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Groundwater Potential Mapping of the Major Aquifer in Northeastern Missan Governorate, South of Iraq by Using Analytical Hierarchy Process and GIS

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Abstract

As a result of the increasing demand for water in recent years, particularly after the emergence of drought conditions in Iraq, water policies in neighboring countries and the need to expand the uses of water for the purpose of food security, there is a truly urgent need for reassessment of groundwater resources in the light of modern efficient techniques for better managing and protecting of the aquifer system. In this study an attempt was made to delineate groundwater availability zones for the major aquifer in northeast Missan governorate, south of Iraq using GIS and analytical hierarchy process (AHP) decision making technique. Because of the data lacking, a total set of four criteria/features believed to be influencing groundwater productivity in the area were selected and mapped to demarcate groundwater potential classes after assign appropriate weights using AHP. All thematic layers were integrated and analyzed in ArcGIS 9.3 software. The final groundwater potential map was produced by linear weighted combination technique. The delineated groundwater potential map was finally verified using the available abstraction rates of existing wells. The prediction accuracy of the developed model was 72%. The groundwater potential map of the study area reveals three distinct zones: high, moderate, and low groundwater availability. The areas covered by these zones were 1138, 554, and 157 km^2 for low, moderate, and high zones, respectively. The results demonstrate that the groundwater resources in the study area require careful management and pumping extraction plans. The generated model will help as a guideline for designing a suitable groundwater exploration plan in the future and thereby help efficient planning of scare groundwater in the study area.

Keywords: Groundwater, GIS, AHP, Missan governorate, Iraq

1. Introduction

Water is a primary life-giving resource. Its availability is an essential component in socio-economic development, human evolution, poverty reduction, and ecological diversity. Even though there always has been plenty of fresh water on Earth, water has not always been available when and where it is needed, nor it always of suitable quality for all uses. Water must be considered as a finite resource that has limits and boundaries to its available and sustainable for use. Today, there are significant factors such as poverty, dramatic effect of demographic changes, and the recent manifestation of climate change which have a devastating impact on this resource and on managing water in a sustainable manner. Generally, the conventional approaches for water resources investigation and development are time consuming, high cost, uneconomical and sometimes poorly successful. With the advent of powerful computers, advance in geographical information system (GIS), global positioning system (GPS), groundwater flow simulation codes, and amazing artificial intelligent techniques such as artificial neural network (ANNs) and fuzzy inference, efficient and powerful techniques for water resources management have evolved. These techniques have reassigned the ways to manage natural resources in general and water resources in particular.

The term '*groundwater potential*' denotes the amount of groundwater available in an area and it is a function of several hydrologic and hydrogeological factors (Jha et al., 2010). From a hydrogeological exploration point of view, this term may be defined as the possibility of groundwater occurrence in an area. Proper assessment of groundwater potential can serve as useful guidelines for decision maker in identifying suitable groundwater policies within an area and proper manage of aquifer system in sustainable manner. The methodology proposed in the literature (Chi and Lee, 1994; Krishnamurthy and Srinivas, 1995; Kamaraju et al., 1995; Krishnamurthy et al., 1996; Sander et al., 1996; Edet et al., 1998; Saraf and Choudhury, 1998, Shahid et al., 2000; Jaiswal et al., 2003; Rao and Jugran, 2003; Sikdar et al., 2004; Sener et al., 2005; Ravi Shankar and Mohan, 2003; Solomon and Quiel, 2006; Madrucci et al., 2008; Ganapuram et al., 2009; Suja Rose and Krishnam, 2009; Pradeep Kumar et al., 2010; Chowdhury et al., 2010; Jha et al., 2010; Machiwal et al., 2010; Dar et al., 2010;Manap et al., 2011; Khodaei and Nassem, 2011; Sahu and Sikdar, 2012; Abdalla, 2012; Pandey et al., 2013; and Gumma and Pavelic, 2013) to demarcate groundwater potential zone of an area is illustrated in (Fig. 1), in which several selected thematic maps from different sources such as remote sensing data, geophysical data, and conventional data are integrated in the GIS environment to generate groundwater potential index (GWPI). The GWPI is computed by using the weighted linear combination method as follows: (Malczewski, 1999)

$$GWPI = \sum_{j=1}^{m} \sum_{i=1}^{n} \left(w_j \times x_i \right) \qquad (1)$$

where x_i is the normalized weight of the ith class/feature of theme, w_j is the normalized weight of the jth theme, m is the total number of themes, and n is the total number of classes in a theme. Prior to integration of thematic maps in GIS using equation (1), thematic maps and their features should be assessed weights to reflect relative importance of them in building a true picture of groundwater potentiality. This step is implemented through application of the multi-criteria decision making (MCDM) such as analytic hierarchy process (AHP) or through personal judgment based on the expert's opinion. The AHP developed by Saaty (1980) provides a flexible and easily understood way of analysis complicated problems. It is a multiple criteria decision making technique that allows subjective as well as objective features to be considered in decision making process. Integration of thematic maps after assign appropriate weights implemented using GIS software such as ArcGIS. The resulting map of such analysis reveals aquifer potentially of an area as classes such as low, medium, and high.

The objective of this study is to map groundwater productivity of the shallow major aquifer in the northeastern Missan governorate, south of Iraq using AHP and GIS. Because of the data limitation, a total set of four criteria/features believed to be influencing groundwater productivity in the study area were selected and mapped to demarcate groundwater potential classes after assign appropriate weights using AHP. The results of the study could be helpful for planner and decision makers in groundwater resource management and planning.

2. The study area

The study area is located in the northeastern Missan governorate, south of Iraq between (32°03′25.52″–32°30′30″) latitude and (47°05′21.16″–47°40′53.52″) longitude (Fig. 2). It encompasses an area of (1856 km^2). The topography elevation ranges from (7 – 230 m). The land surface is relatively flat in the central part of the area and it is bounded by Hemrin hills in the northeastern part and Band hill in the north. The surface elevations of the study area decrease from northeast to southwest (Fig. 3). The area is crossed by two streams namely, Teeb and Dewereg. The source of both is Iran territory. The bigger one is Teeb which enters the Iraqi territory at the Teeb town north of the study area and runs from north to south until it ends in Al-Sanaf marsh outside the study area. The other stream is Dewereg which enters the Iraqi territory at Fauqi area and runs from east to northeast until it finishes in Al-Rais marsh. The total lengths of Teeb and Dewereg streams within the study area are (63 and 35 km), respectively. The surface drainage has an intermittent flow regime because of long drought period. Hence, groundwater constituents the main water resource in the study area. Most of the developments in the study area are restricted in the southern part, especially in oil industries where many foreign oil companies have come to work within Al-Fugi and Bazrgan oil fields. The region is also famous in brick industry and gravel and sand quarries. A total of (36) tube wells are established by the General Commission of groundwater/ Ministry of Water Resources (Iraq), in addition to a few hand dug wells spreading unevenly throughout the area and used by residents for watering life stock and limited agricultural activities in particular the advancement and cultivation of watermelons and paper. Also, a few deep artesian wells (< 5 wells) with potable water were drilled in the Al-Zubidat area northeast of the study area close to the Hemrin hills.

2.1 Geological Setting

Rocks of uppermost Miocene and Pliocene dip towards the Mesopotamian plain from the foothills along the Iraqi-Iranian border on the east. These rocks are buried beneath the Mesopotamian plain by thick deposits of Pleistocene and Holocene age. Most part of the study area is covered with fluviatile, lacustrine, and aeolian sediments of recent age. The Quaternary deposits represent about 72% while Tertiary sediments extend over 28%, (Fig. 3). The exposed formations in the study area are Mukdadiyah and Bai Hassan (lower and upper Bakhtiari) Formations and sediments of Quaternary deposits. The Bakhtiari Formation was first described in Iran. Bellen et al. (1959) introduced the formation in Iraq and later divided it into the lower and upper Bakhtiaria formation. Jassaim et al. (1984) replaced the names of upper and lower Bakhtiaria with Mukdadiya and Bai Hassan, respectively. The two formations are strongly diachronous but can be recognized throughout the foothill and high folded zones. The two formations occur on the southwest flank of Jabal Hemrin to Jabal Faugi along the Iraq – Iran border (Parsons, 1957). The Mukdadyia Formation comprises up to 2000 m of fining upwards cycles of gravely sandstone, sandstone and red mudstone (Jassim and Goff, 2006). The formation is replaced almost totally by the Bai Hassan conglomeratic facies in the high folded zone of NE but not in N Iraq. The Mukdadiya Formation was deposited in fluvial environment in a rapidly subsiding foredeep basin. The age of the Bakhtiari Formation is Pliocene. The boundary between the lower and upper Bakhtiari is merely a facies change and arbitrarily assumed to be at the base of the first coarse conglomerate. Most part of the study area is covered with different types of Quaternary deposits mainly sand and alluvium deposits of recent and Pleistocene age. The Quaternary sediments are unconsolidated and usually finer grained than the underlying Mukdadiya and Bai Hassan Formations (Bellen et al., 1959; Naqib, 1967; Al-Siddiki, 1978). Alluvial fan, flood plain, depression fill, and aeolian deposits are the major units of the Quaternary deposits in the study area. Alluvial fans deposits comprise gravel, sand and silty sand. These sediments form a strip along the foothill zone. The maximum thickness of the alluvial deposits may reach to 15 m. poorly sorted coarse deposits of cobbles and sometimes boulder occur in apical parts passing into finer grained, better sorted layered fluvial sediments. The outer rimes of the fans consist of sand and silt. Gepcrete also developed on the surfaces of some fans. Flood plain sediments comprise layers of silt clay and clay typically 10-20 cm but sometimes up to 1m thick. Depression fill deposits are generally reddish- brown fine sand, silt and clayey silt. Three types of aeolian sediment are currently found in the area: dust fill-out, mobile and without clear forms and sand dunes. The dust is silty, reddish brown and calcareous (Khalaf et al., 1985 in Jassim and Goff, 2006).

