A Report For
Term Paper Leading to Thesis
On

Identification of Groundwater Potential Zone using Remote Sensing Drived Indices &

Machine Learning Techniques

School of Water Resources Engineering
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Sayak karmakar

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1.ABSTRACT

Groundwater is a most important resource in arid and semi-arid regions and is required for drinking, irrigation and industrialization. Assessing the potential zone of groundwater recharge is extremely crucial for the protection of water quality and the management of groundwater systems. To identify the groundwater potential zone in the study areas, thematic layers of **lithology, slope, karst degrees, land cover, lineament drainage density** and others were generated using topographic maps, thematic maps, field data and satellite image, and were prepared, classified, weighted and integrated in a geographic information system (GIS) environment by the means of **fuzzy** logic and other machine learning techniques. In this paper I tried to summarize some selective papers on this topic.

2.INTRODUCTION

The knowledge of groundwater potential zones is very essential for the wise use and management of water resources, especially when groundwater forms the main source for supply of water. The remote sensing data can provide useful information on the factors governing the potential and movement of groundwater. A systematic study of the different geoenvironmental features could help in better delineation of groundwater sources in any region. Besides, identification of linear features, certain geomorphic units, soil moisture zones and topographic and vegetation indicators help in selecting potential areas for groundwater exploration. A groundwater model using GIS has many advantages over traditional methods. The most important benefit of using GIS is that everything is defined within spatial context. The distribution of precipitation, surface water bodies, groundwater recharge zone, water table depth, groundwater yield data, etc., can be depicted on a single map. The relationship between these components is easily determined because geographical information system is essentially a database that can combine this information in an infinite number of ways. GIS is one of the advanced information systems which can be used for scientific investigations, research and development. The use of different tools and modules such as **ArcGIS** with other software package will facilitate easy analysis which would have been otherwise tedious and time consuming. **Frequency ratio model, Shannon's entropy model, multi-criteria decision-making model, decision tree algorithms, weights-of-evidence (WOE) model and evidential belief function (EBF) models** are some of the procedures applied for aquifer mapping.

GIS tools can be useful to facilitate the evaluation process and serve to implement a multicriteria analysis (MCA). MCA is a method used to evaluate several criteria defined for specific objective, whose results able making decisions. This method with help of GIS-based geospatial analysis was performed to identify those areas suitable for pumping wells by considering different criteria, such as topography, hydrography, lithology, lineaments and land cover… etc. Some of the major MCA techniques available as follows: **fuzzy set analysis, analytical hierarchy process (AHP), ELECTRE, PROMETHEE, TOPSIS, multi-attribute utility theory (MAUT**)… etc

In recent years, the applications of artificial intelligence techniques have been used to convert human experience into a form understandable by computers. One useful model for combining information concerning hydrogeological characteristics is fuzzy logic, and can be easily implemented within a GIS environment. A fuzzy set is a collection of degrees of membership .Membership of a fuzzy set, however, is expressed on a continuous scale from 1 (full membership) to 0 (full non-membership). The membership function methods are based on fuzzy logic of segment features to classify image objects

3.Discussions of different Thematic layers

Each thematic layer which will be in a raster layer is assigned a weight depending upon their influence in groundwater potentiality. Different authors have used different number of thematic layers in their studies. Thematic layers such as **drainage density, geomorphology, slope, lithology, soil, land use/land cover, lineament density, topographic wetness index, rainfall distribution, roughness, curvature, dissection index, depth to water level and topographic position** index are discussed from which groundwater potential zones are delineated in different studies.

3.1. Geomorphology

Groundwater and geomorphology have much to offer each other in several fields such as river-groundwater interactions, location and evolution of aquifers and landform evolution. Thomas et al. (2009) reported that geomorphology has a dominant role in the movement and storage of groundwater in an area. **The relief, slope, depth of weathering, type of weathered material, thickness of alluvium, nature of the deposited material** and the overall grouping of different landforms play an important role in defining the groundwater regime, especially in the hard rock terrain.

3.2. Slope

The slope of a topographic landform refers to the amount of inclination of that surface to horizontal. Topography relates to the local and regional relief and gives an idea about the general direction of groundwater flow and also its influence on groundwater recharge. Slope plays significant role in infiltration. **Infiltration is inversely related to slope**; i.e the gentler the slope is, infiltration would be more and runoff would be less and vice versa.

