, Iran
e-mail: Omid_Rahmati@ut.ac.ir

O. Rahmati
e-mail: Orahmati68@gmail.com

A. Nazari Samani
e-mail: aknazari@ut.ac.ir

M. Mahdavi
e-mail: Mahdavy@ut.ac.ir

H. R. Pourghasemi
Department of Natural Resource and Environment, College of Agriculture, Shiraz University, Shiraz, Iran
e-mail: hamidreza.pourghasemi@yahoo.com

H. Zeinivand
Faculty of Natural Resources, University of Lorestan, Lorestan, Iran
e-mail: hzeinivand@gmail.com

Introduction

Groundwater is considered as the main portion of the water supply in arid and semi-arid regions. In these environments, complexity of the groundwater management is increased when these regions face scarcity of data (Bastani et al. 2010). Moreover, their groundwater resources can hardly meet an increasing demand driven by population growth, improved living conditions, and economic development (Vaux 2011; Mukherjee et al. 2012; Page et al. 2012).

Two thirds of Iran's landmass is considered a desert land devoid of forests and green pastures. Such a harsh environmental condition and water scarcity have mostly led Iranian people to rely on groundwater resources instead of surface water (Baghvand et al. 2010; Bastani et al. 2010; Nosrati and Eeckhaut 2012). However, having knowledge on groundwater resources and potential mapping always need sophisticated costly instruments as well as methodology. Groundwater potential prediction using a standard method is necessary for

Published online: 24 October 2014

groundwater resource management, especially in data-scarce areas. From a groundwater exploration viewpoint, the term 'groundwater potential' can be defined as the possibility of groundwater occurrence in an area (Jha et al. 2010). The traditional approaches of groundwater exploration through drilling, hydro-geological, geological, and geophysical methods are extremely costly, are time-consuming, and require skilled manpower (Todd and Mays 1980; Roscoe, Moss Co 1990; Israil et al. 2006; Jha et al. 2010).

The advent of geographic information system (GIS) and remote sensing (RS) has also provided another cost and time effective means of groundwater potential mapping (Godebo 2005; Jha and Peiffer 2006; Prasad et al. 2008; Pradhan 2009; Arkoprovo et al. 2012; Davoodi Moghaddam et al. 2013; Manap et al. 2013; Nampak et al. 2014). GIS is an excellent and useful tool to handle huge amount of spatial data and can be used in the decision making process in a number of fields such as hydrology and environmental management (Gogu et al. 2001; Brunner et al. 2004; Bandyopadhyay et al. 2007; Jha et al. 2007; Jha and Chowdary 2007; Chowdhury et al. 2009; Gaur et al. 2011; Magesh et al. 2012). It is because of the quick access to data obtained through global positioning systems and RS techniques (Ganapuram et al. 2009; Zare et al. 2013). Although satellite imagery cannot directly detect groundwater, the surface features prepared from such imagery (e.g., landforms and fractures) act as indicators of groundwater potential prediction (Vittala et al. 2005; Jha and Peiffer 2006; Adiat et al. 2012; Hammouri et al. 2012).

Several studies have been applied using index-based methods for assessing groundwater potential mapping (Solomon and Quiel 2006; Prasad et al. 2008; Dar et al. 2010; Elewa and Qaddah 2011; Manap et al. 2012). In some studies, probabilistic models such as frequency ratio (FR) (Oh et al. 2011; Davoodi Moghaddam et al. 2013), weight of evidence (WofE) (Corsini et al. 2009; Lee et al. 2012a), evidential belief function (EBF) (Mogaji et al. 2014), logistic regression (LR) (Ozdemir 2011), Shannon's entropy (Naghibi et al. 2014), and analytical hierarchy process (AHP) (Machiwal et al. 2011; Adiat et al. 2012; Shekhar and Pandey 2014) have been used for groundwater potential mapping.

Over the past decades, many researchers have found that methods of multi-criteria decision analysis (MCDA) are effective tools for providing a framework for groundwater resource management (Pietersen 2006; Madrucci et al. 2008; Jha et al. 2010). The AHP method is one of the most widely used MCDA models, which has also been employed for the environmental management purpose (Pourghasemi et al. 2012a, b; Chandio et al. 2013; Althuwaynee et al. 2014). Interestingly, in using the AHP method, experts can remark on relative importance of thematic layers for assessment of groundwater potential (Hajkowicz and Higgins 2008; Murthy and Mamo 2009; Chowdhury et al. 2010; Kaliraj et al. 2014). Hajkowicz and Collins (2007) reviewed the application of the MCDA methods in water resource management and indicated that the AHP is widespread and growing. Chenini et al. (2010) showed that GIS-based multi-criteria analysis has a good functionality for mapping groundwater recharge zone. As it can be seen in the aforementioned literature, the GIS and AHP methods have been widely used in groundwater potential assessment.

In Iran, more than 70 % of the rural and nearly 50 % of the urban populations depend on groundwater resources for meeting their drinking and domestic requirements (Rahmati 2013). Unfortunately, water scarcity is common in several parts of Iran that will be exacerbated by human activities and global climate change (Ghayoumian et al. 2007; Abbaspour et al. 2009; Ayazi et al. 2010; Zarghami et al. 2011; Hosseini et al. 2012; Neshat et al. 2013). It seems that such conditions are to some extent similar around the arid and semi-arid areas of the world.

The main aim of this study is examine the capability of AHP, GIS, and RS techniques for groundwater potential mapping, and for this purpose, Ghorve–Dehgolan plain of Kurdistan province in western Iran was selected. Assessing the groundwater potential will be helpful to the decision makers in groundwater management and identifying suitable locations for drilling production wells. Because no such studies have been reported in the study area till now, therefore, the current study is the pioneer work in this subject which is crucial for rapid assessing of ground water potential. Also, inadequate public water supply has led to increased demand for groundwater in Kurdistan province during the past decade. Therefore, to understand the groundwater potential, a quick and low expense methodology is needed for preventing the undesirable effects of water resource development.

Description of study area

The aquifer of Ghorve–Dehgolan plain in Kurdistan Province, west of Iran, is located between 47° 10′ E to 48° 8′ E longitudes and 34° 55′ N to 35° 25′ N latitudes (Fig. 1). The total area is 890.3 km^2 inhabited by population number of 300,000. The sources of water supply are surface (river water) and mostly groundwater. Surface water is primarily used for irrigation, while groundwater is used for both irrigation and drinking water purposes via dug wells and pumping wells. From the groundwater availability viewpoint, the inhabitants of the study area have been facing declining groundwater levels for the past few years. In this region, the people's living costs depend on dry farming and irrigated agriculture production. The most common land uses within the study area are residential area, rangelands, and irrigated and dry farming agriculture, accounting for proportions of the total area of 1.2, 3.5, 66.6, and 28.7 %, respectively. Unfortunately, limited