From the tectonic point of view, large part of the study area lies within the Mesopotamian Zone. The Mesopotamian Zone is the easternmost unit of the stable shelf. It is bounded in the NE by the folded ranges of pesh-i-kuh in the east, and Hemrin and Makhul in the north. The zone was probably uplifted during the Hercynian deformation but it subsided from late Permian time onwards. The study area contains buried faulted structure below the Quaternary cover, separated by broad synclines (Buday and Jassim, 1987). The fold structures mainly trend NW- SE in the eastern part of the zone and N-S in the southern part. Small anticline folds are found between Al-Teeb and Shike Fars areas in addition to another fold close to the Al-Swar hills with NW-SE trend. This structure comprised Bazrgan oil field.

2.2 Geomorphological Setting

The geomorphological feature of an area determines the characteristics of runoff, flooding, groundwater recharge and to some extent rainfall occurrence. The study area is flat and featureless surface bounded by the foothill zone (Hemrin hills) in the northeast along the Iraqi-Iranian border. These hills are southeastern trending low folding parallel series adjacent to Zagros Mountains. Hills are not continuous ridges, but rather a series of ridges with their axes oriented in a northwest- southeast direction. The upper cover of these hills is removed by action of weathering and erosion forming a thick soil layer of fine texture (Parsons, 1957d). This geomorphological unit is restricted to a narrow belt along the Iraqi-Iranian border. The most common landforms within the study area are (Fig. 4): **(1)** Valley networks which represent a common landform within the area especially in Teeb. These valleys are filled with water after heavy rain and significantly contribute in groundwater recharge. They can be classified into two types depending on their occurrence; mountain or flat area. Valleys in mountain area are very rugged and dissected due to action of strongly water coming from Iran (Fig. 5a). Shallow valleys in flat area are simple depression with gentle slope and commonly terminate in marshes (Fig. 5b), and consist mainly from mixture of gravel, sand, and silt sediments **(2)** Alluvial fans are rock debris that are eroded into fine sediments and subsequently transported by ephemeral streams to the valley floor and deposited there as a result of gradient decrease of the mountain at higher elevation on the drainage basin periphery. These sediments are then subsequently distributed into fan-shaped landforms called alluvial fans. Alluvial fans within the study area are developed along the boundary of foothill zone with the Mesopotamia. They are deposited by the ephemeral streams draining the foothill zone to the northeast. The surface of the fans is generally weathered and consists of a veneer of red clay and coarse particles coated by desert varnish (Jassim and Goff, 2006). Older fan bodies are often truncated by younger ones. Fan deposits consist of lenticular bodies of poorly sorted fine to coarse-grained sand and gravel with varying amounts of clay **(3)** Flood plain is the flat area occurring on both sides of the Teeb and Dewerage streams which is flooded and filled with large amount of deposits. The thickness of these sediments may reach several meters with very steep slopes. The thickness decreases considerably to reach few meters near the Iraqi border. Sediments mainly consist of sand and clay with different combinations **(4)** Sebkhas During periodic rain in the winter months, water from the Iranian side of the border drains onto the flat area resulting in occasional flood. The evaporation of this water results in large area of salt accumulation (i.e., Sebkhah) (Fig 5c). The sediments that fill Sebkhahs consist of sand, silt, and clay in varying combinations **(5)** Marshes contain a complicated network of channel passing through reed beds forming open lakes and reed islands (Jassim and Goff, 2006). The surface sediments of the marshes consist mainly of sandy or clayey silt (Aqrawi and Evans, 1994). Marsh sediments rich in organic matter and generally black grey to olive-colored sediments down to 1 m depth (Fig 5d) **(6)** Sand dunes are accumulation of loose, well sorted windblown sand grains in wave-like mounds or ridges whose characteristics shapes are maintained by periods of wind – induced, grain by grain movement (Fig 5e). The aeolian deposits in the Teeb area are derived from alluvial fans. They are often rich in grains which occur in the older Mio-Pliocene molasse (Buday and Jassim, 1987). A series of sand dunes which vary in size and degree of stability occur parallel to the Hemrin Hills.

2.3 Soil

Soil is defined in different ways for different processes. Generally, it is a complex biogeochemical material on which plants may grow. Information on the type of soil is often needed as a basic input in hydrologic evaluation. Mapping soil usually involves delineating soil types that have identifiable characteristics. The delineation is based on many factors garment to soil science such as geomorphologic origin and conditions under which the soil formed (Vieux, 2004). The primary hydrologic interest in soil maps is the modeling of infiltration and runoff as a function of soil properties. Adequate measurement of infiltration and runoff for ungauged watershed is complex task. Therefore, vigorous efforts have been carried out to relate soil properties with soil texture. Soil texture is a term that used to designate the proportionate distribution of the different sizes of mineral particles in a soil. According to their size, these mineral particles are grouped into "separate". A soil separate is a group of mineral particles that fit within defined size limits expressed as diameter in (mm). A Varity of systems are used to define the size ranges of particles. The mostly used is the U.S. Department of Agriculture (USDA). There are twelve major textural classes. Their compositions are defined by USDA with other relevant factors. The USDA soil texture triangle was designed so that any combination of particle sizes could be included within a textural class. Each corner of the textural triangle represent 100% of size fractions: sand, silt, and clay within the triangle are areas that represent the allowable combinations of the three size particles. Once the sand, silt, and clay percentages of a soil are known, the textural class can be read from the textural triangle. Using more than 3000 specifically named soil types, the Natural Resource Conservation Service (NRCS) divided each into one of four hydrologic groups, Table (1) depending on infiltration, soil classification and other criteria (USDA-SCS, 1975). Soil group is of great use in estimation the runoff for any given watershed as soil influence the process of generate runoff from rainfall.

The collected soil samples of the study area were assigned texture name based on the web-based USDA soil texture calculator (http://soils.usda.gov/technical/aids/investigations/texture/). The soil types in the study area are then converted to soil permeability values based on soil taxonomy (Table 1). According to this classification each soil hydrological group is assigned a range of values of infiltration rates in mm/hr. The average value of infiltration rates is then interpolated using kriging techniques in Geostatistical analyst extension of ArcGIS 9.3 to produce the soil hydrological group layer of the study area (Fig. 6). Areas covered by each of these groups are summarized in (Fig. 7).

3.4 Hydrogeological Setting

According to the hydrogeological conceptual model of the study area (Atiaa, 2011), the aquifer system within the area is subdivided into three aquifers: shallow, major, and deep. These aquifers are separated by two less permeable aquitards the hydraulic characteristics of them are unknown. The hydraulic connection between aquifer units is possible and the confined portion of aquifer system is not fully separated. Shallow aquifer is unconfined in nature, less important and less exploitable than the other two aquifers in the study area. Fine sand and sand with little silt represents the main constituents of this unit. Only few dug wells penetrate this unit of aquifer and extract water for life stocks and small farms. Dug wells are shallow and partially penetrate the aquifer; only a few meters with irregular diameters. Although most of net recharge from rainfall goes to this part of the aquifer system, water quality is unsuitable for human consumption due to surface salt washing process. Depth to groundwater table ranges from 2 to 5 m. This aquifer is also of limited extend over the study area and might disappear in the west and southwest. The most important aquifer in the study area is the major aquifer where most of the operating wells penetrate it to some extent. This aquifer is also widespread over the whole area and consists mainly of gravel and sand mixture with significant amount of silt and clay in some parts of the aquifer. The maximum thickness of the aquifer may reach 42 m while the minimum thickness is about 20 m. (Fig.8). The major aquifer is semi-confined where the confined and unconfined occupy 72% and 18% of the whole study area, respectively (Fig. 9). The latest map is produced through interpolation of upper aquifer thickness over the area validated by the lithological section of well points. The deep aquifer is found in the eastern part of the area within the Bai Hassan and Mukdadiyah Formations. Currently, only five wells penetrate this part of the aquifer and pumps are needed to lift water; the water flows under pressure once the water bearing layer is reached (Fig.**9**). These flowing wells are operated all the time from day to night without any controlling device. The groundwater quality of this part of system is very good where the total dissolved solid does not exceed 600 ppm. The average discharge of these wells ranges from 1 ℓ/s to 3 ℓ/s.The two aquitard systems consist of silt and silt clay with little amount of sand. The upper one separates the shallow and major aquifer. The maximum and minimum thickness of this confining unit is 0 and 30 m, respectively. The second aquitard separates the main aquifer from the artesian aquifer. The minimum and maximum thickness of this unit is 0 and 8 m, respectively. The value of zero means that the main and artesian aquifers are connected at this well point location. Thickness of this unit increases from northeast to southwest. The hydraulic characteristics of these confining units are unknown and no evidence available against hydraulic connection between aquifer units across these confining units.

Hydraulic conductivity values of the main aquifer in the study area are acquired from previous studies such as Al-Jaburi (2005) and Lazim (2002).Table (**2**) shows the hydraulic conductivities of Quaternary and Tertiary major water bearing layers in the study area, in which the hydraulic conductivity of the Quaternary is less than of the Tertiary. The spatial distribution of hydraulic conductivity over the study area is shown in (Fig. **10**) for 14 points distributed in the center and north part of the study area. Generally, the values of this parameter increase from south to north, reflecting the nature of the sediments which changes from Quaternary to Tertiary.

3.5 Lineaments density

Lineaments are generally used in the analysis of remote sensing observations of fractures and structures. A lineament is a linear feature in a landscape which is an expression of an underlying geological structure such as a fault (http://en.wikipedia.org/wiki/lineaments). O'Leary et al. (1976) defined the lineaments as the simple and complex linear properties of geological structure such as faults, cleavages, fractures, and various surfaces of discontinuity, that are arranged in a straight line or a slight curve, as detected by remote sensing. Therefore, geological maps and on-site investigations must be used to eliminate possible errors. These features can be mapped at various scales from local to regional and can be utilized in mineral, oil and gas, and groundwater exploration studies. Lattman and Parizek (1964) are the first to adopt lineaments map to exploit groundwater. Thereafter, many scholars have applied this approach in complicated geological regions (Solomon and Quiel, 2006).

The lineaments map for the eastern Missan Governorate is obtained from Al-Moozani's (2008) study. The map is first scanned, rectified, clipped for the study area boundary, and then digitized using Editor tool in ArcMap of ArcGIS software (Fig. 11). From this map, lineament orientations are dominantly found in NE to SW and slightly NW to SE orientations. Generally these orientations correspond to the groundwater flow from NE to SW reflecting the importance of structural factor in determining groundwater flow through the area. The lineament – length density (L_d/L^{-1}) represents the total length of lineament in a unit area as: (Greenbaum, 1985)

$$L_d = \frac{\sum_{i=1}^{n} Li}{A} \qquad (2)$$

where $\sum_{i=1}^{n} Li$ denote the total length of lineament (L) and A denote the unit area (L^2).

