Development of Ground Water Exploration in Karst Areas Using Remote Sensing and GIS

Saied Pirasteh[1], *Syed M. Asghar Rizvi*[2]

1- Remote Sensing and GIS, Faculty of Engineering, Islamic Azad University, Dezful Branch, Dezful Iran
OR
1-Institute of Advance Technology, Engineering, University Putra Malaysia, Malaysia
Email: moshaver1380@yahoo.co.uk
2- Remote Sensing center, Department of Geology, Aligarh Muslim University, Aligarh India

Abstract

The Pabdeh anticline belongs to the Zagros Mountains in the southwest Iran. This area is exposed in the karst region of Iran. Remote sensing and GIS are rapidly increasing role in the field of hydrology and water resources development. The Landsat ETM -7 data with path/row 167/038 dated September 2002 were used in conjunction to digital topographic maps in scale 1:25000 within GIS environment to study the development of ground water in the main watersheds of the Pabdeh. The area has been visually and digitally interpreted to delineate DEM, drainage network, drainage basin, karst landforms, lineaments and lithology for the development of ground water and favorable areas for exploration. Image elements are used during visual and digital interpretation. Extensive field works have been attempted using global positioning system (GPS) to collect water samples and to emphasis image interpretation. Water samples were chemically analyzed. The study shows that the ground water is controlled by geomorphology, chemical properties of water, lineament analysis, lithology and topography. The integration and combination of these parameters in geographic information system (GIS) environment reveals that the thick layer of alluvial, Asmari dolomite and limestone formation in the study area is suitable for ground water development. The study shows 10 suitable locations as potential zone. This study also shows the advantages of remote sensing and GIS techniques for Karst and water resources study. The study also suggests that for increasing the accuracy for exploration, geophysics methods should be applied.

1. Introduction

The Zagros Mountains are parts of Alpine-Himalayan orogenic system. Basically Zagros mountain is divided the orogene into three structural zones, such as 1-An inner crystalline Zone of overthrusting, 2-An Imbricated Belt, and 3-Zone of Folding often referred to the Simply Folded Belt (Stocklin,1968 and Falcon,1969) 4- Molasse Cover Sequence (MCS) which are characterized by distinct geological and geophysical signatures (Pirasteh and Ali, 2005). Zagros mountain is well developed for water exploration and other natural resources. Pabdeh area in Khuzestan province is one of the parts of Zagros Fold Belt (ZFB) and is exposed by karst topography and high tectonic activities. Ground water is a precious of limited extend (Saraf et al., 2004).

Karst terrain is a complicated and widespread phenomenon on the surface of the earth. Karst topography is commonly found in carbonate rocks, including limestone and dolomite of the Pabdeh area in the Zagros mountain southwest Iran. This area is characterized by closed surface depression and a well-developed drainage system (Berberian, M. and King, 1981, Pirasteh and Ali, 2002, and Pirasteh, 2004). The remotely sensed data and geographic information system (GIS) techniques are used for the hydrology and hydrological studies of karst areas. One of the greatest advantages of using remote sensing data for hydrological investigations, groundwater monitoring and karst region is ability to generate information in spatial and temporal domain, which is very crucial for successful analysis, predication and validation (Saraf, 1999).

Satellite data was visually interpreted and further digitally processed to enhance the objects and identify different lithologies in the area. The digital geological map of the area is prepared in conjunction to the geological map in scale 1: 100,000. Digital topographic maps in scale 1: 25000 are also used in GIS environment to generate digital elevation model (DEM). Water samples were chemically studied and used as a theme for analyzing in GIS environment to delineate groundwater potential areas.

Basically, the area is tectonically active and generates lineaments and fractures, which control the ground water. Therefore analysis of the total length of the fractures, number of fractures and fracture's junctions are carried out in order to find suitable areas for groundwater exploration. Geomorphology of the area is studied on the basis of DEM in GIS environment. Landforms such as sinkhole, doline, cave, karren, large valleys, and water gap is interpreted and extracted on the image using image elements beside extensive field works. The various themes were extracted within the GIS environment in order to analyze the favorable areas for groundwater exploration.However, there are reasons for the present study: **a**- Zoning suitable areas for groundwater exploration and generation a map for water plant energy of Iran **b-** influences of structure and tectonic activities in controlling groundwater in karst region and finally **c-** to emphasis great advantage of using of remote sensing, GIS techniques and DEM in groundwater potential zoning in karst areas.

2. Study area

The Pabdeh anticline lies between 49° 15′ 00″ – 49° 30′ 00 ″E and 32° 00′ 00″- 32° 25′ 00″ (Figure1). The Pabdeh anticline falls within the Pabdeh-Lali district of north Kuzestan province in the southwest of Iran. It is parts of the Zagros Mountains.The area has rugged topography. Elevation ranges between 230 meters to 1690 meters.