3.3. Lithology

One of the most important requirements for groundwater occurrence and flow is that the geological horizon must be **porous and permeable**, so that it may store and permit easy movement of water. Geologically, area forms part of Pre- Cambrian crystalline rocks composed of mainly carnotite and khondalite, which have undergone weathering to form laterite at varying depths, and also, a part of the area is occupied by migmatite complex eg. Valley and low-lying areas are covered by fluvial sediments/materials like colluvium and alluvium composed of sand, silt and clays of varying proportions. Generally hard rocks are unable to hold or transmit water due to the absence of porosity unless otherwise traversed by intersecting features like **fractures, joints or fault planes**. The groundwater is occurring under water table condition in the pore spaces of the weathered material, viz., laterite. Therefore, the extent of laterite and its thickness is considered as one of the factors controlling groundwater under unconfined condition in a tropical crystalline terrain. The lithological unit, laterite, has been assigned a higher rank next to valley fill material which is composed of sandstone and clay.

3.4. Soil

Weightage of soil has been assigned on the basis of their infiltration rate. **Gravelly clay has high infiltration rate**, hence given high priority, whilst the clayey soil has least infiltration rate, hence assigned low priority.

3.5. Drainage Density

A drainage map of the area gives an idea about the permeability of rocks and also gives an indication of the yield of the basin. Drainage density is an inverse function of permeability, so it is an important parameter in evaluating the groundwater zone. **High drainage density indicates less infiltration and hence acts as poor groundwater potential zone** compared to low drainage density zones, implying an inverse relation between the two. Low network of drainage course indicates existence of highly resistant and permeable rock where as high drainage course indicates highly weak and impermeable rocks. For groundwater prospecting, higher rank was assigned to low drainage density zones and a lower rank was assigned to a high drainage density zone

3.6. Land Use/Land Cover

The land use/land cover (LULC) of the area provides important indications of the extent of groundwater requirement and utilisation. The synoptic viewing through remote sensing has provided the multi-spectral data, which has been utilised for classifying LULC. The major land use/land cover classes such as forest, plantation, barren land, agriculture and built-up were identified in the study area. From the point of view of land use, **crop land with vegetation** is an excellent site for groundwater exploration. The area with water bodies is good for groundwater recharge and fallow land is poor for it**. Basin area covered by forest, crop land and water bodies are favourable for groundwater storage and hence act as potential zones**.

3.7. Lineament Density

Lineaments are defined as **naturally occurring linear or curvilinear features**. Lineaments play an important role in groundwater recharge in hard rock terrains. These factors are hydro-geologically important as they provide the **pathways for groundwater movement**. The groundwater potential is high near high-density lineament zones and vice versa. In hard rock terrains, lineaments represent areas and zones of faulting and fracturing, resulting in increased secondary porosity and permeability and are good indicators of groundwater potential. **Lineament density is total length of all the lineaments present in the basin/watershed divided by the area of basin/watershed**.

3.8. Topographic Wetness Index

The topographic wetness index (TWI) is commonly used to compute topographic control on hydrological processes and reflects the potential groundwater exfiltration caused by the effects of topography; thus, **higher TWI value represented higher groundwater potential value**. The index is a function of both the slope and the upstream contributing area per unit width orthogonal to the flow direction. Its definition is as follows:

TWI =ln (α)/tan(β)

where 'α' denotes the local upslope area draining through a certain point per unit contour length and β denotes the slope angle**. A higher TWI indicates a gentler slope and larger slope area**.

3.9. Rainfall Distribution

Rainfall distribution along with the slope gradient directly affects the infiltration rate of runoff water hence increases the possibility of groundwater potential zones

3.10. Dissection Index

Dissection index (DI) is a parameter referring to **the degree of dissection or vertical erosion**, and the stage of landform development in any given watershed. **DI is the ratio between the total relief (relative relief) and absolute relief of the basin** which always varies between 0.0 (complete absence of dissection and hence the dominance of flat topography) and 1 for infrequent cases such as vertical cliff topography at the seashore or vertical escarpment of hillslope. **The lower value of DI will have high influence in groundwater potential.**

3.11. Roughness

More the roughness means the area is more undulated and vice versa. Generally undulated topography is characteristic of a mountainous region where weathering and erosion process continuously modify the landscape of a rugged into a smooth and plane surface in long run. In the hard rock terrain, the roughness is associated with nature and thickness of weathered product retained on the surface that controls the groundwater occurrence. If there is considerably thick weathered zone, such area can be treated as groundwater potential zone to a limited extent than a highly rugged terrain where normally only a thin layer of weathered zone exists and therefore no scope for groundwater occurrence**. Roughness is synonymous to relief ratio**.

3.12. Curvature

Curvature is **quantitative expression** of the nature of surface profile. It can be concave upward or convex upward profiles. Gentle slopes usually attain concave upward profile in platform. In the convex profile, water tends to decelerate, and in the concave, upward profile water tends to accumulate, which is true for groundwater also.

3.13. Groundwater fluctuation

The zone of the groundwater fluctuation reveals the recharge potentiality of a region. The areas where the pre-monsoon and post monsoon **groundwater level difference is high signifies poor recharge** of the aquifer layers from the monsoonal precipitation.