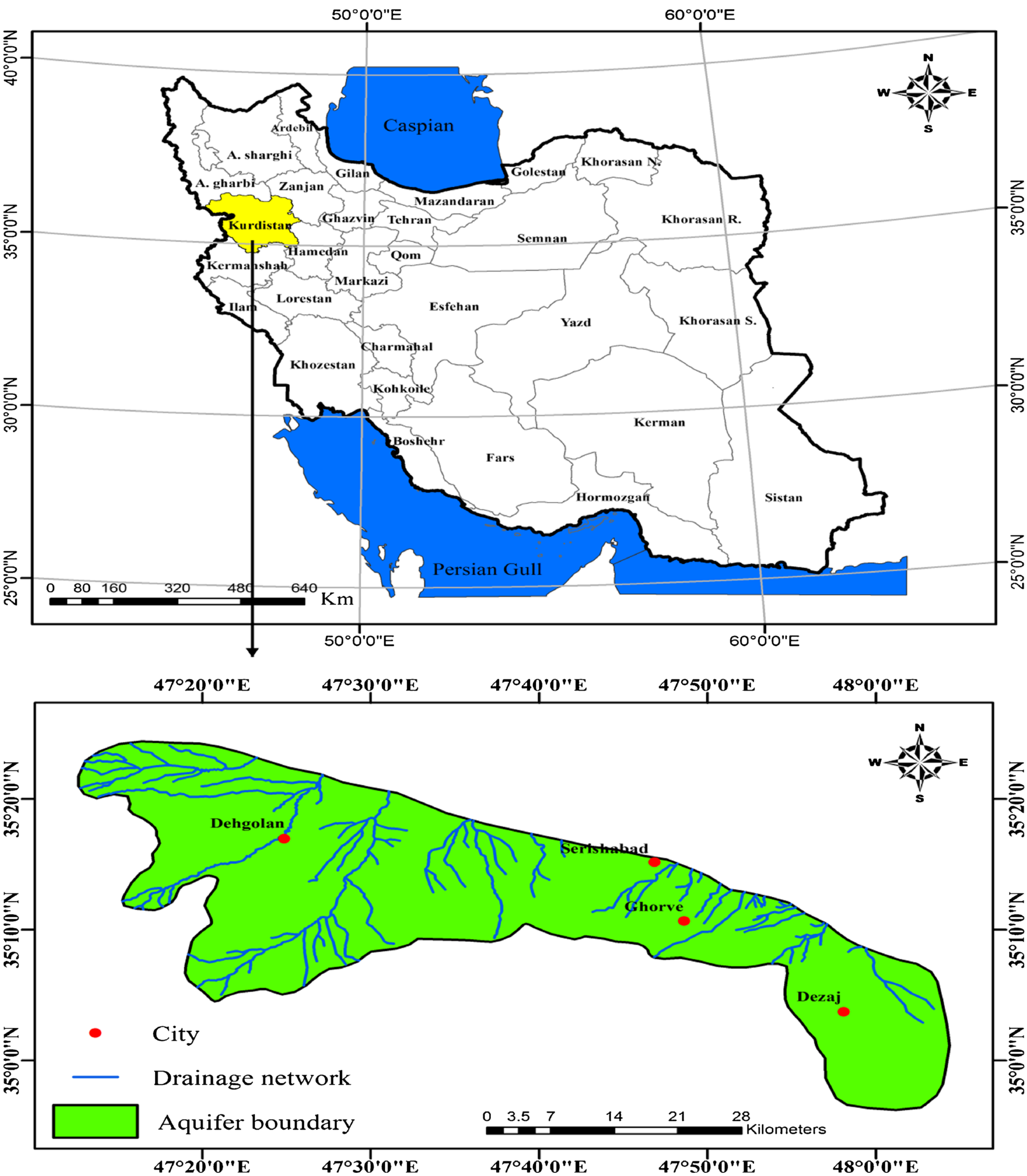

Fig. 1 Location of the study area

studies have been conducted in the study area related to water resource management.

The study area is considered to have a semi-arid climate with an average annual rainfall of 345 mm and an irregular yearly distribution (more than 75 % of the rainfall occurs from December to April). The average daily minimum temperature is 5.5 °C in the winter, and average daily maximum temperature is 36 °C in the summer. The study area is located in Sanandaj–Sirjan structural zone of Iran. The Sanandaj–Sirjan is identified as a region of polyphase deformation, the latest reflecting the collision of Arabia and Eurasia and the subsequent southward propagation of the fold–thrust belt (Alavi 1994). Therefore, the geology of the study area is characterized by geologic structures and fracture systems, which play a role in increasing the permeability of rocks.

Methodology

Selecting thematic layers influencing groundwater potential

The number of thematic layers used depends on the data availability in the study area. In order to assess groundwater potential zones, five thematic layers, viz. rainfall, lithology, drainage density, lineament density, and slope percent, were chosen as the effective factors. Hydrology conditions are largely dependent on these thematic layers and hence influencing the occurrence of groundwater. These thematic layers provide a reliable base for an effective prediction of the groundwater potential of an area. The complete process of the groundwater potential prediction is shown in Fig. 2.

Geospatial database generation

A database was built for managing the used thematic layers in GIS framework. Then, the layers were converted to grid format with grid size of 10 km^2 for the study area using ArcGIS 10.2 software.

Rainfall (Rf)

The rainfall availability was considered as a major source of recharge (Musa et al. 2000; Magesh et al. 2012; Shekhar and Pandey 2014). The rainfall has a significant effect on the groundwater potential and the efficiency of MCDA (Adiat et al. 2012). Monthly rainfall data of ten meteorological stations within the study area for a period of 15 years (i.e., 1996–2010) were obtained from the Iranian Meteorological Organization. The resulting map was classified into five major classes: 266–293, 293–320, 320–347, 347–374, and 374–400 mm/year (Fig. 3a). Based on this map, the average annual rainfall in the elevated areas is relatively more than the area with low elevation.

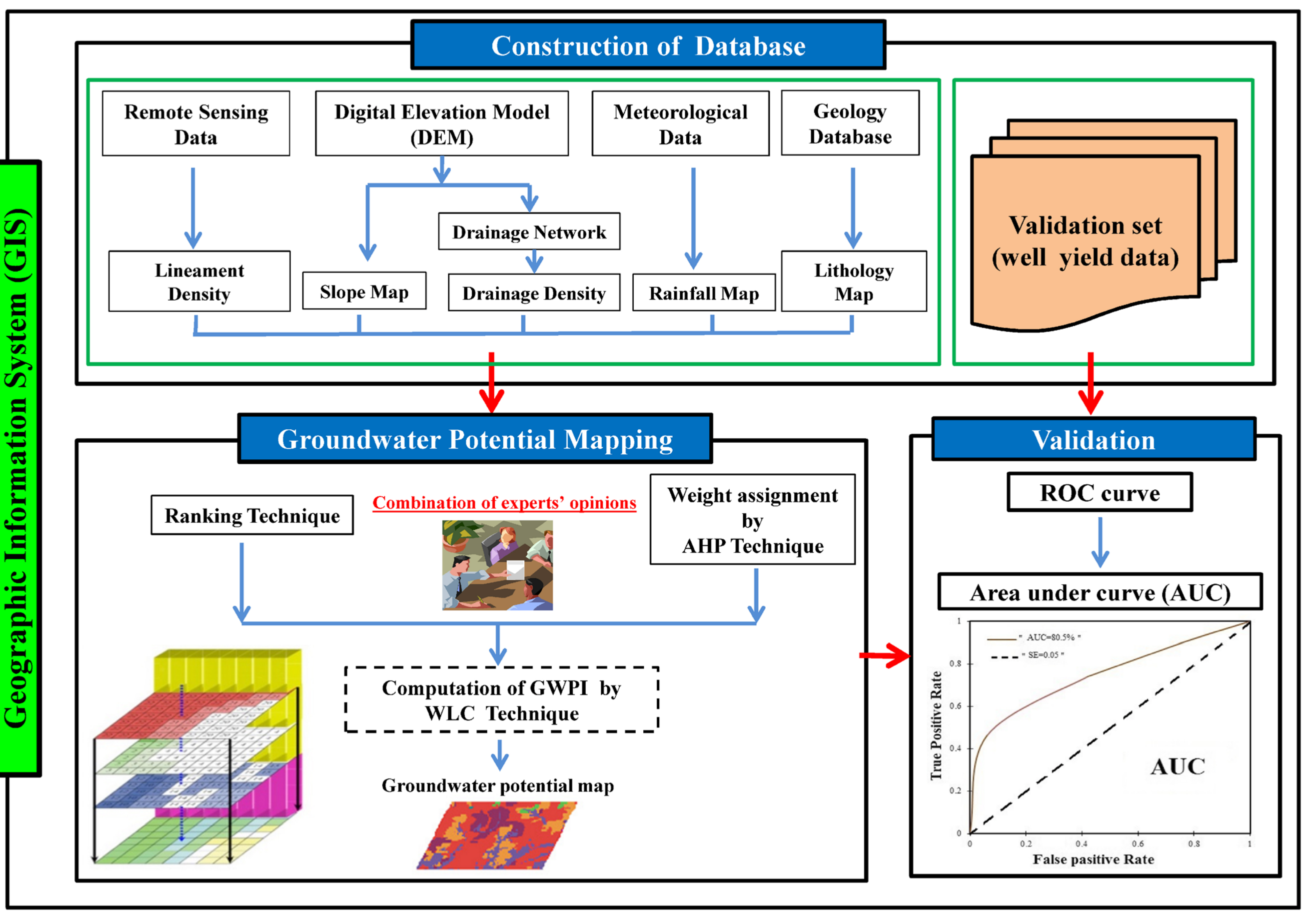

Fig. 2 Flowchart showing the methodology adopted in this study

Lithology (Lt)

The lithology influences on both the porosity and permeability of aquifer rocks (Ayazi et al. 2010; Chowdhury et al. 2010). The occurrence of groundwater is common in quaternary alluvial sediments in the study area. The lithology layer was prepared by digitizing the geological map (Geological Survey Department of Iran, Ghorve sheet at 1:100,000 scale) (Fig. 3b). The lithology of the study area consists mainly of quaternary alluvial, diorite, and diorite–gabbro rocks. The most common quaternary formation includes travertine (Qtr), alluvial fan deposits (Qf), alluvial terraces (Qt2), alluvial-plain deposits (Qt3), and calcareous sandstone with marl sediments. Due to hardness and low fractures, the groundwater movement in diorite and diorite–gabbro rocks is difficult and therefore assumed as a poor groundwater potential (Thakur and Raghuwanshi 2008; Manap et al. 2013).