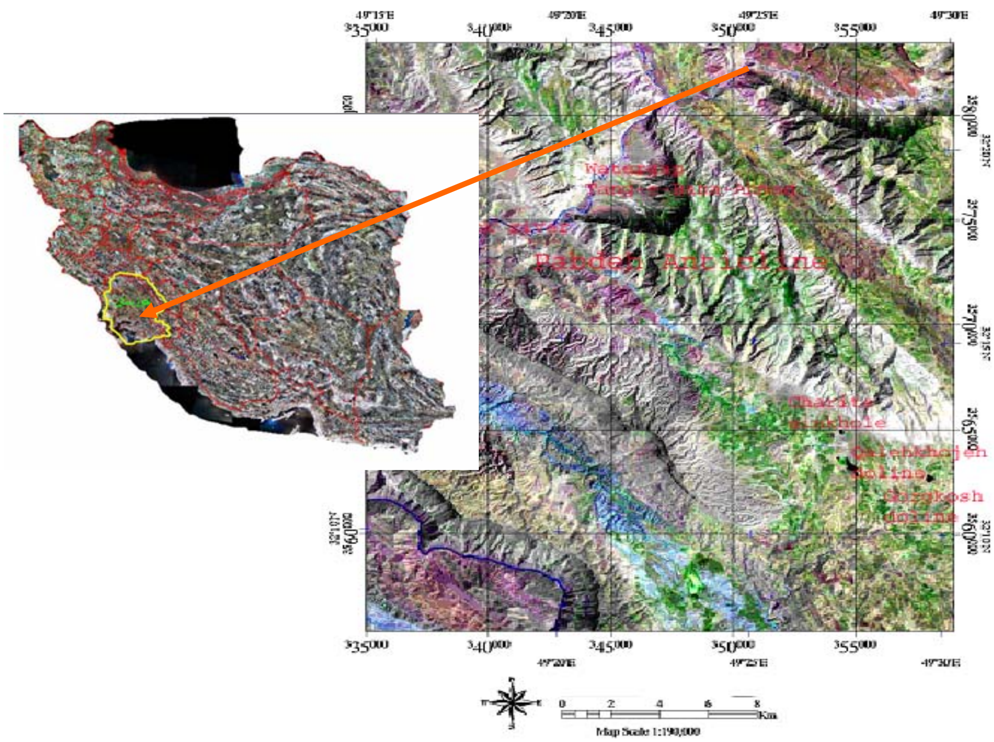

Figure 1: Showing the study area in Papbdeh anticline, Khuzestan province southwest Iran

3. Geological Setting and Geomorphology

Geologically, study area comprises of gray marls, red marls, limestone, dolomite, conglomerates, sandstone, sandy lime, calcareous and alluvial. The age of the study area ranges from Lower Cretaceous to Recent and Subrecent. Lithologically, the Papbdeh area consists of different lithounits Formation such as Ilam-Sarvak, Pabdeh-Gurpi, Pabdeh, Mishan, Asmari, Gachsaran, Aghajari, Lahbari member of Aghajari, Bakhtyari Formations, Subrecent conglomerate, alluvial and Recent deposits (Figure 2). Each litho type has different texture, structure, porosity and permeability. Thus the rock types in the study area play an important role to groundwater potential.

On screen digital interpretation on the ETM+ satellite image and GIS analysis shows that the Asmari Formation comprises a more percentage of lithounits in the study area. It is covered about 25 percent of the total study area. Percentage of rock types beside other information like structural features, karst features,DEM, slope and tectonic-gomorphological features could be used as one of the themes to evaluate the water potential zones in the study area.