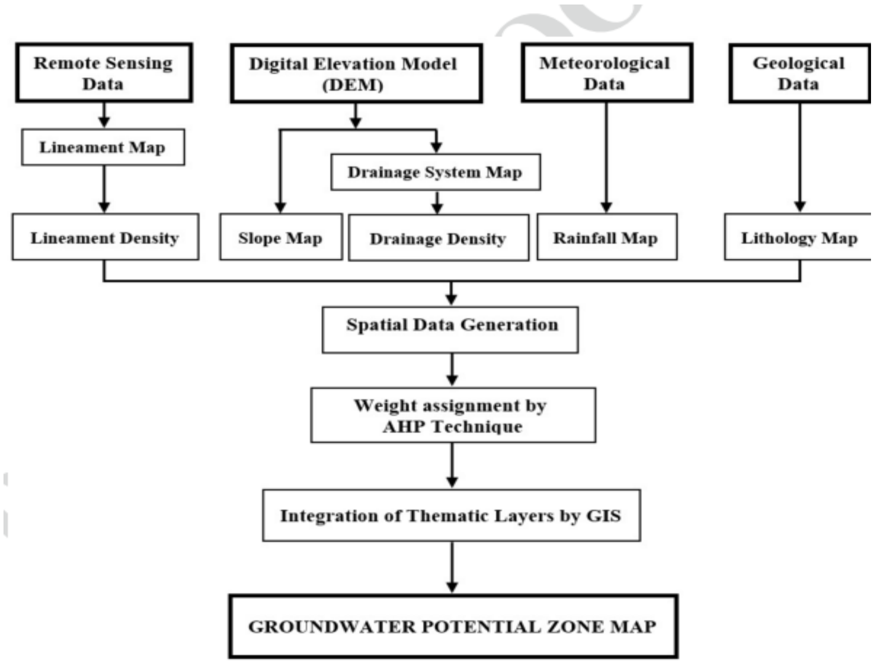
3.14. Distance from river network

Streams and groundwater have a close relation reflecting the effluent and influent character. Areas close to a surface water source are the areas of good groundwater prospects. Groundwater recharge or deep drainage or deep percolation is a hydrologic process where water moves downward from surface to the underground. Extensive groundwater abstraction hampers the inner connectivity between the two systems.

4. General Methodology

4.1. Flow Chart

Figure 1: Flow chart of the methodology for assessing the groundwater potential of the study area



4.2.Fuzzy logic implementation

Zadeh (1965) first used fuzzy set theory in the development of decision support models. It was later applied in MCA applications (Leberling 1981; Buckley 1984). Fuzzy set theory is based on a gradual transition from one class to another. Items can have partial membership in multiple sets. This can be particularly powerful in handling uncertainty inherent in MCA problems. Fuzzy approaches may apply concepts from the other MCA methods.

A fuzzy set is a collection of degrees of membership. Membership of a fuzzy set, however, is expressed on a continuous scale from 1 (full membership) to 0 (full non-membership). Using fuzzy functions can be separated maps of a few classes. Then each class is given a membership degree based on their influencing, in the range (0, 1). A variety of operations can be employed to combine the membership values together (**fuzzy AND, fuzzy OR, fuzzy algebraic product, fuzzy algebraic sum, and fuzzy gamma**).

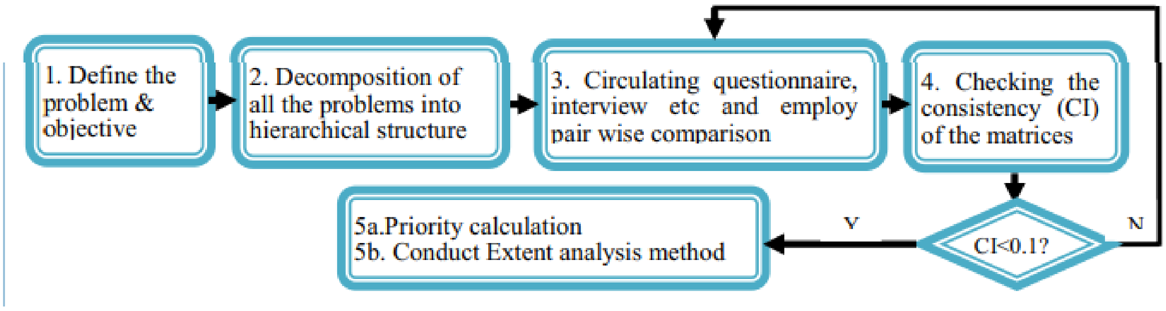


Figure 2: AHP and FAHP Methodology

5. Selected Works on Delineation of groundwater potential zones

Table of Research Works and Author:

Research work	Author
1.Fuzzy logic algorithm based analytic hierarchy process for delineation of groundwater potential zones in complex topography	Sudipa Halder, Malabika Biswas Roy & Pankaj Kumar Roy
2.Delineation of groundwater potential zones in the crystalline basement terrain of SW-Nigeria: an integrated GIS and remote sensing approach	Olutoyin A. Fashae, Moshood N. Tijani, Abel O. Talabi, Oluwatola I. Adedeji
3. Delineation of groundwater potential zones using remote sensing (RS), geographical information system (GIS) and analytic hierarchy process (AHP) techniques: a case study in the Leylia–Keynow watershed, southwest of Iran	H. R. Mohammadi-Behzad1, A. Charchi· N. Kalantari, A. Mehrabi Nejad, H. Karimi Vardanjani
4. Groundwater potential of Middle Atlas plateaus, Morocco, using fuzzy logic approach, GIS and remote sensing	My Hachem Aouragh, Ali Essahlaoui, Abdelhadi El Ouali, Abdellah El Hmaidi and Said Kamel

5. Delineation of Groundwater Potential Zone in Sengipatti for Thanjavur District using Analytical Hierarchy Process	G Siva, N Nasir and R Selvakumar
6. Delineation of groundwater potential zones in Theni district, Tamil Nadu, using remote sensing, GIS and MIF techniques	N.S. Magesh, N. Chandrasekar, John Prince Soundranayagam
7. Delineation of Groundwater Potential Zones in River Basins Using Geospatial Tools—an Example from Southern Western Ghats, Kerala, India	Hema C. Nair, D. Padmalal, Ammini Joseph & P. G. Vinod
8. Delineation of groundwater potential zone in hard rock terrain of India using remote sensing, geographical information system (GIS) and analytic hierarchy process (AHP) techniques	Shashank Shekhar & Arvind Chandra Pandey
9. Groundwater exploration using fuzzy logic approach in gis for an area around an Anticline, Fars Province	S. Rafati, M. Nikeghbal

6. Short Description of each Paper

6.1. Fuzzy logic algorithm based analytic hierarchy process for delineation of groundwater potential zones in complex topography

Author: Sudipa Halder, Malabika Biswas Roy & Pankaj Kumar Roy

Study Area: **Garbeta Block, in Paschim Midnapore district of West Bengal, India**. The study area is about 369 km2 and is located between 22° 47′ 12″ N to 22° 56′ 27″ N latitude and 87° 13′ 17″ E to 87° 23′ 29″ E longitude.

Methodology: The delineation of the groundwater potential zones has been executed using eleven surface and subsurface parameters which influence the groundwater recharge system. These are **land use and land cover, drainage density, distance from river network, relative relief, lineament density, slope, soil type, geology, geomorphology, groundwater fluctuation level and normalised difference water index (NDWI)**. The groundwater potential map has been prepared using MCDM method of Fuzzy AHP and geospatial techniques by incorporating the thematic maps as the input parameters. The step-by-step methodology of the entire process has been shown in a flow chart. **Survey of India, topographical sheet number 73 N/9, 73 N/6, 73 N/5 and 73 N/11 of scale 1:50,000** have been used to digitise the drainage network. **Landsat 8 OLI of path 139 and row 40** has been downloaded from USGS Earth Explorer website (https://earthexplorer.usgs.gov/) to prepare the land use and land cover map. SRTM (Shuttle Rader Topographic Mission) DEM of 30 m resolution has been downloaded from the same USGS Earth Explorer website to prepare the elevation and slope map. Groundwater level data have been obtained from Central ground water Board (CGWB 2018) and soil map from **National Bureau of Soil Survey and Land Use Planning (NBSSLUP**). The maps obtained in raw file have been scanned and digitised for map preparation. Normalised difference water index (NDWI) has been calculated using the same Landsat 8 OLI Image. Geological data including geological map has been downloaded from **Geological Survey of India (GSI)** website https://www.gsi.gov.in, and lineaments have been downloaded from Bhuvan website (https://