A high lineament – length density infers high secondary porosity, thus indicating a zone with high groundwater potential. The lineament density of the study area is computed using density function of spatial extension of ArcGIS (Fig. 12). Most of the study area has lineament density less than 0.58 refers to small contribution of this factor in determining groundwater occurrence in the main aquifer. High class of lineament density is scattered in all parts of the project area. Moderate class concentrates in the northern portion of the study area.

3. Analytical Hierarchy Processes

The AHP are among the most ordinary used multi-criteria methods besides its flexibility in setting the objectives. AHP can commensurate the qualitative and quantitative decision attributes (Kanges, 1993). It is a mathematical method for analysis decisions with multiple attributes (Saaty, 1980). Formulating the decision problem in the form of a hierarchical structure is the first step of AHP. A hierarchy is an efficient way to organize complex systems. It is efficient both structurally for representing a system and functionally, for controlling and passing information down the system. In a typical hierarchy (Fig. 13), the top levels reflect the overall objective, i.e goal, (of the decision problem). The elements affecting the decision are represented in intermediate level (criteria). The lowest level comprises the decision options (alternatives). Once a hierarchy is constructed, the decision maker begins a priorization procedure to determine the relative importance of the elements in each level of the hierarchy. The elements in each level are compared as pairs with respect to their importance in making the decision under consideration. A verbal scale (also called Satty's scale, Table (**3**)) is used in AHP that enables the decision-maker to incorporate subjective, experience, and knowledge in an intuitive and natural way (Saaty and Vargas, 2000). After comparison matrix are created, relative weights derived for the various elements with respect to the elements in the adjacent upper level are computed as the components of the normalized eigenvector associated with the eigenvalue of their comparison matrix. Composite weights are then determined by aggregating the weights through the hierarchy. The outcome of this aggregation is a normalized vector of the overall weights of the options.

Pair-wise comparison is subjective in reality and the quality of the results is highly independent on the experts' judgment. Therefore, an index called consistency (*CR*) is used to indicate the probability that the judgment matrix was randomly generated (Saaty, 1980)

$$CR = CI/RI \qquad (3)$$

Where *RI* is the average of the resulting consistency index depending on the order of the matrix given by Saaty (1980) and *CI* is the consistency index. This index can be calculated as

$$CI = (\lambda_{\max} - n)/(n-1) \qquad (4)$$

where $\lambda_{\max}$ is the largest eigenvalue of the matrix and *n* is the order of the matrix.

4. Results and Discussions

The four thematic layers (geology, geomorphology, soil, and lineaments density) generated in the previous section were arranged in a geospatial database using spatial analyst extension of ArcGIS 9.3 software. All thematic layers were converted into raster grid of cell size 30m (x, y) forming 1826 and 1641 columns and rows, respectively. Prior to the integration of the selected thematic maps from previous sections, thematic maps and their attributes were assigned weights to reflect their importance to groundwater availability within the study area using AHP as implemented in **Expert Choice ™** (EC) software. EC 2000™ is a robust, desktop-based application that enables teams to prioritize objectives and evaluate alternatives and achieve alignment, buy-in, and confidence around important organizational decisions (http://www.expertchoice.com/products-services/expert-choice-115). The weights calculated for each thematic map were the results of pair-wise comparison of each map based on their relative importance to groundwater occurrence. First of all, the selected thematic maps (geology, geomorphology, soil, and lineament density) were assigned weights based on expertise opinion which reflect the importance of these maps in groundwater potentiality of the study area. Table (**4**) shows the result of pair – wise comparison of each map and normalized weighs in addition to consistency ratio.

Classification of geology thematic map attributes were done based on their formation character to transport and store groundwater. As state previously, Tertiary formations (Mukdadiyah and Bai Hassan) are more important than Quaternary sediments from the groundwater occurrence point of view. Pair–wise comparison was calculated, (Table 4), and the reclassified map of geology (Fig. 14), was produced based on the weights computed. The geomorphologic map of the study area was assigned weights and reclassified depending on pair – wise comparison. The reclassified map was shown in Fig. (15). The geomorphologic units were reclassified based on their characteristic to store and infiltrate water. The higher capabilities to infiltrate water, the higher weight assigned. The hydrologic soil group map of the study area was reclassified with respect to groundwater occurrence (Fig. 16), the higher ability of soil to infiltrate water, the higher chance to groundwater accumulation. The pair- wise comparison done was based on this fact. For areas with high infiltration rate higher weight was assigned (Table 4), and vice versa. The reclassified map of hydrologic map of the study area was produced based on these assigned weights. For analysis of lineaments in relation to groundwater availability, map of lineament density is reclassified based on the calculated weights (Fig. 17) after a pair-wise comparison has been done depending on the fact that areas close to lineaments are the higher zone of increased porosity and permeability which in turn have greater chance of accumulating groundwater. Consistency ratios of the assigned weights for all thematic layers and their attributes are found to be less than 10% and thereby suggesting that the assigned weights are consistent.

After assign weights for all thematic maps and their attributes, the data sets are integrated using a model that constructed in the ArcGIS Model Builder engine. Model Builder is an application that uses to create, edit, and manage models. Models are workflows that string together sequences of geoprocessing tools, feeding the output of one tool into another tool as input. Model Builder can also be thought of as a visual programming language for building workflows. The final groundwater potential map (Fig. 18) for the study area was produced by linear weighted combination using equation (1). The groundwater potential map of the study area revealed three distinct zones: high, moderate, and low groundwater availability. Table (4) shows the area covered by each of groundwater potential class, in which most part of the study area is regarded as of low potentiality. The 'high' groundwater potential zone mainly encompasses Tertiary sediments. The area covered by 'high' zone was about 554 km^2, while the moderate zone represents about 157 km^2. Considerable areas of southern and middle portions and small strip in the eastern part of the study area fall under 'low' potential zone. The area encompasses 'low' class was dominant in the study area and extend over an area of 1138 km^2. The result of this map suggests that the groundwater resources in the study area require careful management and pumping extraction plans. Tight control should be set before any plan to increase of extraction pumping wells in the study area is imposed.

4.1 Verification of the Results

The General Commission for Groundwater/ Missan has carried out well inventory for all production wells in the study area and neighboring areas. This was done through the completion of the information sheet for each drilled well. The information sheet contains the necessary information about the well including well coordinates, total depth, well diameter, length of screen, status of the well (operating or closed), pump type and its capacity, depth to groundwater, well discharging and sometimes measuring of some chemical parameters such as the electrical conductivity, pH, and temperature. The results of the well inventory indicate the total number of producing wells reaches 36 wells within the area between Teeb and Dewerage streams and the total drilled depth of these wells varies between (30-65) m. The delineated groundwater potential map was verified using the available abstraction rates of these wells (Fig. 19). It can be seen from Fig. (19) that out of 36 of wells, seven of nine wells with high pumping rate (6-8 ℓ/s) fall in high availability zone, whereas all wells of low pumping rates (4-5 ℓ/s) fall in the low zone. Seven wells of thirteen of medium pumping rates (5-6 ℓ/s) are located in high zone while three fall in low zone. Therefore, the prediction accuracy was 72%. Based on these findings, it can be inferred that the groundwater potential zones identified by GIS and AHP techniques are reliable and representative. The model generated will help as a guideline for designing a suitable groundwater exploration plan in the future and thereby help efficient planning of scare groundwater in the study area.

5. Conclusion

The use of remote sensing data, GIS, decision making techniques such as AHP, and probabilistic models such as frequency ratio, weight of evidence, and logistic regression along with artificial intelligent techniques such as artificial neural networks and fuzzy logic have been increasingly used in recent year for demarcating groundwater availability zones across the world. This study attempted to build a spatial model for delimiting groundwater potentiality using four thematic layers namely geology, geomorphology, soil, and lineaments. The map produced using integrated these thematic layers using spatial analyst extension of ArcGIS software and AHP and verified using available abstraction rates of boreholes reveals three distinct groundwater availability zones: low, moderate, and high. The low zone dominants the study area zone and extents over an area of about 1138 km^2. The moderate and high zones occupy 157 and 554 km^2, respectively. The accuracy of the verified model is 72%, and suggests that the model was satisfactory. The groundwater potential maps of the study area could be used for managing the aquifer in sustainable manner and drilling new wells in the high potential maps instead of low, hence enhance the process of aquifer protection from undesirable randomly pumping schemes.

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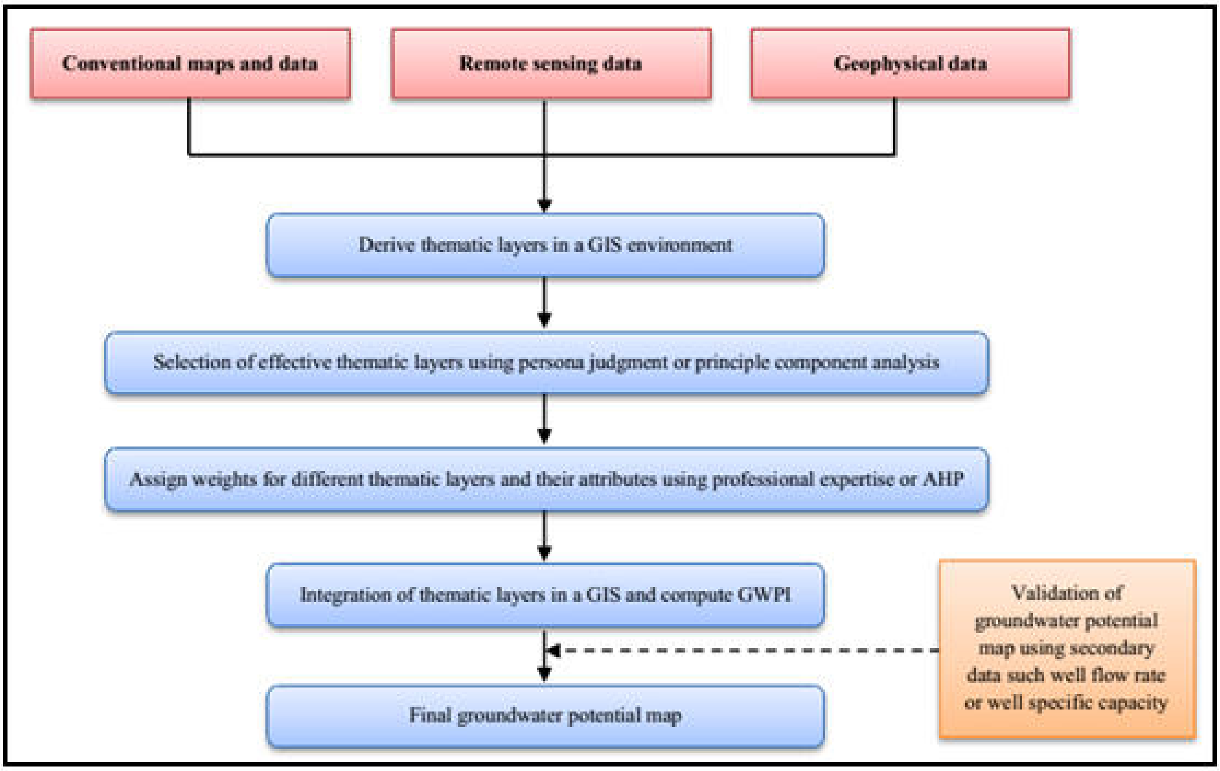

Figure 1. Flowchart for groundwater potential assessment.