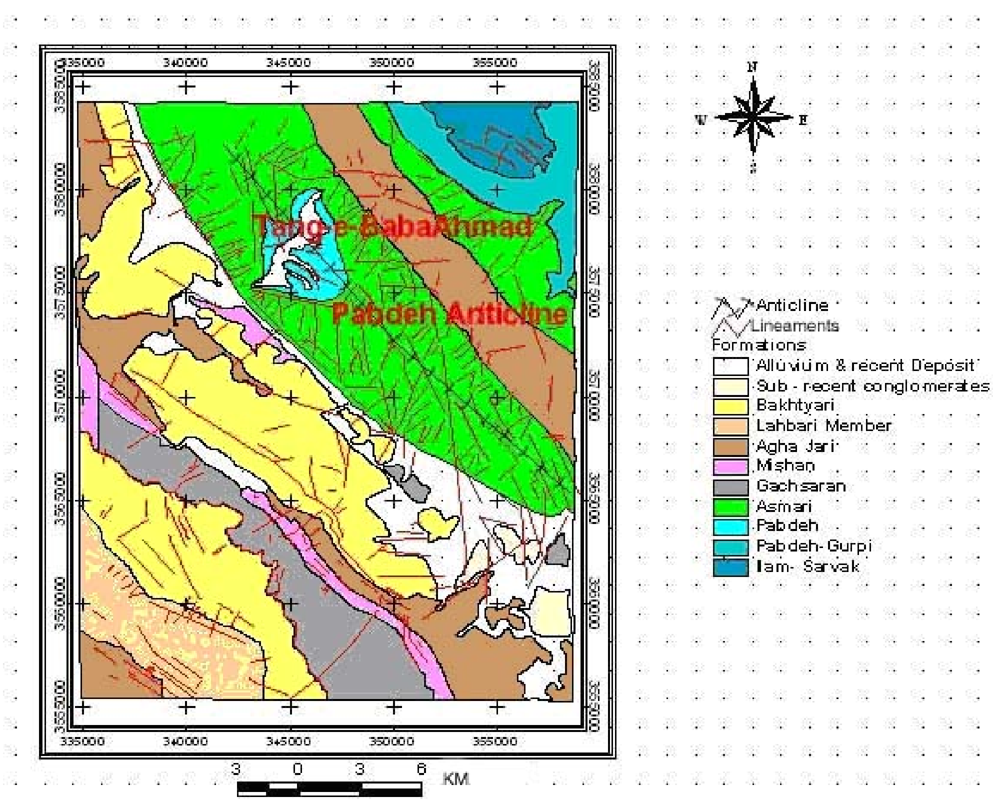

Figure 2: Digital geological map of the study area. Prepared in GIS environment.

Geomorphologically, in the Zagros Mountains as folds are exhumed, variation in the resistance of Asmari strata produce a unique topography which characterized by large anticline. Thus elliptical Asmari hogbacks encircling breached anticlines (Ali and Pirasteh, 2004), where exhumation has been greatest, by rugged topography sculpted from Mesozoic carbonates in the inner cores of the anticlines (Oberlander, 1965 and Stephen et al., 1994).

Synclinal folding tends to close fractures and thicken rock units along the axes of synclines. It is common for synclines to become rugged in the Zagros Fold Belt as the topography of a fold and thrust belt is eroded down.

In the Zagros Fold Belt, young folds and thrusts belt and rivers are generally controlled by topography, faults and lineaments. Rivers and drainages flow along the axes of anticlines, synclines, faults and fractures. This is seen in Tang-e-Baba Ahmad (Figure 3) of Pabdeh anticline in the study area. As the stream system evolves by head ward migration and stream capture, the stream may eventually flows across the regional structure in the Zagros Fold Belt. These structures exhibit tight fold with NW-SE trend and closely space fracture systems. These styles of geological setting facilitated severe erosion and formation of rugged and immature topography with closed drainage system. The drainages also are controlled by fractures and faults system towards NE-SW direction. The hogback ridges in the study area are characterized by high resistance to erosion and structural discordance with the tectonic grain of the Zagros Fold Belt.

Groundwater areas are characterized by geomorphic landforms. Basically, geomorphic karst landforms are seen on the Landsat ETM+ image as well as DEM (Figure 4) is such sinkhole, doline, drainages network (Figure 4), topography, valleys and water gap (Figure 3). Some of other landforms like cave and Karren are delineate from the field check.

Figure 3: Showing water gap in Tange-baba Ahmad, Pabdeh anticline, ZFB, Iran

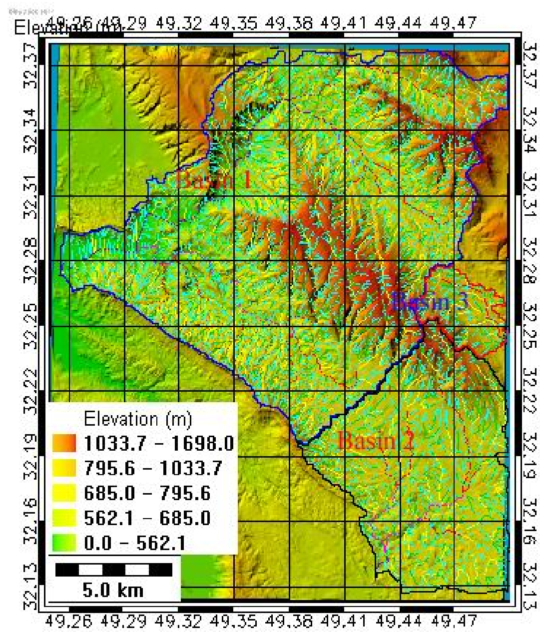

Figure 4: Showing drainage network and basins in the study area overlay on DEM

4. Structures

Structure term is used in structural geological sense, and is concerned with the attitude and deformational effects of bedrock. Limestones and dolomites of Pabdeh anticline at or near the surface tend to be deformed by brittle fractures. This tendency to form complex joint sets is directly responsible for the secondary permeability required for the development of subsurface solution drainage.