Drainage density (Dd)

The drainage system of an area is determined by the nature and structure of the bedrock, kind of vegetation, rainfall absorption capacity of soils, infiltration, and slope gradient (Manap et al. 2013). A low-drainage-density region causes more infiltration and decreased surface runoff. It means that areas having low drainage density are suitable for groundwater development (Dinesh Kumar et al. 2007; Magesh et al. 2012).

The drainage system of the study area is shown in Fig. 1. The drainage pattern was extracted directly from ASTER DEM (28*28 m). The surface drainage density is the ratio of the sum of lengths of streams to the size of area of the grid under consideration (Greenbaum 1989; Adiat et al. 2012; Mogaji et al. 2014). Hence, a mesh network (with cell size of 10 km^2) was designed on the study area, and the drainage density index was calculated through Eq. (1).

$$\mathrm{Dd} = \sum_{i=1}^{i=n} \frac{D_i}{A} \left(\mathrm{km}^{-1}\right) \tag{1}$$

where ΣD_i is the total length of all streams in the mesh i (km) and A is the area of the grid (km^2).

The values calculated for each grid was plotted at the center of the grid using ArcGIS 10.2 software. Then, the coordinates of the center of each grid were used to prepare the surface drainage density map by Kriging interpolation technique. Based on the surface drainage density, the study area can be grouped into five classes: 0–0.15 (very low), 0.15–0.3 (low), 0.3–0.45 (moderate), 0.45–0.6 (high), and 0.6–0.77 (very high) km/km^2, as shown in Fig. 3c. The very high drainage density is scattered in the northern part of the study area. The low and very low drainage densities cover majority of the study area.

Lineament density (Ld)

The lineaments are linear features on the Earth's surface that reflect a general surface expression of underground fractures (Pradhan et al. 2006; Pradhan and Youssef 2010). They are categorized as the secondary porosity and visible on satellite images as tonal differences compared to other terrain features. A lineament may represent a fault, fracture, and master joint; a long and linear geological formation; topographic linearity; or straight course of streams (Pradhan 2009). They effect on the infiltration of surface runoff into subsurface and are of great relevance to the storage and movement of groundwater (Subba Rao et al. 2001). Furthermore, Sree Devi et al. (2001) commented that lineaments have more significance in the groundwater studies. Lineaments of the area were extracted from the Landsat ETM$^+$ image using Sobel directional filtering and high-pass directional filtering (Pradhan and Pirasteh 2010) (Fig. 3d). The concentration of lineaments is more in the western part of the study area. In a similar manner to the drainage density, the lineament density (Ld) was calculated based on the mesh network method (Fig. 3e). The Ld was defined as the total length of all recorded lineaments divided by the area under consideration (Edet et al. 1998). This is shown in the following equation:

$$\mathrm{Ld} = \sum_{i=1}^{i=n} \frac{L_i}{A} \left(\mathrm{km}^{-1}\right) \tag{2}$$

where ΣL_i is the total length of all lineaments (km) and A is the area of the grid (km^2). In this study, the lineament density was classified into five classes: <0.02 km/km^2 (very low), 0.02–0.06 km/km^2 (low), 0.06–0.1 km/km^2 (moderate), 0.1–0.17 km/km^2 (high), and 0.17–0.25 km/km^2 (very high).

*Slope percent (**S**)*

The slope percent can be considered as a surface indicator for identification of groundwater conditions (Al Saud 2010; Ettazarini 2007). In other words, these thematic layers can be considered as the surrogate of surface runoff velocity and vertical percolation (i.e., infiltration is inversely related to the slope) and thus affecting recharge processes (Adiat et al. 2012). The slope percent map for the study area (Fig. 3f) was generated from the ASTER DEM image of the area using ArcGIS 10.2 software.

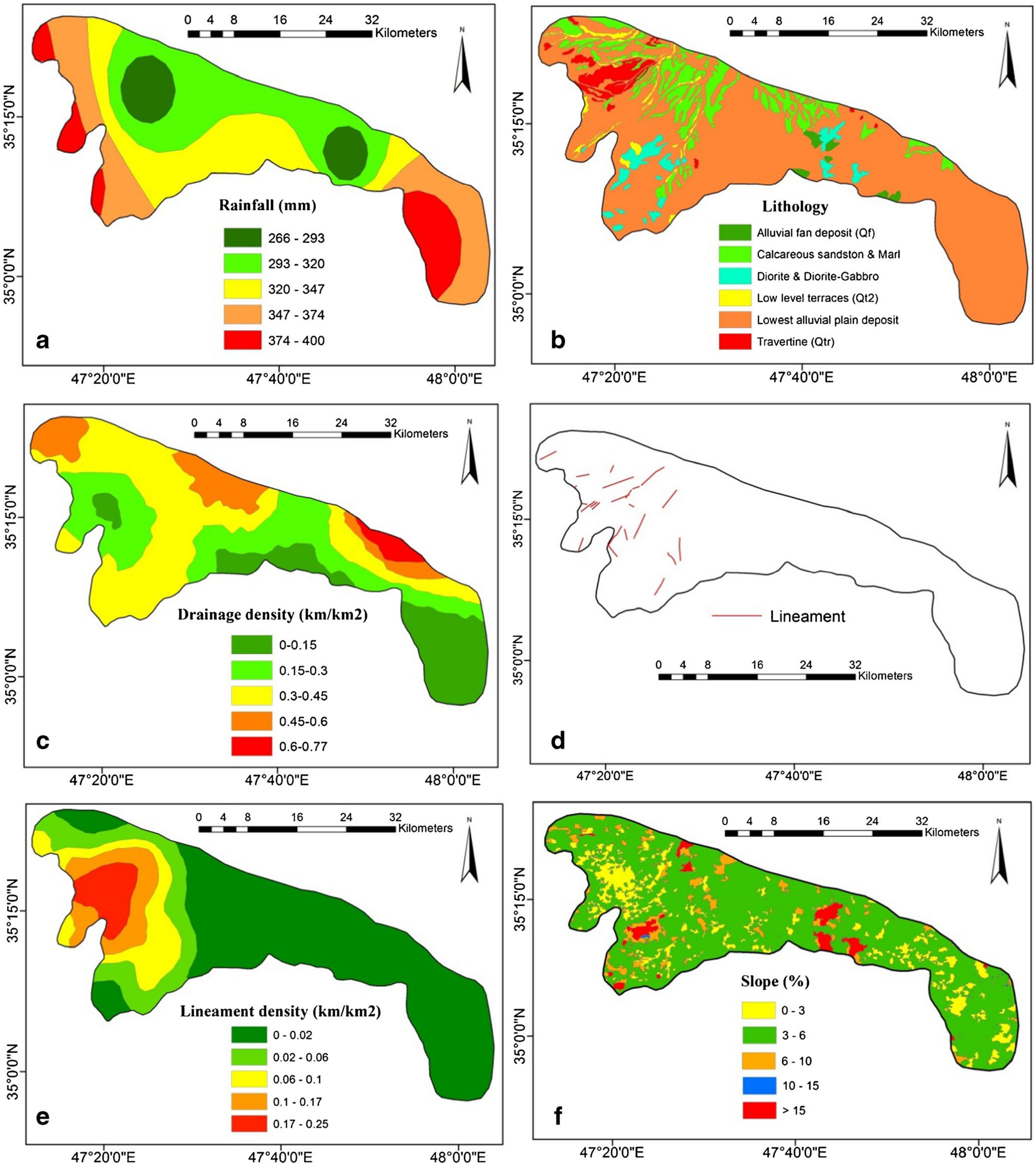

Fig. 3 Thematic layers: **a** annual rainfall, **b** lithology units, **c** drainage density, **d** spatially distribution of lineaments, **e** lineament density, and **f** slope percent map of the study area