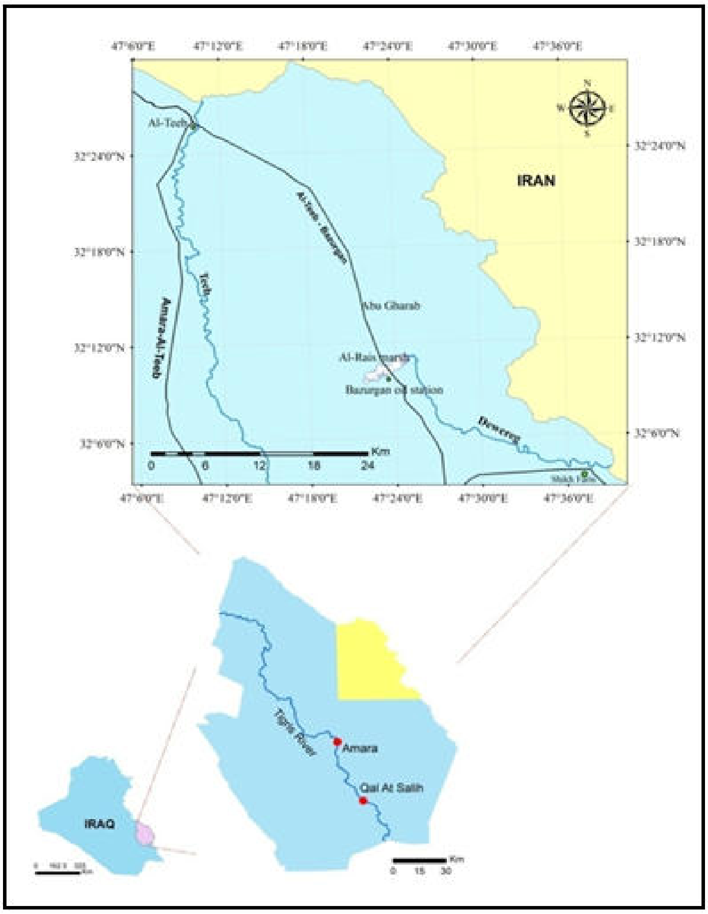

Figure 2. Location map of the study area

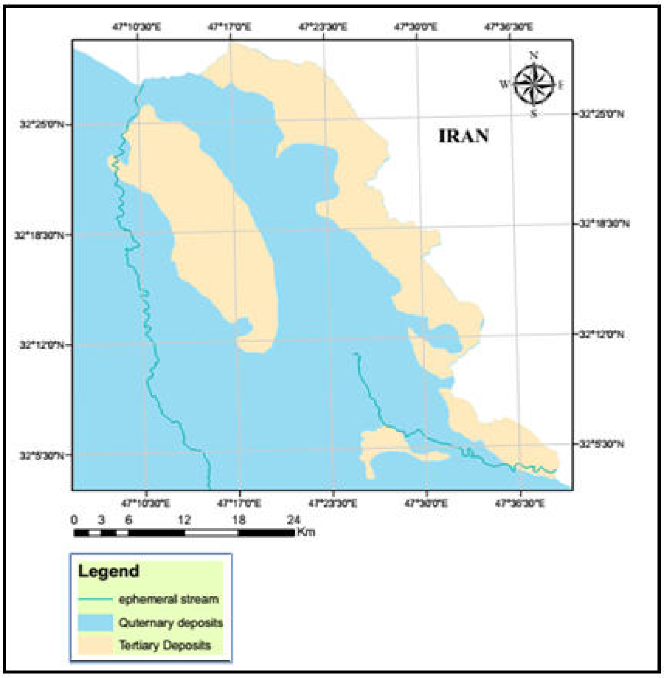

Figure 3. Geological map of the study area

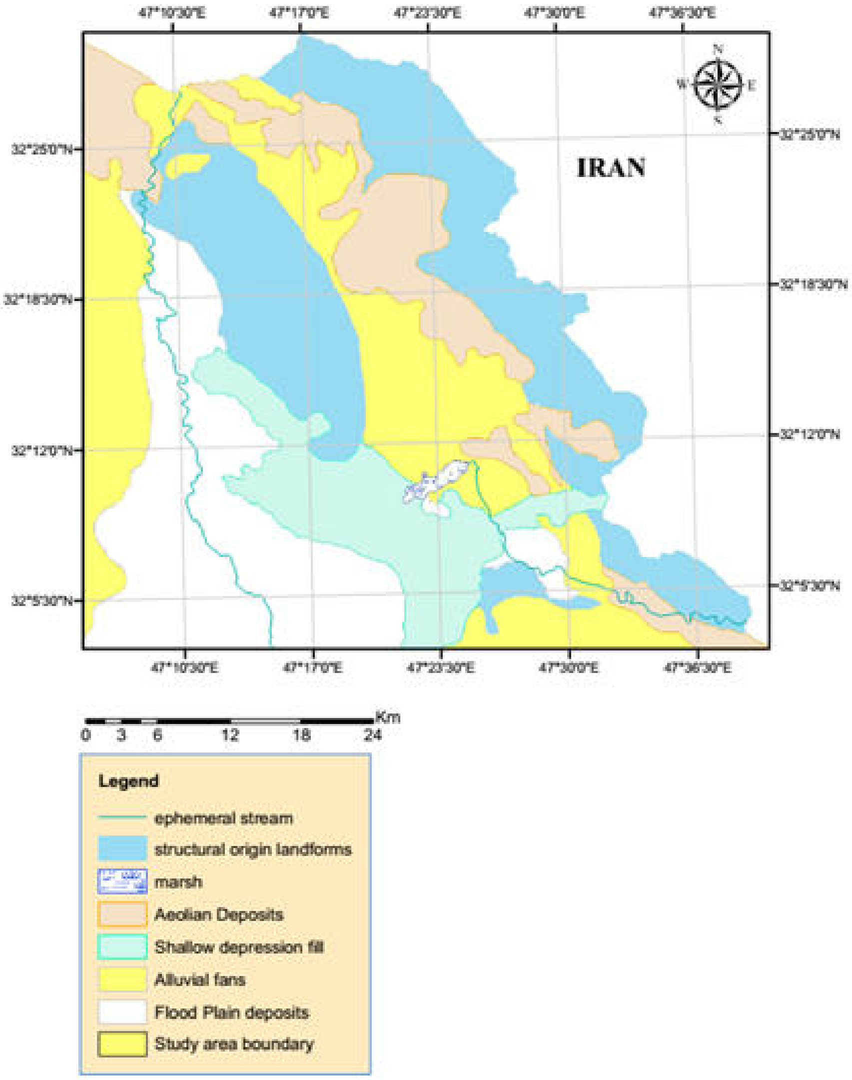

Figure 4. Geomorphological map of the study area

Figure 5. Geomorphological features in the study area. (a) Hills (b) shallow valleys (c) sebkha (d) marshes (e) sand duns