Large-scale structures or tectonics (Ali and Pirasteh, 2003) not only have led to the development of specific landforms like sinkholes in the Pabdeh area but have also influenced the rates and degree of karstification. Faults in the study area are closely spaced along where there is relative sliding movement of the blocks. Most of the litho-tectonic units have responded crustal shortening by brittle failure. The important faults in the study area have been named after settlement features developed in the neighborhood of the failure surfaces. Faults in the study area are commonly: 1- thrust fault, 2- strike faults, 3- normal faults, and 4- reverse faults. Fracture density gives information about the groundwater efficiency in the area. Fracture map of the study area (Figure 5) was prepared in GIS environment using Arcview 3.2 software. The fracture system was used in GIS environment as one of themes to delineate the groundwater for exploration. The digital fracture system is also used in GIS environment to create iso fracture map (Figure 6) as well as incidence map (Figure 7). This type of analysis beside other themes in GIS environment plays an important role to identify groundwater areas for exploration.

The interrelationship of iso fracture with springs and surface water shows the groundwater follows main faults, lineaments and fractures in N-S and E-W directions. The resources of water in back limb of the fold are probably not related to the forelimb. This fact could also satisfy by determining the chemical properties (i.e. water elements) in the laboratory. Thus groundwater in the both limbs of the fold is showing different resources and reservoirs. It is also supported by the geomorphological analyses in GIS environment. It is seen that the study area comprises three main watershed basins showing in Figure 4. A large part of the area is occupied by high lineament density and lineament incidence. These are exhibit in forelimb of the fold with favorable litho units, which do much infiltration and hence are generally favorable and suggested for groundwater exploration. The low density and incidence lineament, gentle slope, presence of sandstone and marls of Aghjari Formation in the back limb of the fold are generally factors to make the back limb of the Pabdeh anticline as a poor zones or moderately favorable zones of groundwater.

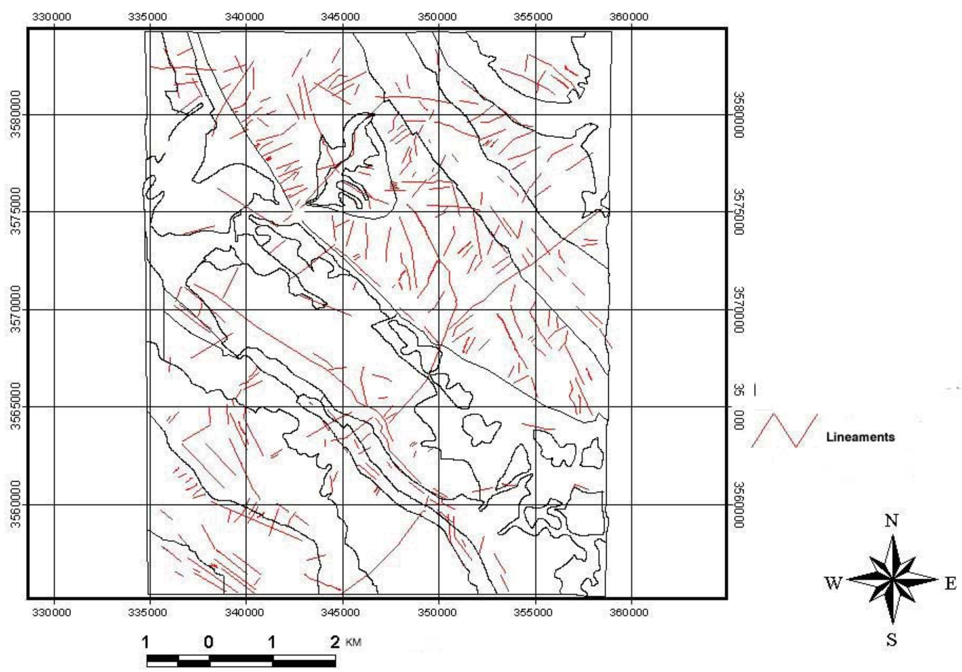

Figure 5: Structural map of the Pabdeh anticline, Zagros Fold Belt, south west Iran