Normalized weights for thematic layers

AHP was used to determine the weights of the thematic layers (Saaty 1980). Saaty's AHP is a widely used MCDM technique in the field of natural resources and environmental management. Interestingly, the GIS-based AHP method has been advanced by the international scientific community as a powerful tool for analyzing complex spatial decision problems. The comparison ratings are on Saaty's 1–9 scale (Saaty 1980). In order to determine the weight of each thematic layer,

Table 1 Pairwise comparison matrix for the AHP process

Theme	Theme				
	Rf	Lt	Ld	Dd	*S*
Rainfall (Rf)	1.00	3.00	3.00	5.00	9.00
Lithology (Lt)	0.33	1.00	5.00	5.00	5.00
Lineament density (Ld)	0.33	0.20	1.00	3.00	3.00
Drainage density (Dd)	0.20	0.20	0.33	1.00	2.00
Slope (*S*)	0.11	0.20	0.33	0.50	1.00
Column total	1.97	4.6	9.66	14.5	20

questionnaires of comparison ratings on the Saaty's scale were prepared and filled by experts (hydrogeologists, geologists etc.) within Iran. Consequently, all the thematic layers are compared against each other in a pairwise comparison matrix (Table 1). The Expert Choice software package (E.C. Inc. 1995) based on the AHP method has been used to estimate weights of the importance of the thematic layers and to test for consistency ratio (CR). In the AHP method, the pairwise comparisons of all the thematic layers were taken as the inputs, while the relative weights of the thematic layers were the outputs. The final weightings for the thematic layers are the normalized values of the eigenvectors that are associated with the maximum eigenvalues of the ratio matrix (Jha et al. 2010; Adiat et al. 2012) (Table 2). The following equation is used to calculate the CR:

$$\mathrm{CR} = \mathrm{CI}/\mathrm{RI} \tag{3}$$

where RI is the random index whose value depends on the order of the matrix and CI is the consistency index which can be expressed as follows:

$$\mathrm{CI} = \frac{\lambda_{\max}{}^{-n}}{n-1} \tag{4}$$

where λ is the largest eigenvalue of the matrix and can be easily calculated from the matrix and n is the number of thematic layers. Saaty (1980) and Malczewski (1999) suggested that the CR must be less than 0.1.

Normalized weights of different features of thematic layers

The map of each thematic layer was classified. Ranks assigned to different features of the individual themes and their normalized weights are presented in Table 3 (Machiwal et al. 2011; Chowdary et al. 2013).

Definition of the GWPI

The groundwater potential index (GWPI) is a dimensionless quantity that helps to predict the groundwater potential zones in an area. The weighted linear combination method was used to estimate the groundwater potential index (GWPI) as follows (Malczewski 1999; Shekhar and Pandey 2014):

$$\mathrm{GWPI} = \sum_{w=1}^{m}\sum_{i=1}^{n}\left(W_i \times X_j\right) \tag{5}$$

where W_j is the normalized weight of the j thematic layer, X_i is the rank value of each class with respect to the j layer, m is the total number of thematic layers, and n is the total number of classes in a thematic layer. The GWPI for each grid was calculated using Eq. (6) below:

$$\mathrm{GWPI} = \mathrm{Lt}_W \mathrm{Lt}_{Wf} + \mathrm{Ld}_W \mathrm{Ld}_{Wf} + \mathrm{Dd}_W \mathrm{Dd}_{Wf} + S_W S_{Wf} + \mathrm{Rf}_W \mathrm{Rf}_{Wf} \tag{6}$$

where Lt is the lithology, Ld is the lineament density, Dd is the drainage density, *S* is the slope, and Rf is the rainfall. While, the subscripts '*W*' and '*Wf*' indicate the normalized weight of a theme obtained through AHP and the normalized weight of the individual features of a theme, respectively.

GWPI values were grouped into five classes of very poor (<0.134), poor (0.134–0.171), moderate (0.171–0.210), good (0.210–0.249), and very good (>0.249) using the quantile classification method. In the quantile classification approach, each class contains the same number of features. This approach was used by several researchers due to its efficiency in classification (Papadopoulou-Vrynioti et al. 2013; Tehrany et al. 2013; Nampak et al. 2014; Tehrany et al. 2014; Umar et al. 2014). The igneous rocks are primarily hard and compact

Table 2 Determining the normalized weights for thematic layers

Theme	Theme					Normalized weights (*W*)
	Rf	Lt	Ld	Dd	*S*	
Rf	1/1.97=0.51	3/4.6=0.65	3/9.66=0.31	5/14.5=0.34	9/20=0.45	2.27/5=0.45
Lt	0.17	0.22	0.52	0.34	0.25	0.3
Ld	0.17	0.04	0.10	0.21	0.15	0.14
Dd	0.10	0.04	0.03	0.07	0.10	0.07
S	0.06	0.04	0.03	0.03	0.05	0.04
Consistency ratio (CR)=0.07<0.1						

Table 3 Assigned and normalized weights of different features of five thematic layers for groundwater potential zoning

Theme	Feature/class	Assigned rank	Feature normalized weight (*Wf*)
Lithology (Lt)	Calcareous sandstone and marl	1	1/14=0.071
	Low-level terraces	2	2/14=0.142
	Alluvial fan deposit	3	3/14=0.214
	Lowest alluvial plain deposit	3	3/14=0.214
	Travertine	5	5/14=0.357
	Diorite and diorite–gabbro	–	–
Total		14	
Rainfall (Rf)	260–290	1	0.067
	290–320	2	0.133
	320–350	3	0.200
	350–380	4	0.267
	380–400	5	0.333
Drainage density (Dd)	0–0.15	5	0.333
	0.15–0.3	4	0.267
	0.3–0.45	3	0.200
	0.45–0.6	2	0.133
	0.6–0.77	1	0.067
Lineament density (Ld)	0–0.02	1	0.067
	0.02–0.06	2	0.133
	0.06–0.1	3	0.200
	0.1–0.17	4	0.267
	0.17–0.25	5	0.333
Slope (*S*)	0–3	5	0.333
	3–6	4	0.267
	6–10	3	0.200
	10–15	2	0.133
	>15	1	0.067

in nature and lack of primary porosity (Dar et al. 2011). This rock type is considered as poor groundwater potential (Thakur and Raghuwanshi 2008; Manap et al. 2013), while assumed as non-potential due to difficulty in terms of groundwater storage and movement.

Preparation of the groundwater potential map

The GWPI was calculated for each grid and then was plotted at the center of the grids (Table 4). The groundwater potential index map was prepared based on Kriging interpolation technique and grids' center coordinates. The geostatistical analysis was carried out using Geostatistical Analyst extension of ArcGIS 10.2 software.

Verifying groundwater potential map

The receiver operating characteristic (ROC) was used to determine the accuracy of groundwater potential map (Mohammady et al. 2012; Davoodi Moghaddam et al. 2013; Pradhan 2013). The groundwater potential map delineated in the present study was verified using the available well yield data of 50 pumping wells (Pradhan 2009; Shekhar and Pandey 2014). Based on the well yield data acquired from the Iranian Department of Water Resources Management, the accuracy assessment of the GWPI map was made. The ROC curve is considered as a graphical representation of the trade-off between the false-negative (*X*-axis) and false-positive (*Y*-axis) rates for every possible cutoff value (Negnevitsky 2002; Pourghasemi et al. 2013). In the ROC curve analysis, the area under curve (AUC) demonstrates the accuracy of a prediction system by describing the system's ability to expect the correct occurrence or non-occurrence of pre-defined "events" (Bui et al. 2011; Jaafari et al. 2014). According to Yesilnacar (2005), the quantitative–qualitative relationship between the AUC and prediction accuracy can be classified as follows: 0.5–0.6 (poor), 0.6–0.7 (average), 0.7–0.8 (good), 0.8–0.9 (very good), and 0.9–1 (excellent).