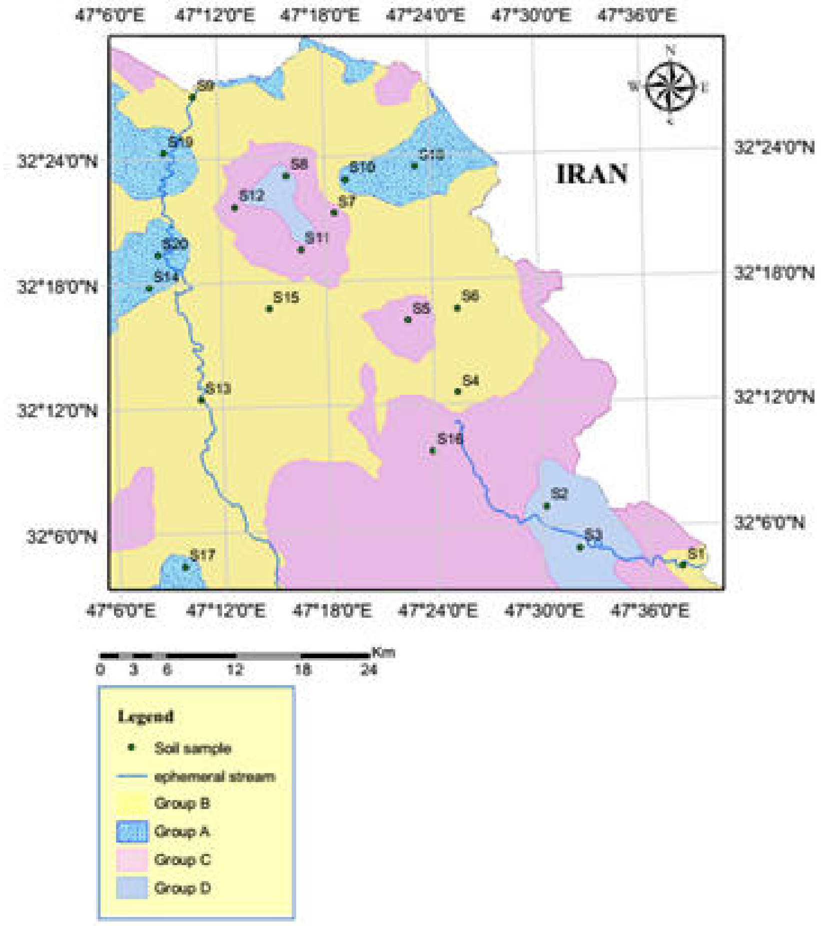

Figure 6. Hydrological soil group map of the study area

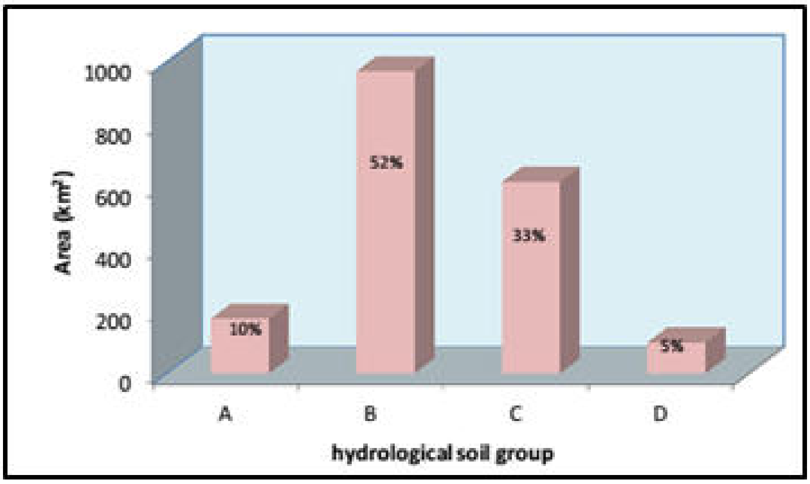

Figure 7. The percentage of area covered by each of the hydrological soil group

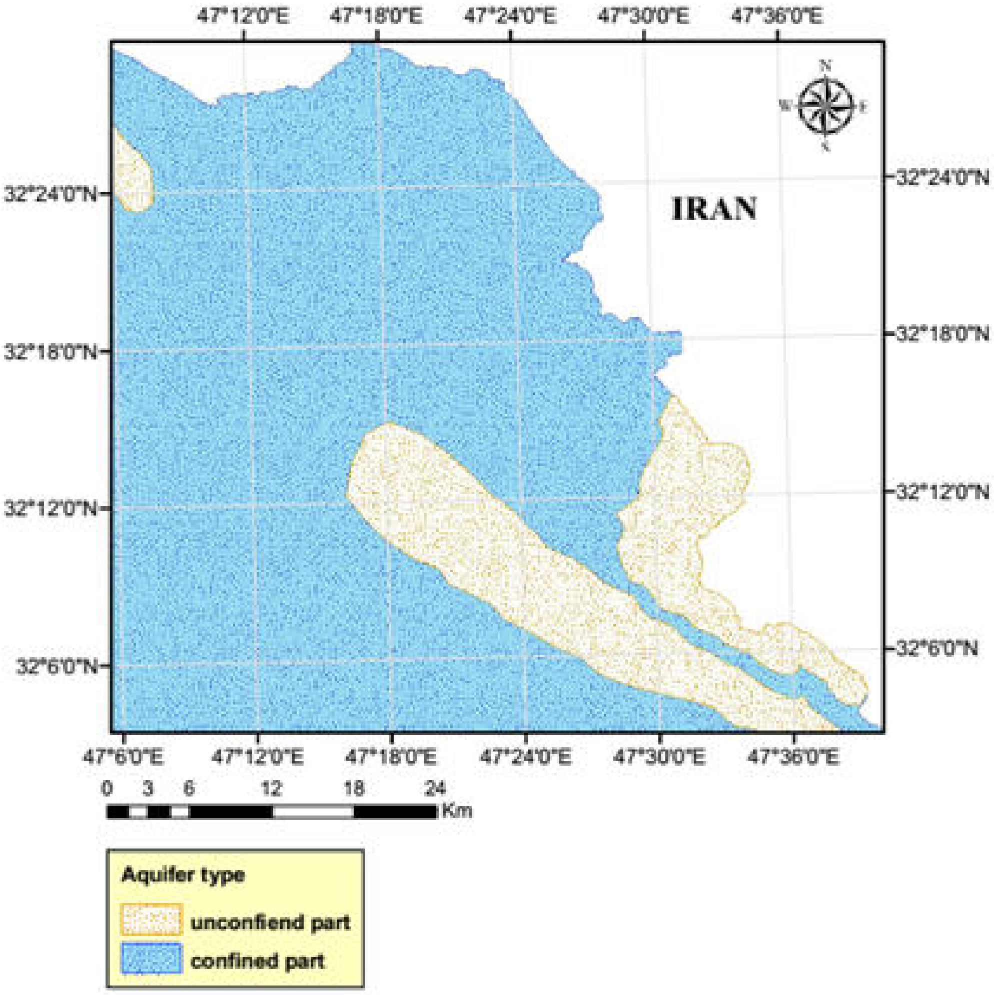

Figure 8. Spatial distribution of major aquifer type (confined or unconfined)

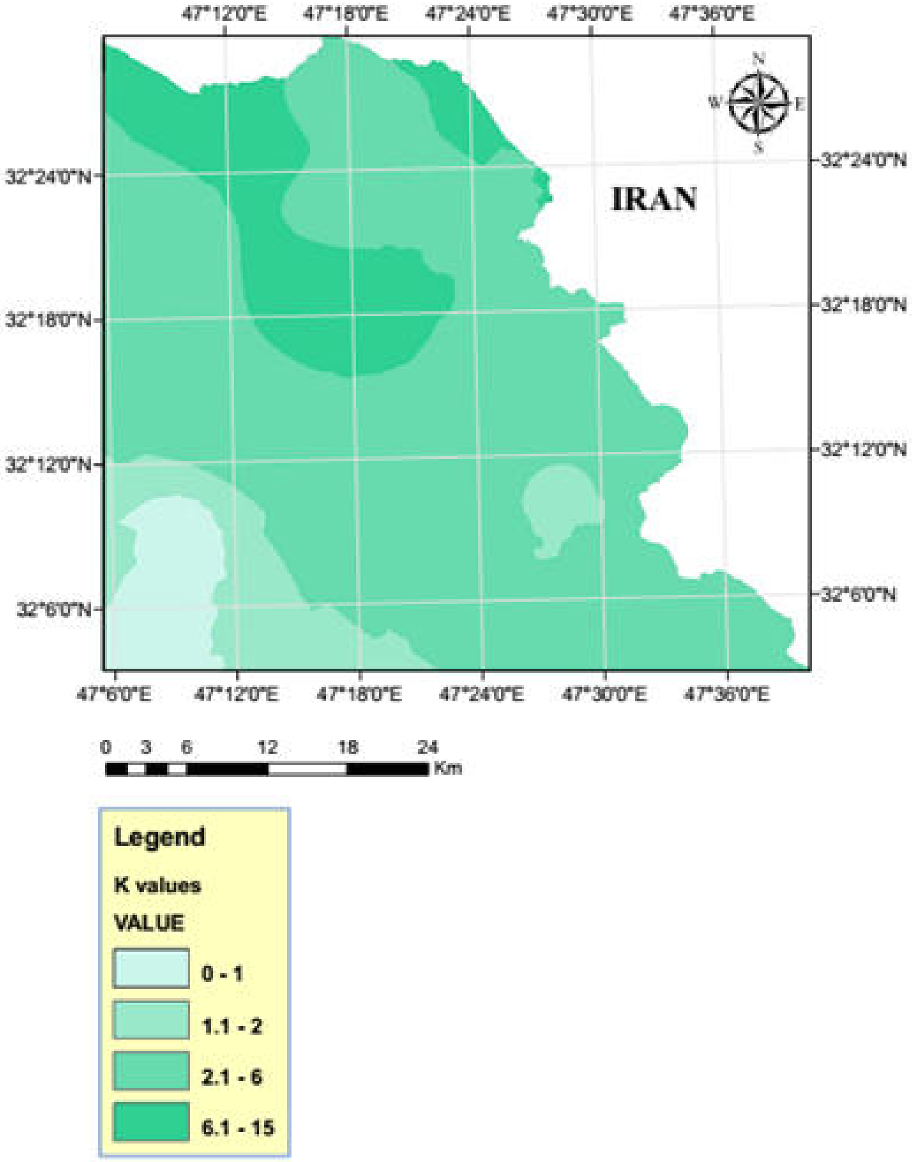

Figure 9. Spatial distribution of hydraulic conductivity in the study area.