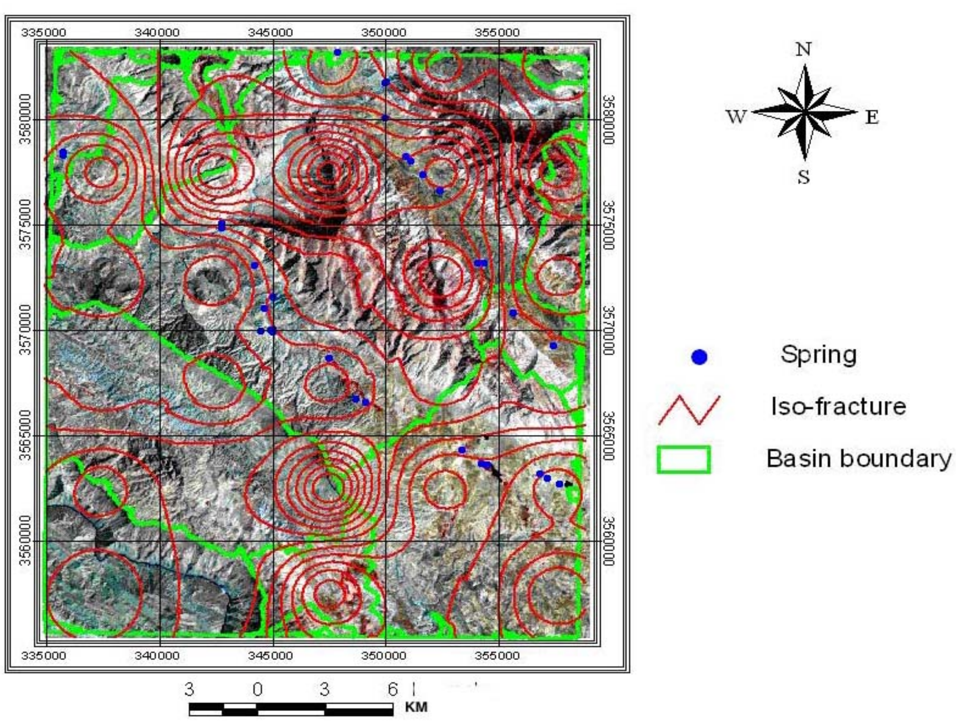

Figure 6: Iso fracture map of Pabdeh anticline, ZFB southwest Iran.