Results and discussion

Groundwater potential map

The groundwater potential map was prepared based on the GIS-based AHP and grid techniques (Fig. 4). According to the quantile method, the GWPI values were classified into six groundwater potential zones: non-potential, very poor, poor, moderate, good, and very good classes. The results also showed that 3.5, 19.75, 18.65, 18.7, 19.4, and 20 % of the area represent non-potential, very poor, poor, moderate, good, and very good, respectively. Based on Fig. 4, the very good groundwater potential zones are located at the west and east of the plain. Moreover, the northern parts of the plain because of high slope, high drainage density, and lithology with low permeability fall under very poor groundwater potential zones.

Validation of groundwater potential map

Validation is the most important process of modeling in that without validation, the models will have no scientific significance (ChungJ and Fabbri 2003). For validation, receiver operating characteristic (ROC) analysis by comparing the existing well yield data with the groundwater potential map obtained by AHP model was used (Pradhan 2009; Mohammady et al. 2012; Pourghasemi et al. 2012b; Davoodi

Table 4 Rating of grids and calculations of GWPI

Grid number	Grid center coordinate		Dd (*W*=0.07)		LD (*W*=0.14)		Lt (*W*=0.3)		Rf (*W*=0.45)		*S* (*W*=0.04)		GWPI Σ*W***Wf*
	Easting	Northing	*Wf*	*W***Wf*	*Wf*	*W***Wf*	*Wf*	*W***Wf*	*Wf*	*W***Wf*	*Wf*	*W***Wf*	
1	704995.6	3921593.4	0.33	0.023	0.067	0.009	0.357	0.107	0.20	0.090	0.200	0.008	0.237
2	708106.6	3921593.4	0.33	0.023	0.067	0.009	0.286	0.086	0.20	0.090	0.200	0.008	0.216
3	711217.5	3921593.4	0.33	0.023	0.067	0.009	0.071	0.021	0.20	0.090	0.200	0.008	0.151
4	701827.1	3918511.3	0.13	0.009	0.067	0.009	0.143	0.043	0.20	0.090	0.200	0.008	0.159
5	704966.8	3918453.7	0.20	0.014	0.067	0.009	0.071	0.021	0.20	0.090	0.200	0.008	0.142
6	708135.4	3918482.5	0.20	0.014	0.067	0.009	0.143	0.043	0.20	0.090	0.200	0.008	0.164
7	711217.5	3918511.3	0.27	0.019	0.067	0.009	0.143	0.043	0.20	0.090	0.200	0.008	0.169
8	714357.3	3918453.7	0.27	0.019	0.067	0.009	0.143	0.043	0.20	0.090	0.200	0.008	0.169
9	717381.8	3918396.1	0.27	0.019	0.067	0.009	0.071	0.021	0.13	0.060	0.200	0.008	0.117
10	720435.1	3918367.3	0.33	0.023	0.067	0.009	0.214	0.064	0.13	0.060	0.200	0.008	0.164
.	.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.
195	779315.0	3875059.0	0.33	0.023	0.067	0.009	0.357	0.107	0.20	0.090	0.267	0.011	0.240
196	769737.3	3872070.4	0.33	0.023	0.067	0.009	0.357	0.107	0.33	0.150	0.267	0.011	0.300
197	773085.9	3872034.4	0.33	0.023	0.067	0.009	0.286	0.086	0.33	0.150	0.200	0.008	0.276
198	776074.4	3872070.4	0.33	0.023	0.067	0.009	0.286	0.086	0.20	0.090	0.267	0.011	0.219
199	779279.0	3872070.4	0.33	0.023	0.067	0.009	0.286	0.086	0.20	0.090	0.267	0.011	0.219
200	773013.9	3869045.9	0.33	0.023	0.067	0.009	0.286	0.086	0.20	0.090	0.133	0.005	0.213
201	776110.4	3868937.9	0.33	0.023	0.067	0.009	0.286	0.086	0.20	0.090	0.133	0.005	0.213

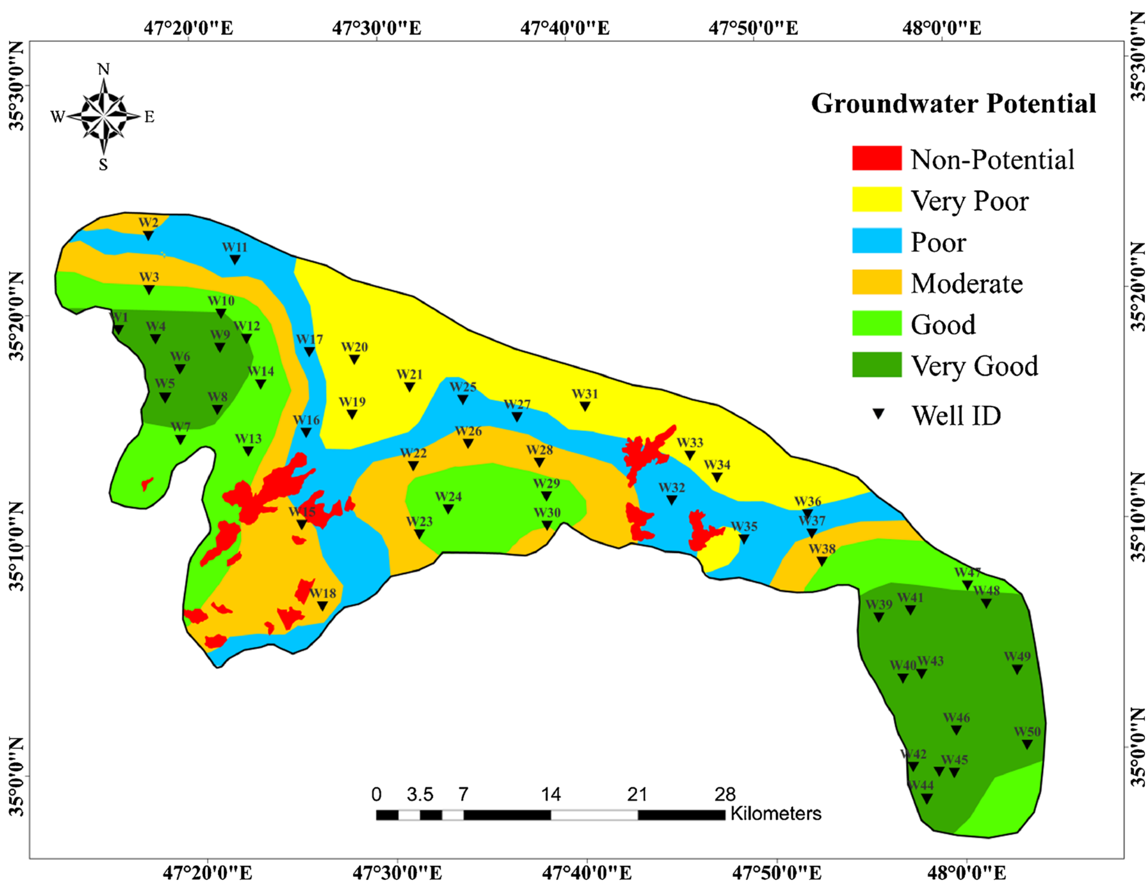

Fig. 4 Spatially distributed groundwater potential zones and well locations

Moghaddam et al. 2013; Pradhan 2013; Regmi et al. 2013; Pourtaghi and Pourghasemi 2014). The prediction curves are shown in Fig. 5. ROC plot assessment results (Fig. 5) show that in the groundwater potential map using AHP, the AUC was 0.7366, which corresponds to the prediction accuracy of 73.66 %. Therefore, it can be implied that the model utilized in this study showed reasonably good accuracy in predicting the groundwater potential. Moreover, it is concluded that the AHP model can be used as a simple tool for the assessment of groundwater potential. Yalcin (2008) and Pourghasemi et al. (2013) stated that AHP as an expert knowledge-based model is very useful for solving complex problems. Srivastava and Bhattacharya (2006) and Jha et al. (2010) demonstrated that the RS, GIS, and MCDA techniques provide a useful integrated tool for evaluating the groundwater conditions at a basin or subbasin scale. Jankowski (1995) stated that the main purpose of the AHP method is to support the decision makers in selecting the best alternative from the various possible choice alternatives under the presence of multiple priorities.

The verification of the groundwater potential map using yield data shows that this prediction method is effective and reliable. This result is in line with the results of Lee et al. (2012b) that applied an artificial neural network (ANN) model and a geographic information system (GIS) to the mapping of regional groundwater productivity potential (GPP) for the area around Pohang City, Republic of Korea. The validation showed prediction accuracies between 73.54 and 80.09 %. They used the weighted overlay modeling technique to develop a groundwater potential model with eight different effective weighted thematic layers, including annual rainfall, lithology, lineament density, topography, slope, and drainage density. The groundwater potential map can be prepared based on surface thematic layers (e.g., drainage density and slope) which are easily accessible and hence are widely used (Jha et al. 2007; Adiat et al. 2012), especially in developing and low-income countries.