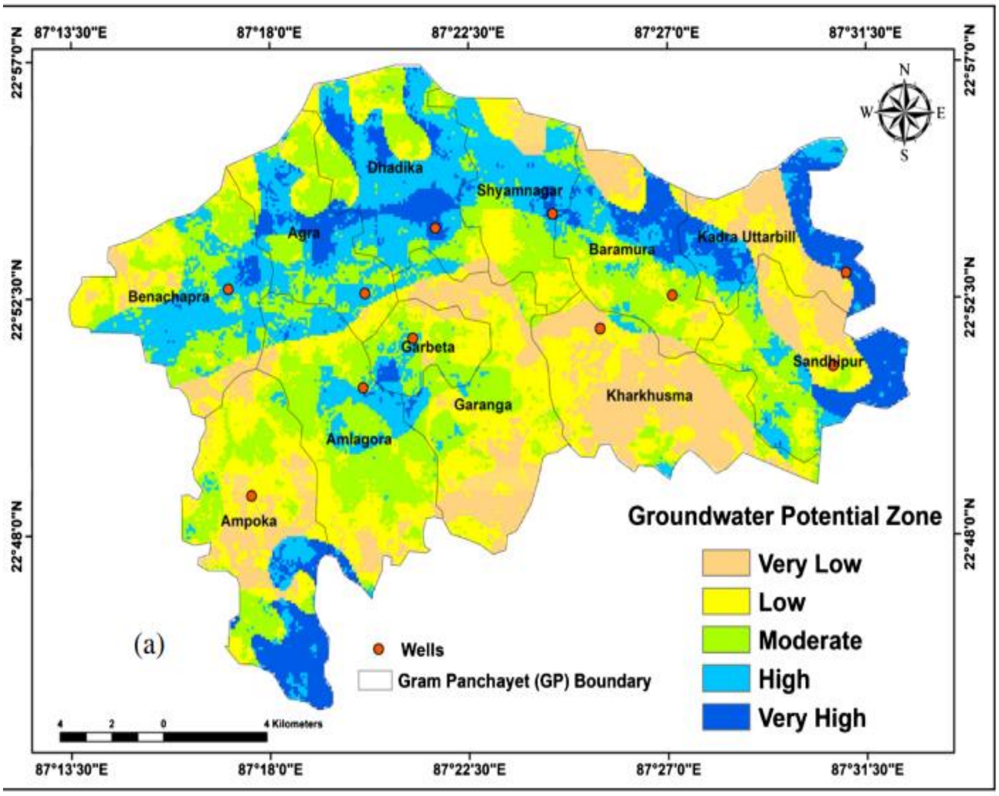
bhuvan.nrsc.gov.in/bhuvan_links.php). To get the specified geology and lineaments of the study area, it has been masked with boundary file and geological map, and lineament density has been prepared and calculated in **the ArcGIS software version 10.3.** Further discussion of each of the thematic layers has been made under the heading description of parameters. **The MCDM technique of Fuzzy AHP approach based on synthetic extent analysis** has been applied here to calculate the weights of each parameter using triangular fuzzy scale. The parameters in vector format have been converted into raster using ArcGIS tool box. These raster files are then reclassified and weights have been assigned to prepare the final potential map using raster calculator in ArcGIS.

Figure 3:

Ground water

Potential Map

Of study area



6.2. Delineation of groundwater potential zones in the crystalline basement terrain of SW-Nigeria: an integrated GIS and remote sensing approach

Author: Olutoyin A. Fashae, Moshood N. Tijani, Abel O. Talabi, Oluwatola I. Adedeji

Study Area: The study area, the Basement Complex terrain of **southwestern part of Nigeria**, lies between longitude 2˚42’ E to 6˚20’ E and latitude 6˚5’ N to 9˚11’ N encompassing Oyo, Ogun, Osun Ekiti and Ondo State regions of Nigeria.