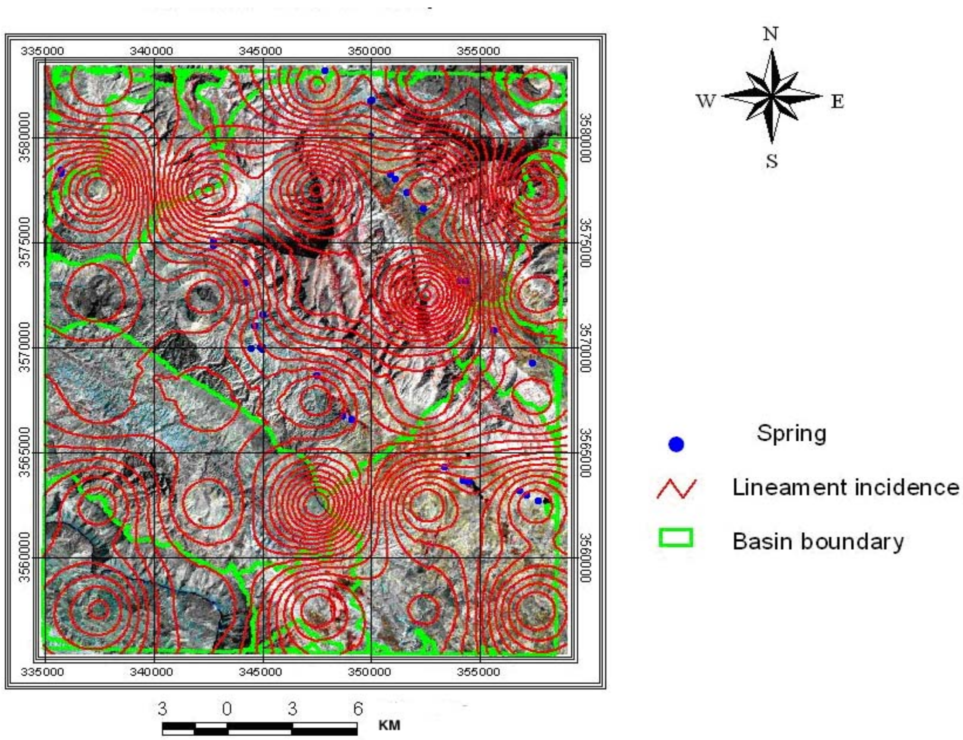

Figure 7: Showing lineament incidence map of the study area

5. Methodology

Remote sensing and GIS techniques are used to extract the ground water suitable areas in karst region. On this purpose to identify the fracture system image elements are used. It is further correlated to the available geological map in scale 1:100,000 of geological survey of Iran with several field checks. Shape, tone, texture, vegetation linearity, topography, erosion, land use, drainage network were used as interpretation keys to extract the objects lineaments, lithology and geomorphological landforms (i.e sinkhole, doline, valleys and water gap) from the image by using environmental visualization image (ENVI 3.6) software. Various enhancements such as linear 2 percent, edge enhancement and sharpen filtering were applied to highlight objects on the image. Karst topography is identified by using light tone and rectangular with medium to coarse grain network system on the image in the study area. Visual interpretation has also done on the image to identify karst landforms like sinkhole and dolines on the basis of the texture, dark tone and topography. On the basis of image elements techniques and available information and field checks the lithological contact in each lithounits was digitized on the satellite image and compiled with the old geology map 1:100,000 scale of Iranian geological survey by using ENVI 3.6 software and further converted to the GIS formats to generate digital geology map of the study area.

Portion of the Landsat ETM+ frame Number 167-038 dated September 2002 is representing the study area (Figure 1) and has digitally divided into cell by using Arcview 3.2 software grid image. The cell boundaries were drawn parallel and perpendicular to the satellite path. The cell grid was superimposed on the digital fracture map generated from the Landsat ETM+ image. The fractures in each cell were digitally counted using Arcview extention density lineament. Lineament density maps is prepared. This can be easily done by using Drainage/lineament/roads density analyst extension of Arc View 3.2 available at http://arcscripts.esri.com/details.asp?dbid=10355. The number of fractures is digitally given in the center of the cell as cell value. The iso fracture density contours were extracted (Figure 6) using spatial analysis in GIS environment (Arcview 3.2 software) to evaluate suitable groundwater area. Lineament incident map is also prepared with counting the number of the incident lineaments in each cell and digitally numbered in Arcview 3.2 environment. The lineament incident contours are overlay on the satellite image (Figure 7).

The knowledge of chemical properties of water can give the idea about the quality water for drinking and an interrelationship of watershed basins. All springs (Figure 5) in the study area are superimposed on DEM and satellite image using field checks and GPS. Reading the GPS during the field check collects location of springs. The chemical properties of samples are also carried out in the laboratory to determine the available elements (i.e EC, Mg, Cl, Ca, Ph, Na and K) of groundwater. The chemical properties of samples from both the limbs of the fold are compared and the result was digitally introduced to GIS environment.

GIS is also used to create a DEM to integrate water potential zones mapping. DEM was generated using text format in the form of x, y and z attributes from the digital topographic map on scale 1:25000 provided by the Iranian survey organization (ISO) using Microstation and Rivertools 2.4 softwares.

The emphasis is given on DEM for morphometric analysis by using Rivertools and Arcview 3.2 softwares. Morphometric parameters such as flow grid, basin outlet, RT treefile were based to extract watershed basin, drainage orders, drainage segment orders, drainage density.

**Flow grid generation*- the objective of the first step in the conditioning phase is to create an adjusted “depression-less” is raise to the lowest elevation value on the rim of the depression. Each cell in the depression-less digital elevation data set will then be part of cells leading to an age of the data set. A path is composed of cells that are adjacent horizontally, vertically, or diagonally in the raster (eight-way connectedness) and that steady decrease in value. The purpose of this routine is to extract a flow grid from a DEM grid.

** *Basin outlet*- this is a graphic routine that allows one to specify the basin that one wants to analyze it by providing rivertools with the precise location of the basin’s outlet. In the present study the complete DEM was used and therefore an outlet was specified in the GIS environment on the basis of DEM and remotely sensed data with filed checks.

****RT Treefile*- This routine creates a rivertools “treefile” for one or more basins on the DEM. The treefile is a vector format file, which can store data for many disjoint basins. Every pixel in the particular basin is the outlet pixel for a sub-basin that is contained in that basin. Detailed morphometric analysis of the drainage network was carried out to extract watershed basins for interpreting the influences of the fault development and tectonic processes.

Using spatial analysis and map calculator methods in Arcview 3.2 software also uses GIS to identify water potential zones and suitable area for groundwater development. The flowchart below is representing methodology of the research (Figure8).