Conclusion

In this study, a GIS-based AHP approach over a variety of MCDA techniques was chosen to obtain spatially distributed groundwater potential zones of the area. The aquifer of Ghorve–Dehgolan plain in western of Iran was selected as the study area and five thematic layers, viz. rainfall, lithology, drainage density, lineament density, and slope percent, were included for assessing groundwater potential zones. The results indicated that the groundwater potential mapping is controlled mostly by rainfall, lithology, and lineament density factors. Finally, for testing the accuracy of the AHP model, the ROC curve was prepared (Fig. 5). The validation of results demonstrated that the AHP has fairly good predication accuracy of 73.66 %. Hence, based on the results of this research and the accuracy of the derived groundwater potential prediction map, it can be concluded that the applied methodology, together with the used indices, is a useful framework for the rapid assessment of groundwater potential and can be

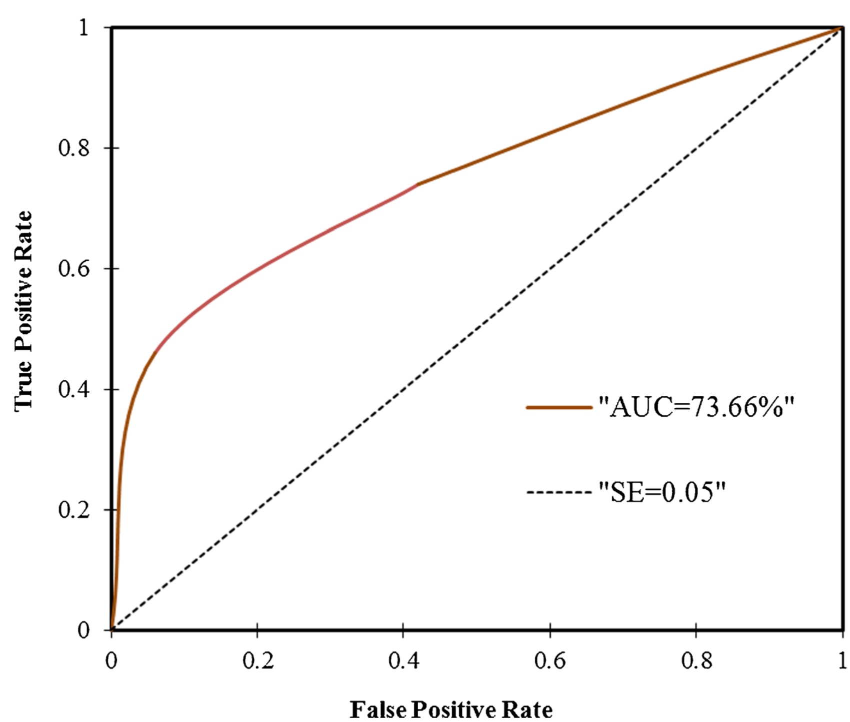

Fig. 5 ROC curve for the groundwater potential map

recommended to be applied in other areas especially in data-scarce areas.

In summary, the results of this study proved that GIS-based AHP approach could be successfully applied for the groundwater potential mapping. Hence, the result of groundwater potential map can be useful for planners in the water resource management and comprehensive evaluation of groundwater exploration development for future planning.

Acknowledgments This research was carried out as part of the first author's M.Sc thesis at the Watershed Management Engineering, Tehran University, Iran. Also, the authors would like to thank anonymous reviewers and editor for their helpful comments on the previous version of the manuscript.

References

Abbaspour KC, Faramarzi M, Ghasemi SS, Yang H (2009) Assessing the impact of climate change on water resources in Iran. Water Resour Res. doi:10.1029/2008WR007615

Adiat KAN, Nawawi MNM, Abdullah K (2012) Assessing the accuracy of GIS-based elementary multi criteria decision analysis as a spatial prediction tool—a case of predicting potential zones of sustainable groundwater resources. J Hydrol 440:75–89. doi:10.1016/j.jhydrol.2012.03.028

Alavi M (1994) Tectonics of the Zagros orogenic belt of Iran: new data and interpretations. Tectonophysics 229:211–238

Al Saud M (2010) Mapping potential areas for groundwater storage in Wadi Aurnah Basin, western Arabian Peninsula, using remote sensing and geographic information system techniques. Hydrogeol J 18: 1481–1495. doi:10.1007/s10040-010-0598-9

Althuwaynee OF, Pradhan B, Park HJ, Lee JH (2014) A novel ensemble bivariate statistical evidential belief function with knowledge-based analytical hierarchy process and multivariate statistical logistic regression for landslide susceptibility mapping. Catena 114:21–36

Arkoprovo B, Adarsa J, Shashi Prakash S (2012) Delineation of groundwater potential zones using satellite remote sensing and geographic information techniques: a case study from Ganjam district, Orissa, India. Res J Recent Sci 9:59–66

Ayazi MH, Pirasteh S, Arvin AKP, Pradhan B, Nikouravan B, Mansor S (2010) Disasters and risk reduction in groundwater: Zagros Mountain Southwest Iran using geo-informatics techniques. Dis Adv 3(1):51–57

Baghvand A, Nasrabadi T, Bidhendi GN, Vosoogh A, Karbassi A, Mehrdadi N (2010) Groundwater quality degradation of an aquifer in Iran central desert. Desalination 260:264–275. doi:10.1016/j.desal.2010.02.038

Bandyopadhyay S, Srivastava SK, Jha MK, Hegde VS, Jayaraman V (2007) Harnessing earth observation (EO) capabilities in hydrogeology: an Indian perspective. Hydrogeol J 15(1):155–158

Bastani M, Kholghi M, Rakhshandehroo GR (2010) Inverse modeling of variable-density groundwater flow in a semi-arid area in Iran using a genetic algorithm. Hydrogeol J 18:1191–1203

Brunner P, Bauer P, Eugster M, Kinzelbach W (2004) Using remote sensing to regionalize local rainfall recharge rates obtained from the chloride method. J Hydrol 294(4):241–250

Bui DT, Pradhan B, Lofman O, Revhaug I, Dick OB (2011) Landslide susceptibility mapping at Hoa Binh Province (Vietnam) using an adaptive neuro-fuzzy inference system and GIS. Comput Geosci. doi:10.1016/j.cageo.2011.10.031

Chandio IA, Matori ANB, WanYusof KB, Talpur MAH, Balogun AL, Lawal DU (2013) GIS-based analytic hierarchy process as a multi-criteria decision analysis instrument: a review. Arab J Geosci 6(8): 3059–3066

ChungJ F, Fabbri AG (2003) Validation of spatial prediction models for landslide hazard mapping. Nat Hazards 30(3):451–472

Chenini I, Mammou AB, May MY (2010) Groundwater recharge zone mapping using GIS-based multi-criteria analysis: a case study in Central Tunisia (Maknassy Basin). Water Resour Manag 24:921–939. doi:10.1007/s11269-009-9479-1

Chowdary VM, Chakraborthy D, Jeyaram A, Krishna Murthy YVN, Sharma JR, Dadhwal VK (2013) Multi-criteria decision making approach for watershed prioritization using analytic hierarchy process technique and GIS. Water Resour Manag 27:3555–3571. doi:10.1007/s11269-013-0364-6

Chowdhury A, Jha MK, Chowdary VM, Mal BC (2009) Integrated remote sensing and GIS-based approach for assessing groundwater potential in West Medinipur district, West Bengal, India. Int J Remote Sens 30(1):231–250

Chowdhury A, Jha MK, Chowdary VM (2010) Delineation of groundwater recharge zones and identification of artificial recharge sites in West Medinipur District, West Bengal using RS, GIS and MCDM techniques. Environ Earth Sci 59(6):1209–1222

Corsini A, Cervi F, Ronchetti F (2009) Weight of evidence and artificial neural networks for potential groundwater spring mapping: an application to the Mt. Modino area (Northern Apennines, Italy). Geomorphology 111:79–87