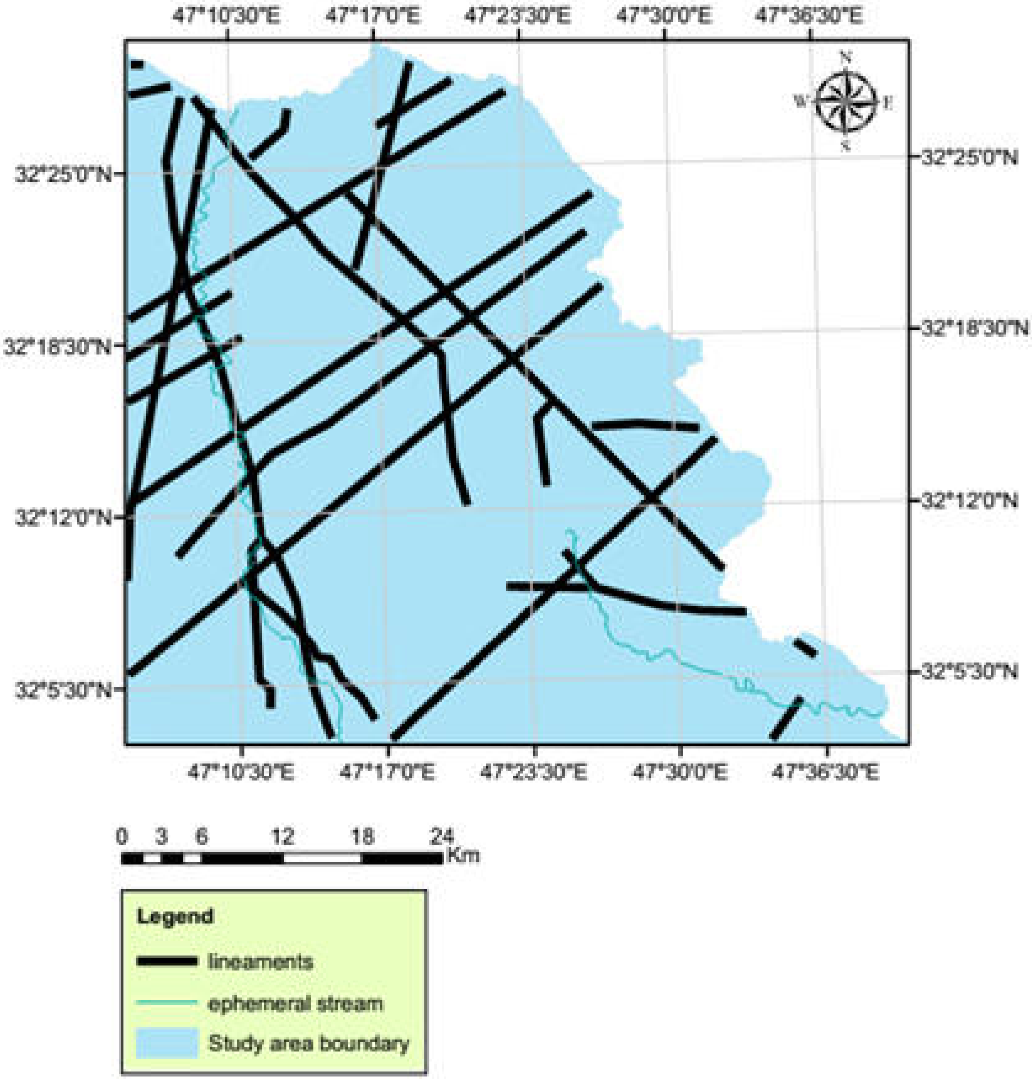

Figure 10. Lineaments in the study area

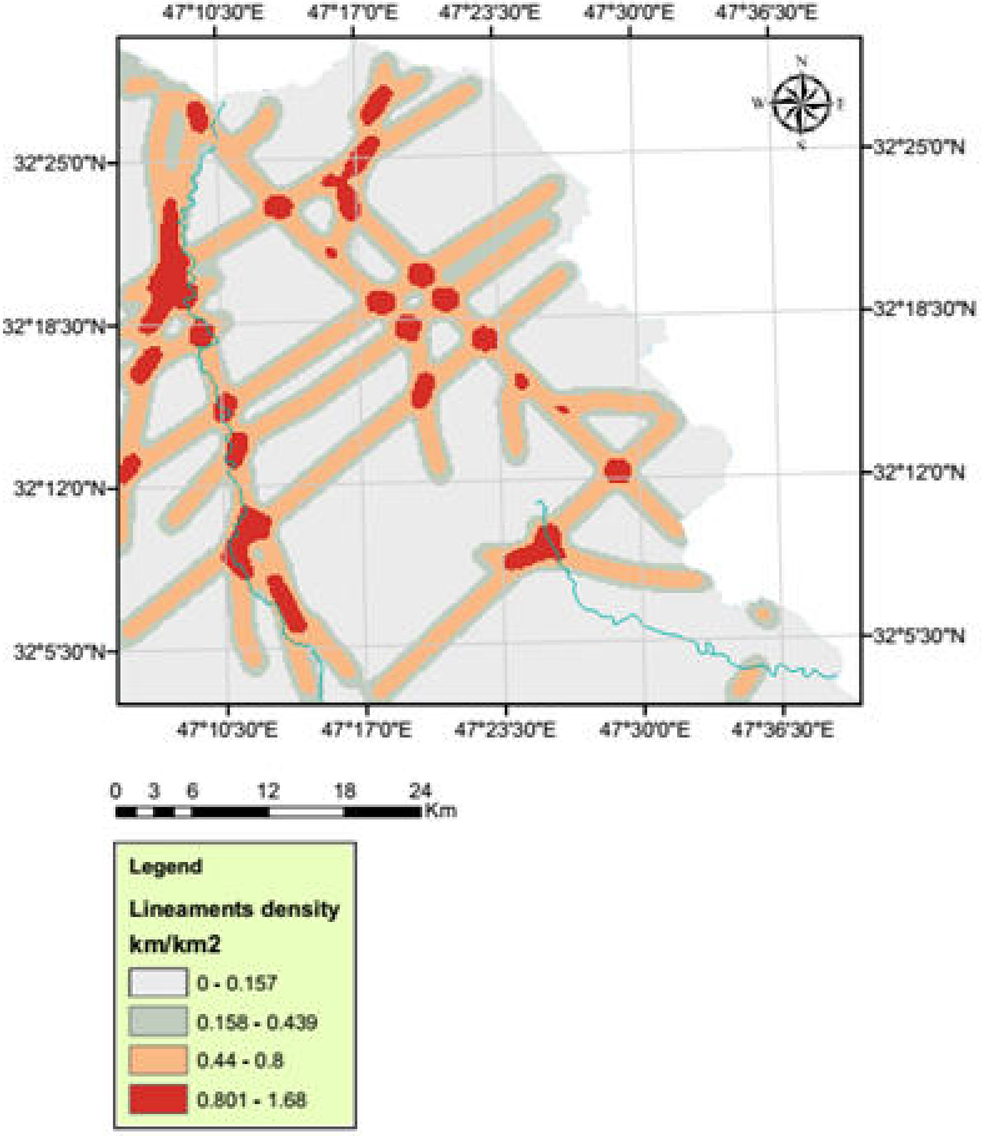

Figure 11. Lineaments density (km/km^2) in the study area

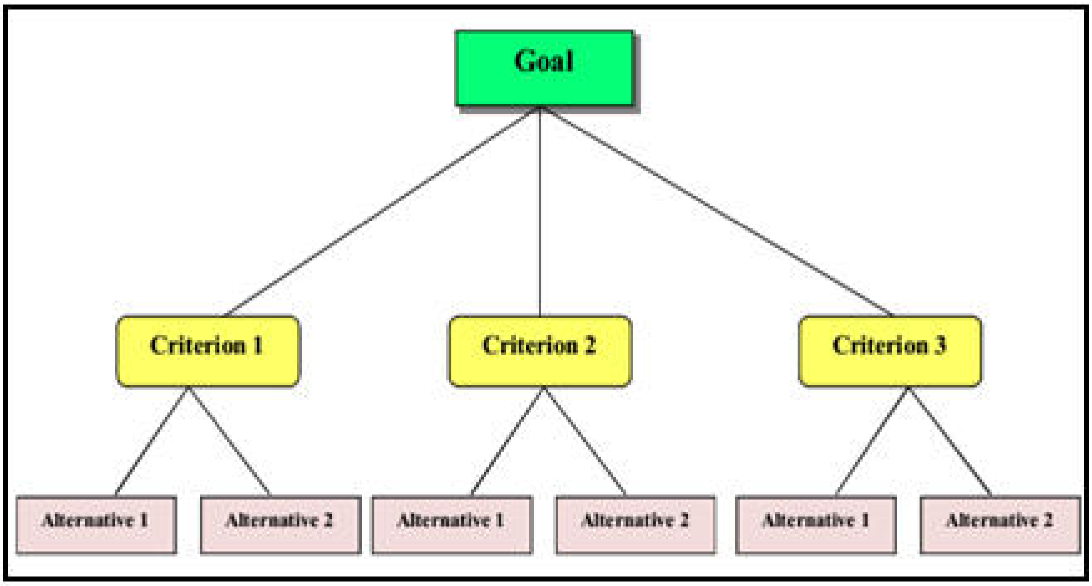

Figure 12. A three levels hierarchy

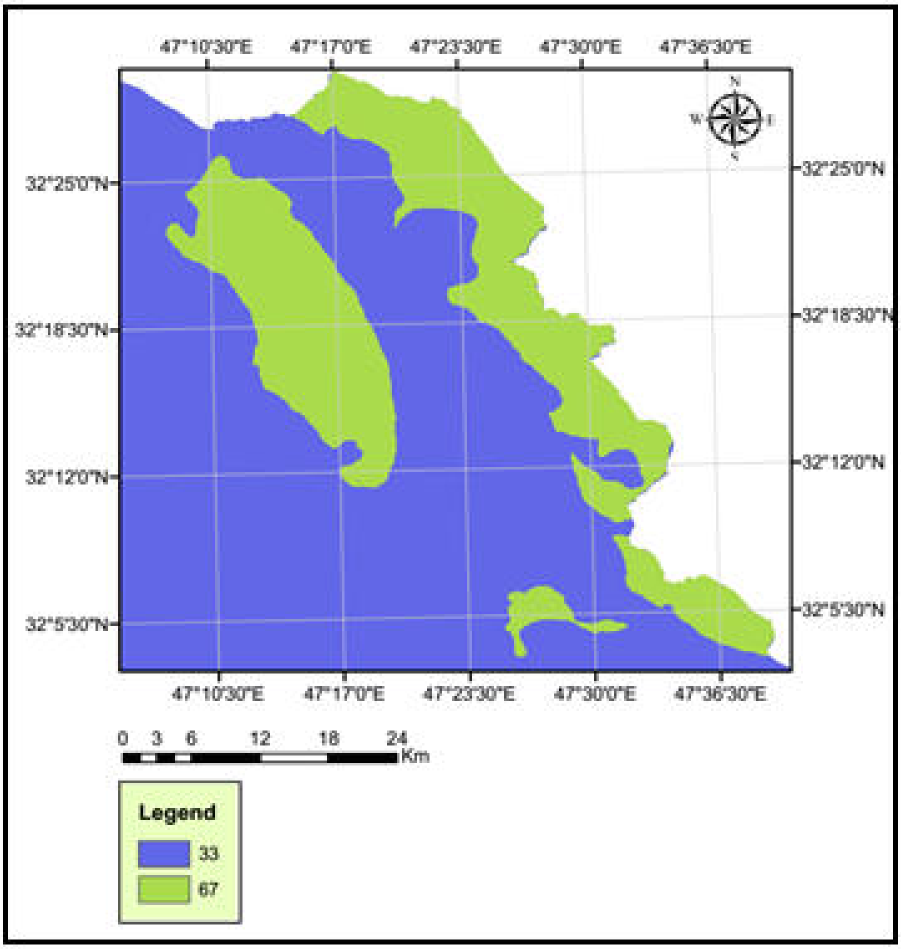

Figure 13. Reclassified geological map

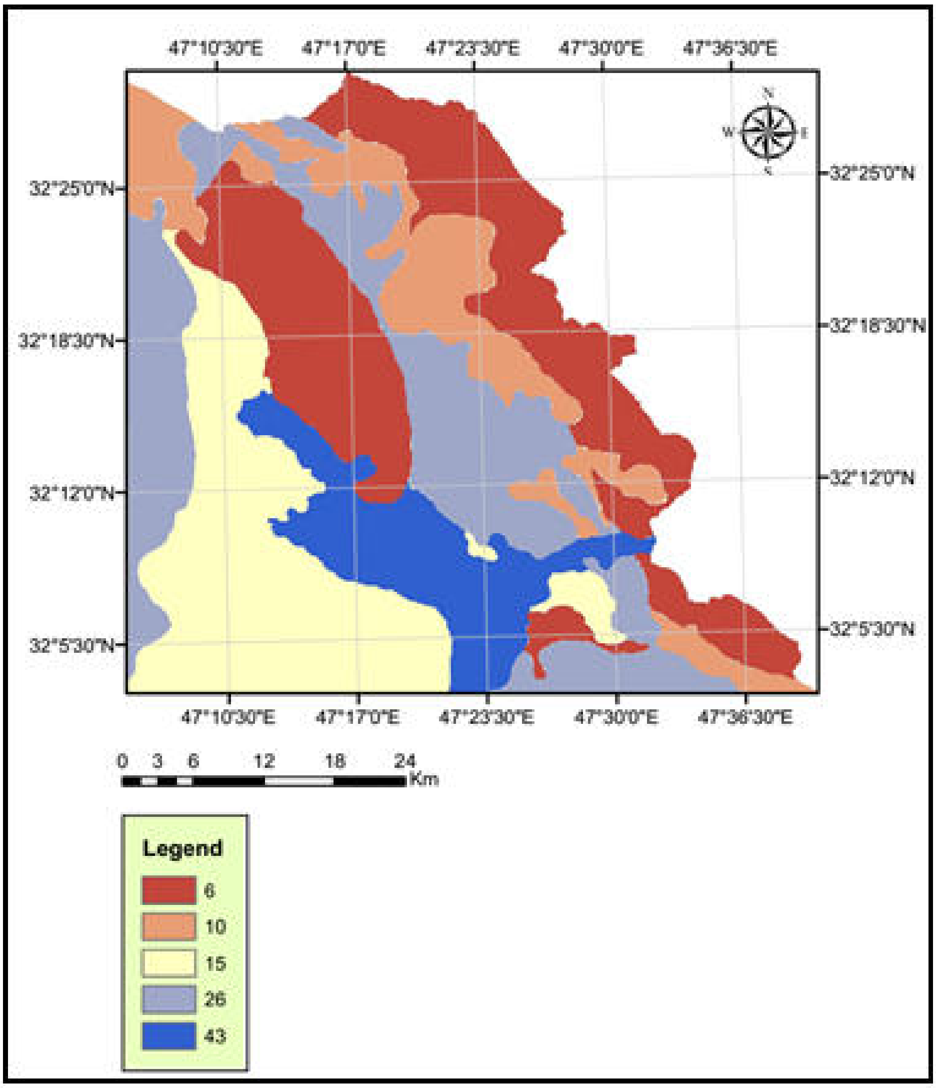

Figure 14. Reclassified geomorphological map

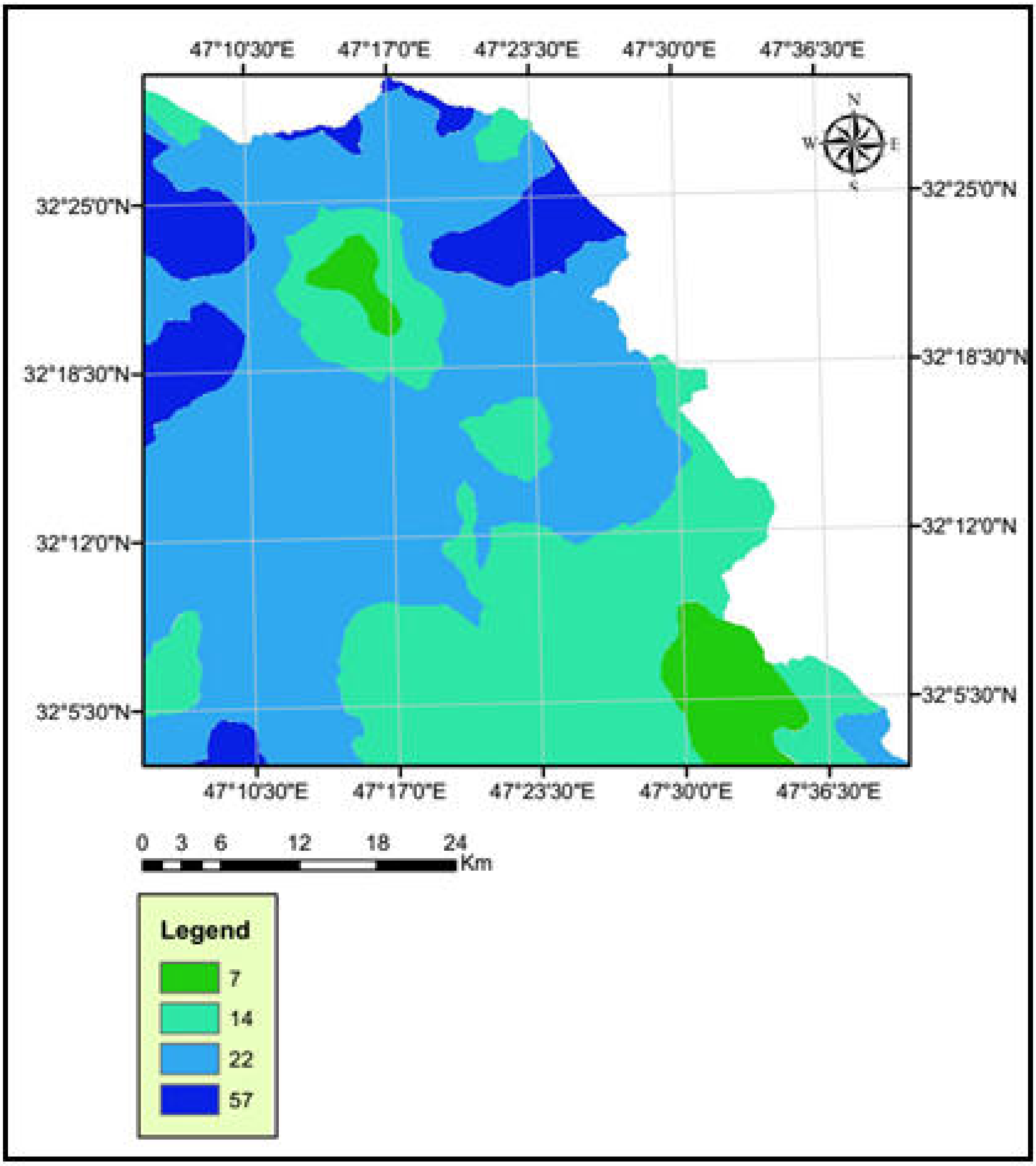

Figure 15. Reclassified map of soil

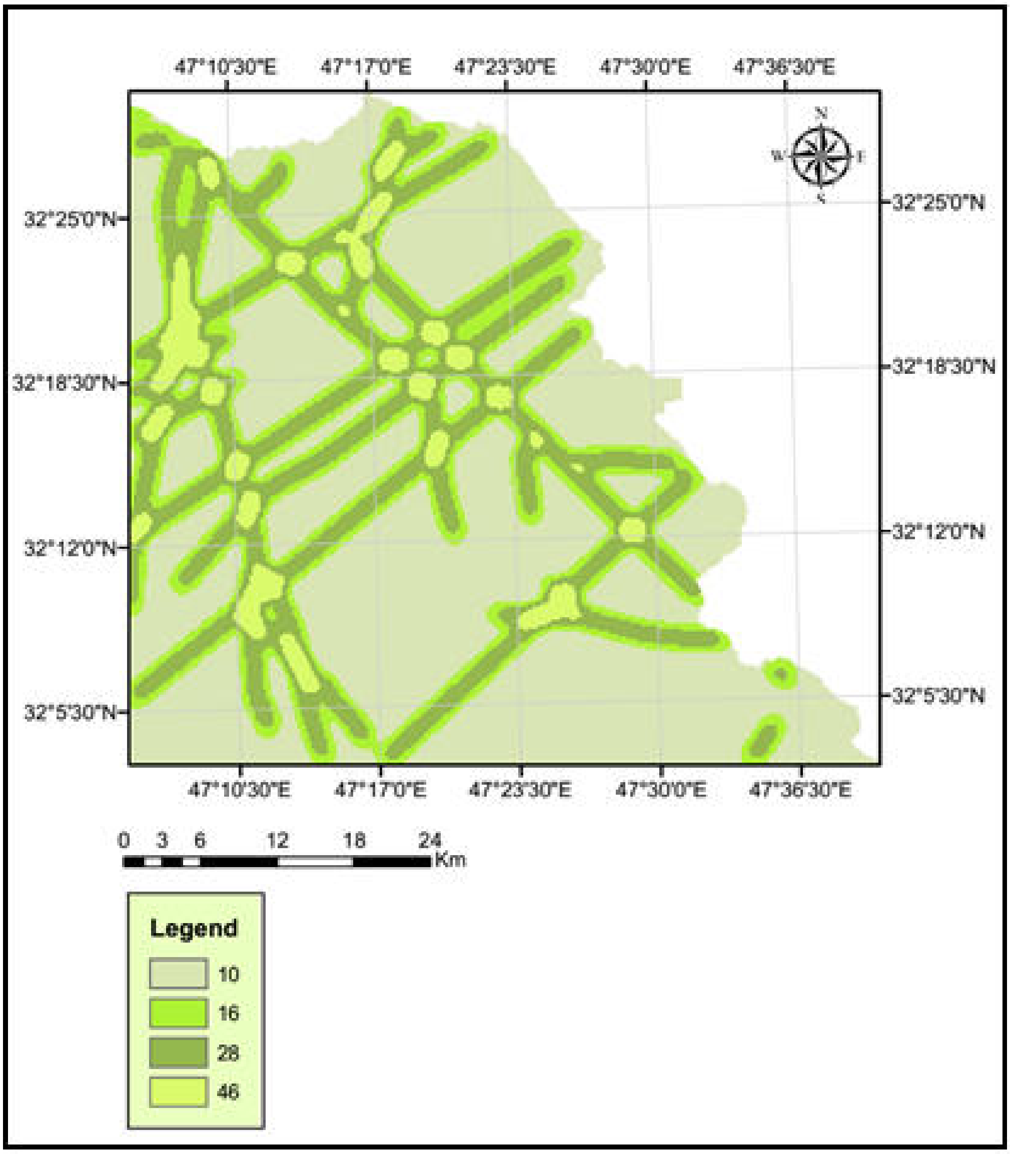

Figure 16. Reclassified map of lineaments

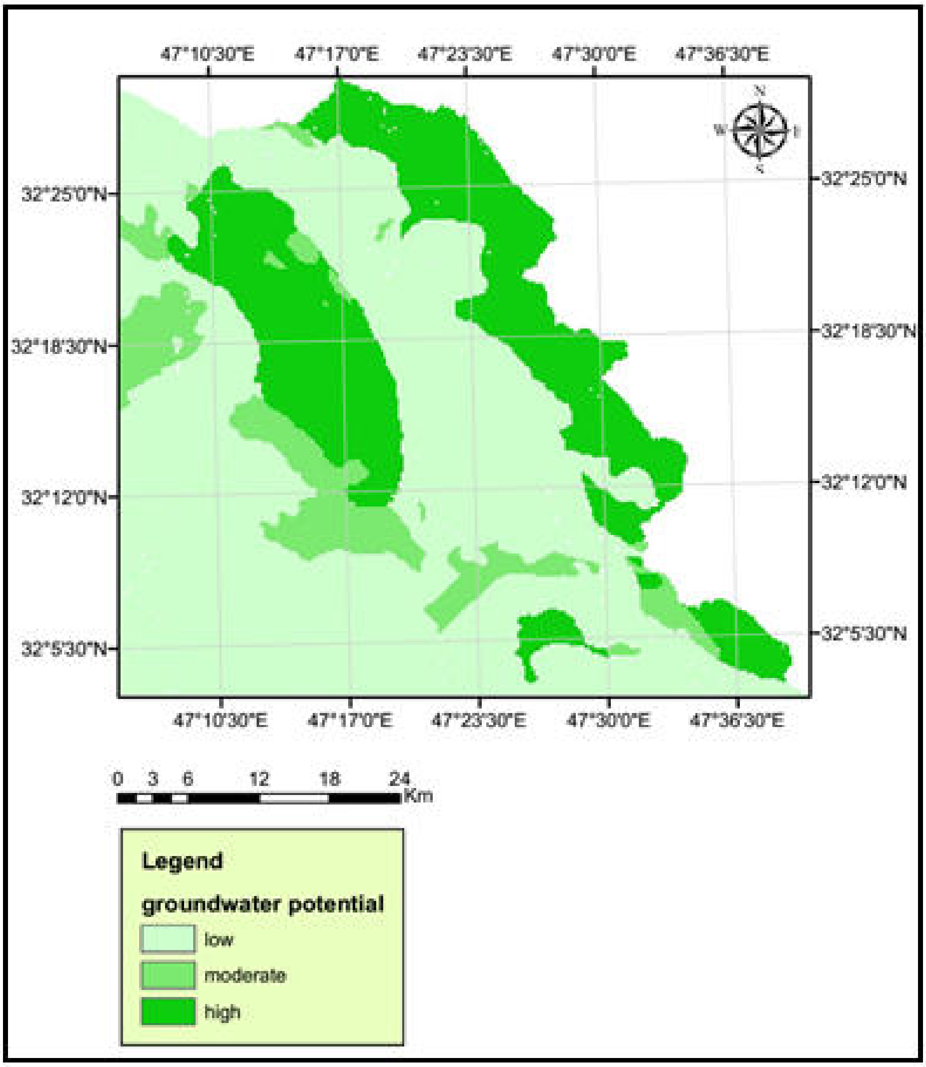

Figure 17. Groundwater availability map

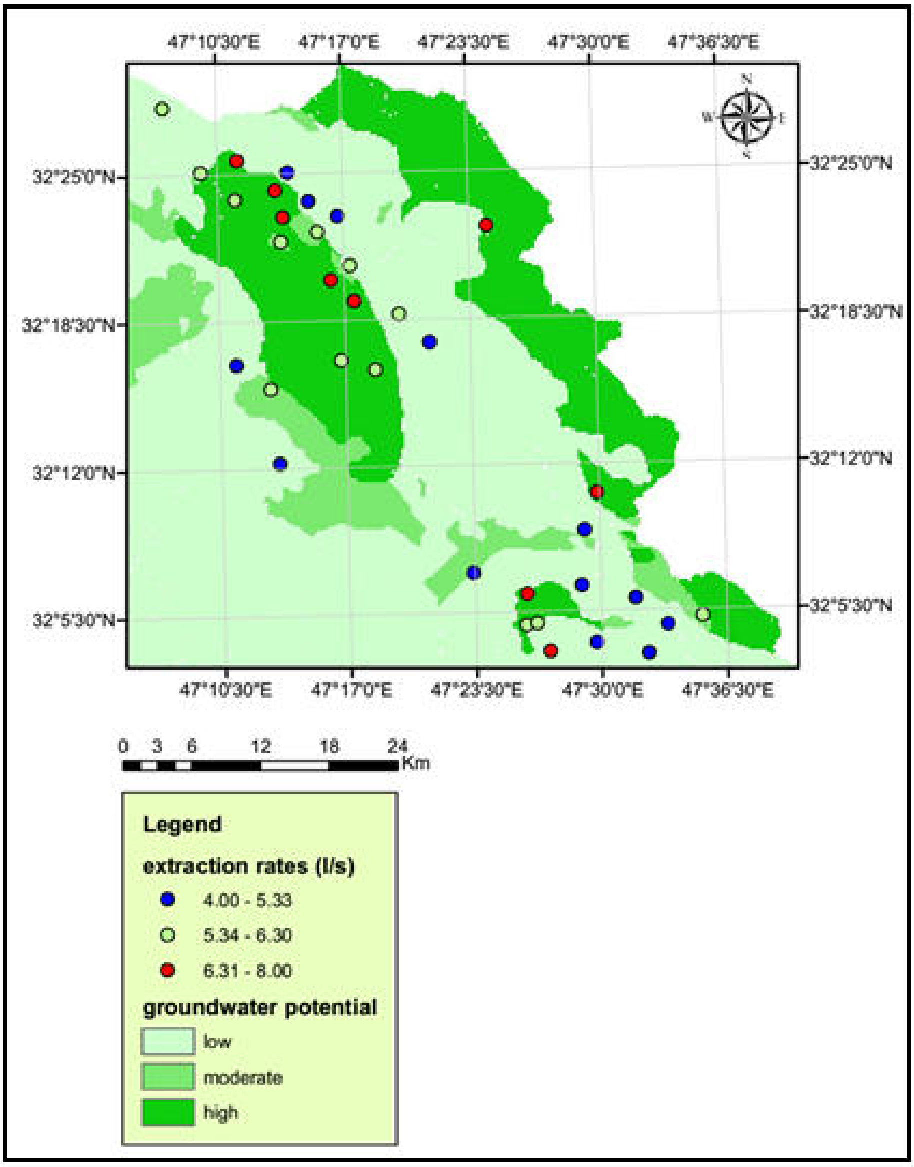

Figure 18. Verification results of analysis

Table 1. SCS Hydrologic soil group (USDA, 1986)

Soil group	Description	Final infiltration rate (mm)
A	**Lowest runoff potential**. Includes deep sands with very little silt and clay, also deep, rapidly permeable loess.	8 – 12