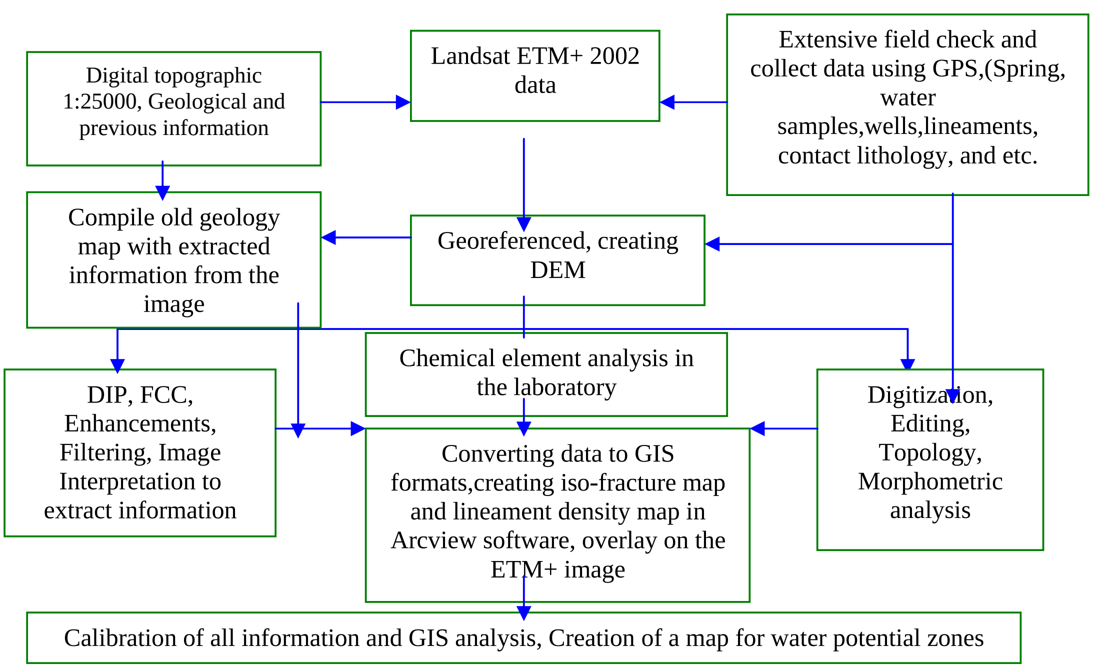

Figure 8. Flowchart of the method used

6. Results and Discussions

Remote sensing and GIS techniques are found to be very useful to analysis water potential zones in Karst terrain. For such analyses, the first task is to identify the themes facilitating suitable groundwater area. The iso-fracture density map exhibits contour trend with linear and circular anomalies. The orientation of the anomaly axes was plotted on the basis of highs and lows. The iso-fracture distributions in terms of highs and lows exhibit correlation with variable response of the ZSB. The dominant trend has roughly coincided with the orientation of the ZFB. The anomaly axes are oriented N13ºE- S13ºW and N77ºW-S77ºE. The N13ºE – S13ºW axis represents the direction of compression and N77ºW–S77ºE axis reflects the mean elongation trend of the ZFB. Integration of iso-fractures map with lithology and geomorphological studies of the area beside the extensive field checks reveal that groundwater are available mainly in both the limbs of the fold and controlled by fracture system. The groundwater in both the limbs of the fold conducts the direction of water towards the plunge of the fold. The various geomorphic and geological units in the study area are classified as favorable (class-1), moderately favorable (class-2) and poor (class-3) in terms of potential zones for groundwater. Groundwater development is probably promising in the forelimb of the fold, alluvial, limestone and dolomite of Asmari Formation and valleys and water gaps that are associated with thick alluvium that have high porosity and permeability characteristics. Therefore the three features/landforms of karst such as Charite sinkhole and Abezaloo and Gorgkosh doline (Figure 1) are easily seen in the forelimb of the fold (i.e. south limb). Geomrphologically, the area is spliced into three watershed basins and each watershed is nourishing from different resources. It is also supported by the chemical element analysis in the laboratory and ground truth data. The chemical analysis of water samples from both sides of the limbs shows different chemical properties. It is also observed that both of the limbs have different water resources. This study also shows that nourishing resources of dolines and sinkholes in the study area are not same and may be changed due to tectonic activities and movement. However, calibration of different layers in GIS environment such as lithology, drainage network, drainage basin, DEM and fracture system beside chemical properties in GIS environment could assess us the groundwater potential areas for exploration(Figure9).