Dar IA, Sankar K, Dar MA (2010) Remote sensing technology and geographic information system modeling: an integrated approach towards the mapping of groundwater potential zones in Hardrock terrain, Mamundiyar basin. J Hydrol 394:285–295

Dar IA, Sankar K, Dar MA (2011) Deciphering groundwater potential zones in hard rock terrain using geospatial technology. Environ Monit Assess 173(1–4):597–610

Davoodi Moghaddam D, Rezaei M, Pourghasemi HR, Pourtaghie ZS, Pradhan B (2013) Groundwater spring potential mapping using bivariate statistical model and GIS in the Taleghan watershed, Iran. Arab J Geosci. doi:10.1007/s12517-013-1161-5

Dinesh Kumar PK, Gopinath G, Seralathan P (2007) Application of remote sensing and GIS for the demarcation of groundwater potential zones of a river basin in Kerala, southwest cost of India. Int J Remote Sens 28(24):5583–5601

ECInc (Expert Choice Inc.) (1995) Decision support software: tutorial, expert choice, student version 9. Expert Choice Inc., Pittsburgh

Edet AE, Okereke CS, Teme SC, Esu EO (1998) Application of remote-sensing data to groundwater exploration: a case study of the Cross River State, southeastern Nigeria. Hydrogeol J 6: 394–404

Elewa HH, Qaddah AA (2011) Groundwater potentiality mapping in the Sinai Peninsula, Egypt, using remote sensing and GIS-watershed-based modeling. Hydrogeol J 19:613–628

Ettazarini S (2007) Groundwater potential index: a strategically conceived tool for water research in fractured aquifers. Environ Geol 52:477–487

Ganapuram S, Kumar GTV, Krishna IVM, Kahya E, Demirel MC (2009) Mapping of groundwater potential zones in the Musi basin using remote sensing data and GIS. Adv Eng Softw 40(7):506–518

Gaur S, Chahar BR, Graillot D (2011) Combined use of groundwater modeling and potential zone analysis for management of groundwater. Int J Appl Earth Obs 13:127–139

Ghayoumian J, Mohseni Saravi M, Feiznia S, Nourib B, Malekian A (2007) Application of GIS techniques to determine areas most suitable for artificial groundwater recharge in a coastal aquifer in southern Iran. J Asian Earth Sci 30:364–374

Godebo TR (2005) Application of remote sensing and GIS for geological investigation and groundwater potential zone identification, Southeastern Ethiopian Plateau, Bale Mountains and the surrounding areas. Dissertation, Addis Ababa University

Gogu RC, Carabin G, Hallet V, Peters V, Dassargues A (2001) GIS based hydrogeological databases and groundwater modeling. Hydrol J 9: 555–569

Greenbaum D (1989) Hydrogeological applications of remote sensing in areas of crystalline basement. Paper presented at the In: Proc Groundwater Exploration and Development in Crystalline Basement Aquifers, 1989

Hajkowicz S, Collins K (2007) A review of multiple criteria analysis for water resource planning and management. Water Resour Manag 21: 1553–1566

Hajkowicz S, Higgins A (2008) A comparison of multiple criteria analysis techniques for water resource management. Eur J Oper Res 184: 255–265

Hammouri N, El-Naqa A, Barakat M (2012) An Integrated approach to groundwater exploration using remote sensing and geographic information system. J Water Resour Prot 4(9):717–724

Hosseini M, Ghafouri AM, Amin MSM, Tabatabaei MR, Goodarzi M, Abde Kolahchi A (2012) Effects of land use changes on water balance in Taleghan Catchment, Iran. J Agric Sci Tech 14:1159–1172

Israil M, Al-hadithi M, Singhal DC (2006) Application of a resistivity survey and geographical information system (GIS) analysis for hydrogeological zoning of a piedmont area, Himalayan foothill region, India. Hydrogeol J 14:753–759. doi:10.1007/s10040-005-0483-0

Jaafari A, Najafi A, Pourghasemi HR, Rezaeian J, Sattarian A (2014) GIS-based frequency ratio and index of entropy models for landslide susceptibility assessment in the Caspian forest, northern Iran. Int J Environ Sci Technol. doi:10.1007/s13762-013-0464-0

Jankowski P (1995) Integrating geographical information systems and multiple criteria decision-making methods. Int J Geogr Inf Sci 9: 251–273

Jha MK, Chowdary VM (2007) Challenges of using remote sensing and GIS in developing nations. Hydrogeol J 15(1):197–200

Jha MK, Chowdhury A, Chowdary VM, Peiffer S (2007) Groundwater management and development by integrated remote sensing and geographic information systems: prospects and constraints. Water Resour Manag 21(2):427–467

Jha MK, Chowdary VM, Chowdhury A (2010) Groundwater assessment in Salboni Block, West Bengal (India) using remote sensing, geographical information system and multi-criteria decision analysis techniques. Hydrogeol J 18:1713–1728. doi:10.1007/s10040-010-0631-z

Jha MK, Peiffer S (2006) Applications of remote sensing and GIS technologies in groundwater hydrology: past, present and future. Bayreuth University Press, Bayreuth, Germany

Kaliraj S, Chandrasekar N, Magesh NS (2014) Identification of potential groundwater recharge zones in Vaigai upper basin, Tamil Nadu, using GIS-based analytical hierarchical process (AHP) technique. Arab J Geosci 7:1385–1401. doi:10.1007/s12517-013-0849-x

Lee S, Kim YS, Oh HJ (2012a) Application of a weights-of-evidence method and GIS to regional groundwater productivity potential mapping. J Environ Manag 96(1):91–105

Lee S, Song KY, Kim Y, Park I (2012b) Regional groundwater productivity potential mapping using a geographic information system (GIS) based artificial neural network model. Hydrogeol J 20(8): 1511–1527

Machiwal D, Jha MK, Mal BC (2011) Assessment of groundwater potential in a semi-arid region of India using remote sensing, GIS and MCDM techniques. Water Resour Manag 25:1359–1386

Madrucci V, Taioli F, Cesar de Araujo C (2008) Groundwater favorability map using GIS multicriteria data analysis on crystalline terrain, Sao Paulo State, Brazil. J Hydrol 357:153–173

Magesh NS, Chandrasekar N, Soundranayagam JP (2012) Delineation of groundwater potential zones in Theni district, Tamil Nadu, using remote sensing, GIS and MIF techniques. Geosci Front 3(2):189–196

Manap MA, Nampak H, Pradhan B, Lee S, Sulaiman WNA, Ramli MF (2012) Application of probabilistic-based frequency ratio model in groundwater potential mapping using remote sensing data and GIS. Arab J Geosci. doi:10.1007/s12517-012-0795-z

Manap MA, Sulaiman WNA, Ramli MF, Pradhan B, Surip N (2013) A knowledge-driven GIS modeling technique for groundwater potential mapping at the Upper Langat Basin, Malaysia. Arab J Geosci 6: 1621–1637. doi:10.1007/s12517-011-0469-2

Malczewski J (1999) GIS and Multicriteria decision analysis. Wiley, United States of America, pp 177–192

Mogaji KA, Lim HS, Abdullah K (2014) Regional prediction of groundwater potential mapping in a multifaceted geology terrain using GIS-based Dempster–Shafer model. Arab J Geosci. doi:10.1007/s12517-014-1391-1

Mohammady M, Pourghasemi HR, Pradhan B (2012) Landslide susceptibility mapping at Golestan Province, Iran: a comparison between frequency ratio, Dempster–Shafer, and weights-of-evidence models. J Asian Earth Sci 61:221–236

Mukherjee P, Singh CK, Mukherjee S (2012) Delineation of groundwater potential zones in arid region of India—a remote sensing and GIS approach. Water Resour Manag 26:2643–2672

Murthy KSR, Mamo AG (2009) Multi-criteria decision evaluation in groundwater zones identification in Moyale–Teltele subbasin, South Ethiopia. Int J Remote Sens 30:2729–2740

Musa KA, Akhir JM, Abdullah I (2000) Groundwater prediction potential zone in Langat Basin using the integration of remote sensing and GIS. http://www.gisdevelopment.net (accessed on July 24, 2008)

Naghibi SA, Pourghasemi HR, Pourtaghie ZS, Rezaei A (2014) Groundwater qanat potential mapping using frequency ratio and Shannon's entropy models in the Moghan Watershed. Iran Earth Sci Inform. doi:10.1007/s12145-014-0145-7