B	**Moderately low runoff potential**. Mostly sandy soils less deep than A, and less deep or less aggregated than A, but the group as a whole has above-average infiltration after thorough wetting.	4 – 8
C	**Moderately high runoff potential**. Comprises shallow soils and soils containing considerable clay and colloids, though less than those of group D. The group has below – average infiltration after presaturation.	1 – 4
D	**Highest runoff potential**. Includes mostly clays of high selling percent, but the group also includes some shallow soils with nearly impermeable sub-horizons near the surface.	0 – 1

Table 2.: Hydraulic conductivity and transmissivity for sediments in the study area (after Al-Jaburi (2005))

Sediment type	Hydraulic conductivity (m/d)	Transmissivity (m^2/d)
Quaternary	0.5 – 15.5	12 – 290
Tertiary	2 – 25	400 – 500

Table 3. The fundamental scale of Saaty (after Saaty and Vargas, 2000).

Intensity of importance	Definition	Explanation
1	Equal importance	Two objective contribute equally to the objective
2	Weak	
3	Moderate importance	Experience and judgment slightly factor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity i has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with j	A reasonable assumption
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining n numerical values to span the matrix

Table 4. Normalized weights for factors and their classes used for analysis of groundwater potential mapping

Theme	Normalized weight of theme w_j	classes	Normalized weight of class x_i	$w_j x_i$
Geology	55	Tertiary	67	3685
		Quaternary	33	1815
Geomorphology	23	Originally structured units	6	138
		Aeolian deposits	10	230
		Flood plain	15	345
		Alluvial fan	26	598
		Shallow depression	43	989
Soil	14	A	57	798
		B	22	308
		C	14	196
		D	7	98
Lineaments density (km/km^2)	8	Highly dense	46	368
		Dense	28	224
		Moderate	16	128
		Less dense	10	80

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