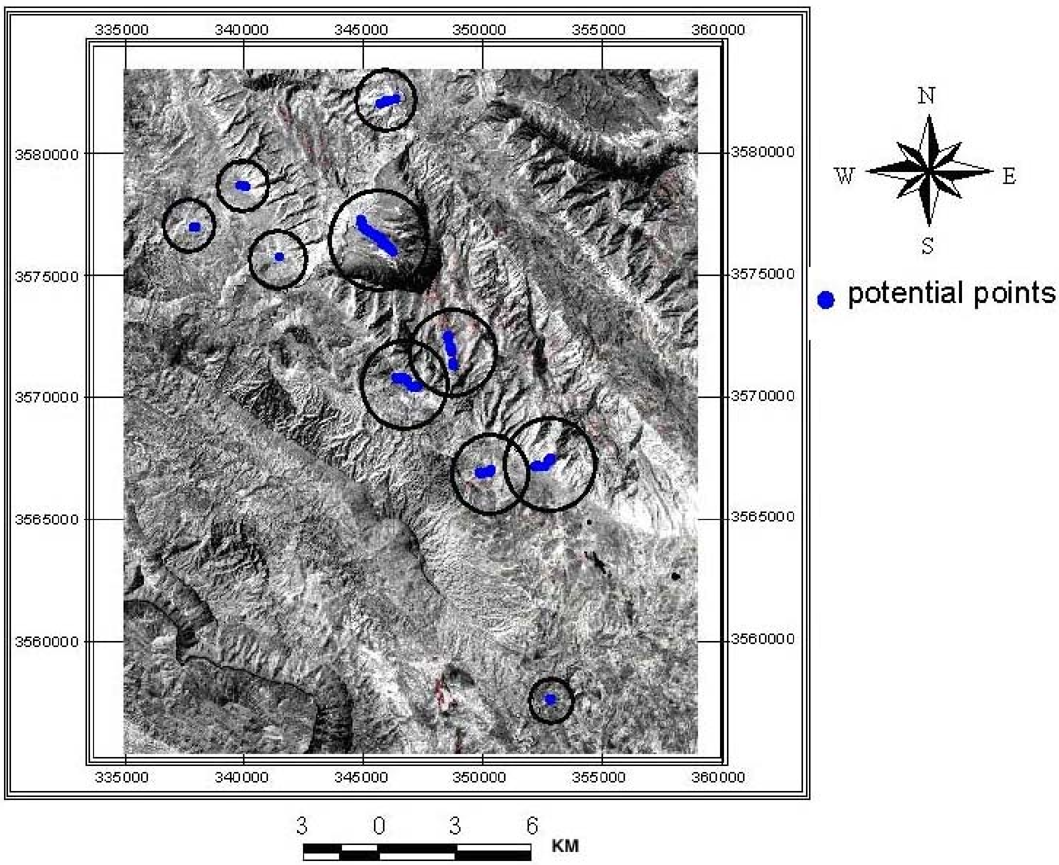

Figure 9: Suitable locations for water potential zoning sustainable management

7. Conclusions

This paper highlights finding shifts of water potential zones due to tectonic movment using geospatial technology like remote sensing, GIS and GPS. Extensive field works have been done to collect the useful data and verify the findings of this work. The following classes are suggested zones in order to explore groundwater. These classes are given as follows:

Class- 1: Recent alluvial with thick layered is more suitable for the water potential zone (Figure 10) or favorable zone of groundwater, Class- 2: marls, dolomite and limestone of Asmari Formation that covers 31 percent of the total study area. It is called as moderately favorable zones of groundwater, Class- 3: marls and sandstone of Aghajari Formation with high porosity and permeability or poor zones of ground water. This study has revealed only 10 locations as a suitable area for groundwater exploration. Mostly the suitable areas are in the south limb of the Pabdeh anticline. The chemical properties are also showing that the suitable groundwater for drinking located in the south limb of the anticlinal fold. Therefore, there is a need for giving more attention on development of surface and groundwater in terms of sustainability and management in the study area. This paper shows that integration of remote sensing and GIS technologies are very useful tools for water exploration in large areas to reduce the field checks, time and increase the accuracy. But it also suggests that geophysical analysis should be applied in some locations of the study area.

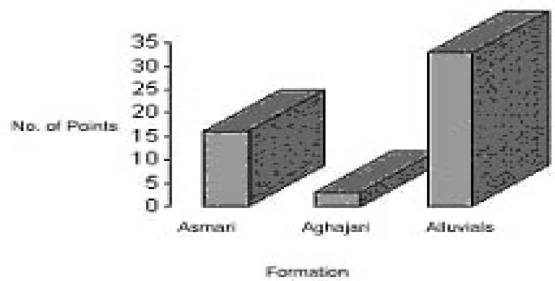

Figure 10: Number of suitable location in Formations

Acknowledgements

The authors are thankful to the authorities of university of Chamran, Ahwaz-Iran for providing facilities during the work. The authors are also thankful to the authorities of the Water Power Plant Energy, Khuzestan, Iran for their kind support.

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