Nampak H, Pradhan B, Manap MA (2014) Application of GIS based data driven evidential belief function model to predict groundwater potential zonation. J Hydrol 513:283–300

Negnevitsky M (2002) Artificial intelligence: a guide to intelligent systems. Addison–Wesley/Pearson, Harlow, England, p 394

Neshat A, Pradhan B, Pirasteh S, Shafri HZM (2013) Estimating groundwater vulnerability to pollution using modified DRASTIC model in the Kerman agricultural area. Iran Environ Earth Sci. doi:10.1007/s12665-013-2690-7

Nosrati K, Eeckhaut MVD (2012) Assessment of groundwater quality using multivariate statistical techniques in Hashtgerd Plain, Iran. Environ Earth Sci 65:331–344. doi:10.1007/s12665-011-1092-y

Oh HJ, Kim YS, Choi JK, Park E, Lee S (2011) GIS mapping of regional probabilistic groundwater potential in the area of Pohang City, Korea. J Hydrol 399:158–172. doi:10.1016/j.jhydrol.2010.12.027

Ozdemir A (2011) Using a binary logistic regression method and GIS for evaluating and mapping the groundwater spring potential in the Sultan Mountains (Aksehir, Turkey). J Hydrol 405(1):123–136

Page ML, Berjamy B, Fakir Y, Bourgin F et al (2012) An integrated DSS for groundwater management based on remote sensing. The case of a semi-arid aquifer in Morocco. Water Resour Manag 26:3209–3230

Papadopoulou-Vrynioti K, Bathrellos GD, Skilodimou HD, Kaviris G, Makropoulos K (2013) Karst collapse susceptibility mapping considering peak ground acceleration in a rapidly growing urban area. Eng Geol 158:77–88

Pietersen K (2006) Multiple criteria decision analysis (MCDA): a tool to support sustainable management of groundwater resources in South Africa. Water SA 32(2):119–128

Pourghasemi HR, Moradi HR, Fatemi Aghda SM (2013) Landslide susceptibility mapping by binary logistic regression, analytical hierarchy process, and statistical index models and assessment of their performances. Nat Hazards 69:749–779. doi:10.1007/s11069-013-0728-5

Pourghasemi HR, Moradi HR, Fatemi Aghda SM, Gokceoglu C, Pradhan B (2012a) GIS-based landslide susceptibility mapping with probabilistic likelihood ratio and spatial multi-criteria evaluation models (North of Tehran, Iran). Arab J Geosci 7(5):1857–1878. doi:10.1007/s12517-012-0825-x

Pourghasemi HR, Pradhan B, Gokceoglu C (2012b) Application of fuzzy logic and analytical hierarchy process (AHP) to landslide susceptibility mapping at Haraz watershed, Iran. Nat Hazards 63:965–996. doi:10.1007/s11069-012-0217-2

Pourtaghi ZS, Pourghasemi HR (2014) GIS-based groundwater spring potential assessment and mapping in the Birjand Township, southern Khorasan Province. Iran Hydrogeol J. doi:10.1007/s10040-013-1089-6

Pradhan B (2013) A comparative study on the predictive ability of the decision tree, support vector machine and neuro-fuzzy models in landslide susceptibility mapping using GIS. Comput Geosci 51:350–365

Pradhan B (2009) Groundwater potential zonation for basaltic watersheds using satellite remote sensing data and GIS techniques. Cent Eur J Geosci 1(1):120–129

Pradhan B, Pirasteh S (2010) Comparison between prediction capabilities of neural network and fuzzy logic techniques for landslide susceptibility mapping. Dis Adv 3(2):26–34

Pradhan B, Youssef AM (2010) Manifestation of remote sensing data and GIS for landslide hazard analysis using spatial-based statistical models. Arab J Geosci 3(3):319–326. doi:10.1007/s12517-009-0089-2

Pradhan B, Singh RP, Buchroithner MF (2006) Estimation of stress and its use in evaluation of landslide prone regions using remote sensing data. Adv Space Res 37:698–709

Prasad RK, Mondal NC, Banerjee P, Nandakumar MV, Singh VS (2008) Deciphering potential groundwater zone in hard rock through the application of GIS. Environ Geol 55(3):467–475

Rahmati O (2013) An investigation of quantitative zonation and groundwater potential (case study: Ghorveh-Dehgolan plain). M.Sc. thesis, Tehran University

Regmi AD, Devkota KC, Yoshida K, Pradhan B, Pourghasemi HR, Kumamoto T, Akgun A (2013) Application of frequency ratio, statistical index, and weights-of-evidence models and their comparison in landslide susceptibility mapping in Central Nepal Himalaya. Arab J Geosci. doi:10.1007/s12517-012-0807-z

Roscoe, Moss Co (1990) Handbook of groundwater development. Wiley, New York, pp 34–51

Saaty TL (1980) The analytic hierarchy process: planning, priority setting, resource allocation. McGraw-Hill, New York

Shekhar S, Pandey AC (2014) Delineation of groundwater potential zone in hard rock terrain of India using remote sensing, geographical information system (GIS) and analytic hierarchy process (AHP) techniques. Geocarto Int. doi:10.1080/10106049.2014.894584

Solomon S, Quiel F (2006) Groundwater study using remote sensing and geographic information systems (GIS) in the central highlands of Eritrea. Hydrogeol J 14:1029–1041. doi:10.1007/s10040-006-0096-2

Sree Devi PDS, Srinivasulu S, Raju KK (2001) Hydrogeomorphological and groundwater prospects of the Pageru river basin by using remote sensing data. Environ Geol 40:1088–1094. doi:10.1007/s002540100295

Srivastava PK, Bhattacharya AK (2006) Groundwater assessment through an integrated approach using remote sensing, GIS and resistivity techniques: a case study from a hard rock terrain. Int J Remote Sens 27(20):4599–4620

Subba Rao N, Chakradhar GKJ, Srinivas V (2001) Identification of groundwater potential zones using remote sensing techniques in and around Gunur town, Andhra Pradesh, India. J Indian Soc Remote Sens 29:69–78

Tehrany MS, Pradhan B, Jebur MN (2013) Spatial prediction of flood susceptible areas using rule based decision tree (DT) and a novel ensemble bivariate and multivariate statistical models in GIS. J Hydrol 504:69–79

Tehrany MS, Pradhan B, Jebur MN (2014) Flood susceptibility mapping using a novel ensemble weights-of-evidence and support vector machine models in GIS. J Hydrol 512:332–343. doi:10.1016/j.jhydrol.2014.03.008

Thakur GS, Raghuwanshi RS (2008) Prospect and assessment of groundwater resources using remote sensing techniques in and around Choral River Basin, Indore and Khargone Districts. J Indian Soc Remote Sens 36(2):217–225

Todd DK, Mays LW (1980) Groundwater hydrology, 2nd edn. Wiley Canada, New York

Umar Z, Pradhan B, Ahmad A, Jebur MN, Tehrany MS (2014) Earthquake induced landslide susceptibility mapping using an integrated ensemble frequency ratio and logistic regression models in West Sumatera Province, Indonesia. Catena 118:124–135

Vaux H (2011) Groundwater under stress: the importance of management. Environ Earth Sci 62:19–23

Vittala SS, Govlndaiah S, Gowda HH (2005) Evaluation of groundwater potential zones in the sub-watersheds of north Pennar river basin around Pavagada, Karnataka, India using remote sensing and GIS techniques. J Indian Soc Remote Sens 33(4):483–493

Yalcin A (2008) GIS-based landslide susceptibility mapping using analytical hierarchy process and bivariate statistics in Ardesen (Turkey): comparisons of results and confirmations. Catena 72:1–12

Yesilnacar EK (2005) The application of computational intelligence to landslide susceptibility mapping in Turkey. Ph.D Thesis Department of Geomatics the University of Melbourne, p 423

Zare M, Pourghasemi HR, Vafakhah M, Pradhan B (2013) Landslide susceptibility mapping at Vaz Watershed (Iran) using an artificial neural network model: a comparison between multilayer perceptron (MLP) and radial basic function (RBF) algorithms. Arab J Geosci 6:2873–2888

Zarghami M, Abdi A, Babaeian I, Hassanzade Y, Kanani R (2011) Impacts of climate change on runoffs in East Azerbaijan, Iran. Glob Planet Chang 78(3–4):137–146. doi:10.1016/j.gloplacha.2011.06.003