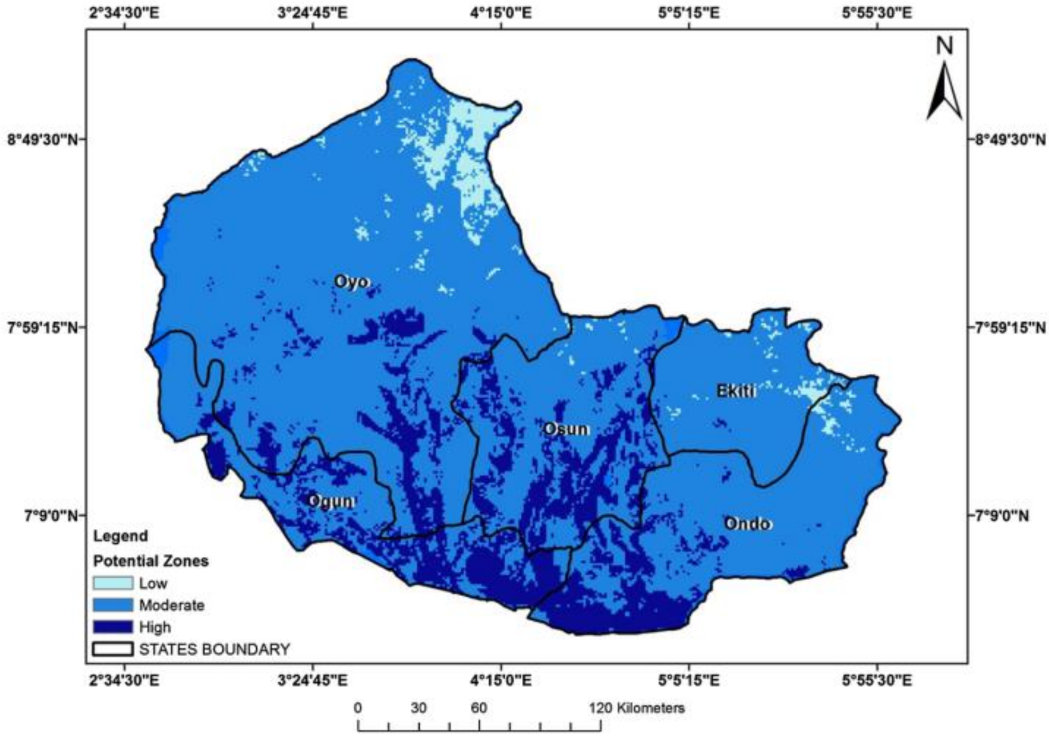
Methodology: This study employed the integration of **multi-criteria decision analysis (MCDA**), **remote sensing (RS) and geographical information system (GIS) techniques** to delineate groundwater potential zones in crystalline basement terrain of SW-Nigeria and validation of the result with existing borehole/well yield data. The study approach involved integration of nine different thematic layers (**geology, rainfall geomorphology, soil, drainage density, lineament density, land use, slope and drainage proximity**) based on weights assignment and normalization with respect to the relative contribution of the different themes to groundwater occurrence using **Saaty’s analytic hierarchy approach**. Following weigh normalization and ranking, the thematic maps were integrated using **ArcGIS 10.0** software to generate the overall groundwater potential map for the study area

Figure 4:

Ground water

Potential Map

Of study area



6.3. Delineation of groundwater potential zones using remote sensing (RS), geographical information system (GIS) and analytic hierarchy process (AHP) techniques: a case study in the Leylia–Keynow watershed, southwest of Iran

Author: H. R. Mohammadi-Behzad1, A. Charchi· N. Kalantari, A. Mehrabi Nejad, H. Karimi Vardanjani

Study Area: The study watershed is comprised of two elongated anticlines namely Leylia and Keynow which have been merged as a result of tectonic forces in the watershed. Geographically, the watershed is located in the north-eastern part of **the Khuzestan province, southwest of Iran** lies between latitude 32°26′ and 32°43′N and between longitude 49°22′ and 49°44′E .The watershed covers an area of 588 km^2.

Methodology: In this research, a standard methodology has been applied to delineate groundwater resource potential zonation based on integrated remote sensing (RS), geographic information system (GIS), and analytical hierarchy process (AHP). A total of five sets of criteria/factors (including **lineament density, rainfall, lithology, slope, and drainage density)** believed to be influencing groundwater storage potential in the area were selected. Each criterion/factor was assigned appropriate weight based on **Saaty's 9-point scale** and the weights were normalized through the **analytic hierarchy process (AHP).** The process was integrated in the GIS environment to produce the groundwater potential prediction map for the area.

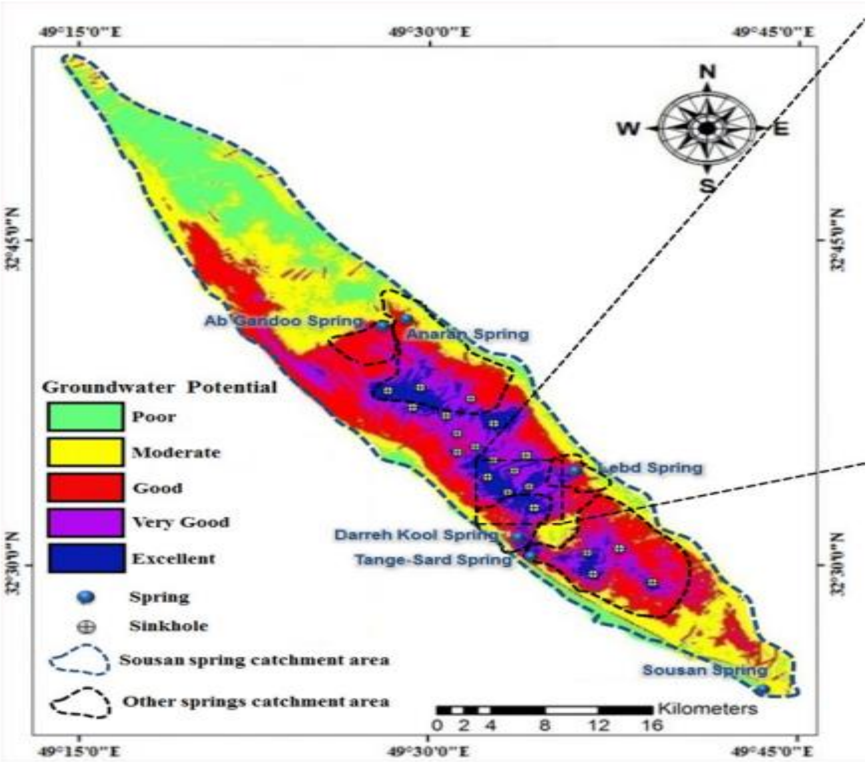


Figure 5:

Ground water

Potential Map

Of study area

6.4. Groundwater potential of Middle Atlas plateaus, Morocco, using fuzzy logic approach, GIS and remote sensing

Author: My Hachem Aouragh, Ali Essahlaoui, Abdelhadi El Ouali, Abdellah El Hmaidi and Said Kamel

Study Area: The study area is a part of **Sebou basin,** and located between the latitudes of 33°30’ and 34° N and the longitudes of 4°30’ and 5° E.

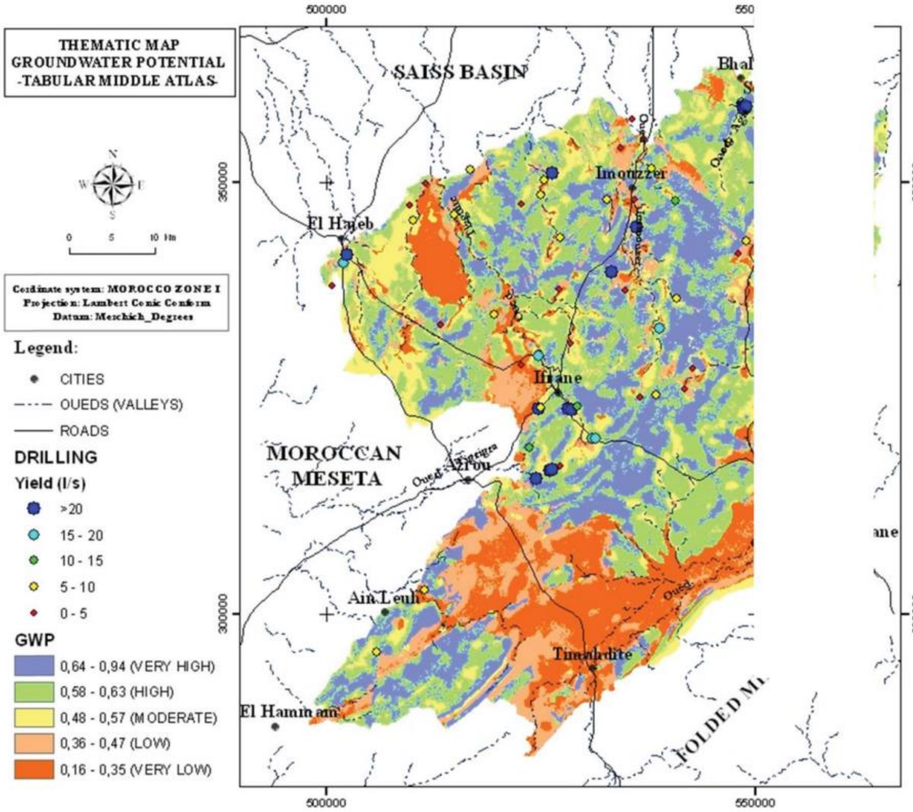
Methodology: Development of thematic layers involves digital image processing of remote sensing data, digitization of existing maps and field data for extraction of pertinent information. To identify the groundwater potential zone in the study area, thematic layers **of lithology, slope, karst degrees, land cover normalized difference vegetation index [NDVI]), lineament and drainage density** were generated using topographic maps, thematic maps, field data and satellite image, and were prepared, classified, weighted and integrated in a **GIS environment by the means of Fuzzy logic**.

Figure 6:

Ground water

Potential Map

Of study area



6.5. Delineation of Groundwater Potential Zone in Sengipatti for Thanjavur District using Analytical Hierarchy Process

Author: G Siva, N Nasir and R Selvakumar

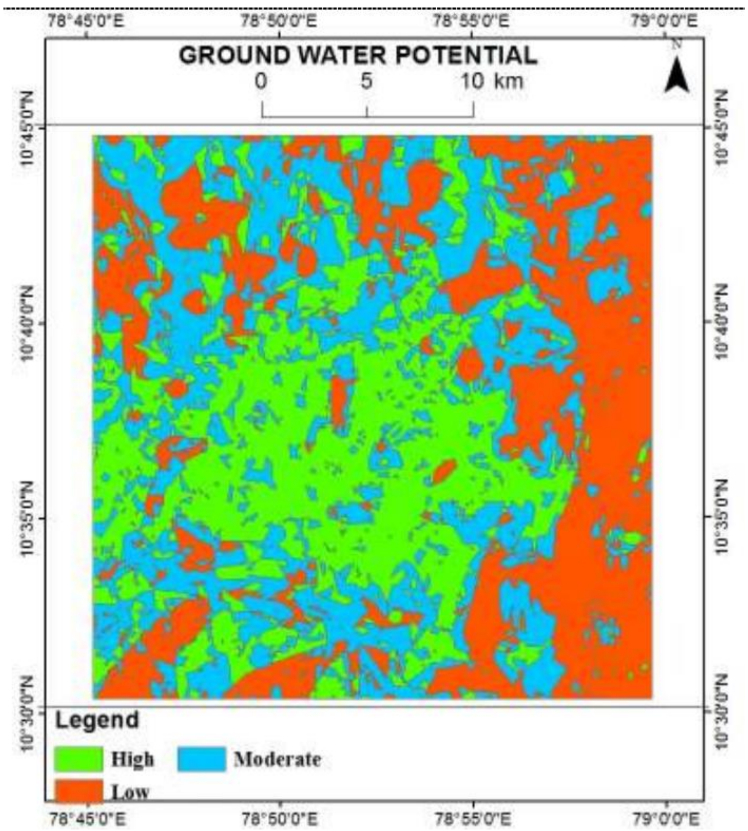
Study Area: the study area Sengipatti is a mid-sized village located in the district of Thanjavur in the state of **Tamil Nadu** in India. The geographical position of the Sengipattiis 10° 43' north Latitude and 78° 57' east Longitude.

Methodology: In the present study **Geocoded satellite data of 20th June 2000 (IRS 1C LISS-III) and Survey of India Toposheet 58J/14 were used.** For analysis, **Analytic Hierarchy Process (AHP)** method is adopted. The parameters which we have used for the identification of ground water prospects zone are **drainage, geomorphology, land use/land cover, slope and lithology (description of rock units**). The weightage is provided to various parameters by manual process and it is qualitative. It is converted into a quantitative number by creating a table indicating the inter dependency between various parameters. To check whether the assigned weightage is appropriate or not, a ratio known as consistency ratio (C.R) is calculated. This C.R value will be less than 0.1 if the assumed weights are appropriate**. Each parameter is further divided into criteria and the individual sub criteria weights are obtained and they are multiplied with the main parameters' weightage**. Finally, the derived weights are assigned to all the parameters in each thematic layer and subsequently converted into **raster datasets**. Then using raster addition tool, they were integrated and cumulative factor scores of each pixel was calculated. Consequently, the derived scores were categorized into three and thereby the final groundwater prospect map showing **(i) High potential (ii) Moderate potential and (iii) Low potential zone** was prepared.

Fig 7: Ground water

Potential Map

Of study area



6.6. Delineation of groundwater potential zones in Theni district, Tamil Nadu, using remote sensing, GIS and MIF techniques

Authors: N.S. Magesh, N. Chandrasekar, John Prince Soundranayagam

Study Area: The study area lies at the foot of **Western Ghats** and is diversified by several ranges and hills. A range of hills which run parallel to Western Ghats from north to south separate the district from neighbouring Kerala State. The district lies between 9530 and 10220 north latitude and 77170 and 77670 east longitudes, covering an area of 2871.48 km^2

Methodology: The base map of Theni district was prepared based on **Survey of India topographic maps (58F/4, 8, 12; 58 G/1, 2, 5, 6, 9, 10) on a 1:50,000 scale**. The drainage network for the study area was scanned from Survey of India (SOI) toposheets and digitized in **ArcGIS 9.3 platform**. The slope map was prepared from SRTM DEM data in ArcGIS Spatial Analyst module. The rainfall map was prepared using the data obtained from the Indian Meteorological Department (IMD) gauge stations. These data were then spatially interpolated using Inverse Distance Weighted (IDW) method to obtain the rainfall distribution map. This interpolation method combines the concepts of proximity to follow Thiessen polygons with gradual change of the trend surface. The drainage density and lineament density maps were prepared using the line density analysis tool in ArcGIS. **Satellite images from IRS-1C, LISS-III sensor, on a scale of 1:50,000 (geo-coded, with UTM projection, spheroid and datum WGS 84, Zone 44 North**) have been used for delineation of thematic layers such as **land-use, lithology, lineament, and soil types**. These thematic layers were converted into a raster format (30 m resolution) before they were brought into GIS environment. The groundwater potential zones were obtained by overlaying all the thematic maps in terms of weighted overlay methods using the spatial analysis tool in **ArcGIS 9.2**. During weighted overlay analysis, the ranking was given for each individual parameter of each thematic map, and weights were assigned according to the **multi influencing factor (MIF)** of that particular feature on the hydro-geological environment of the study area.

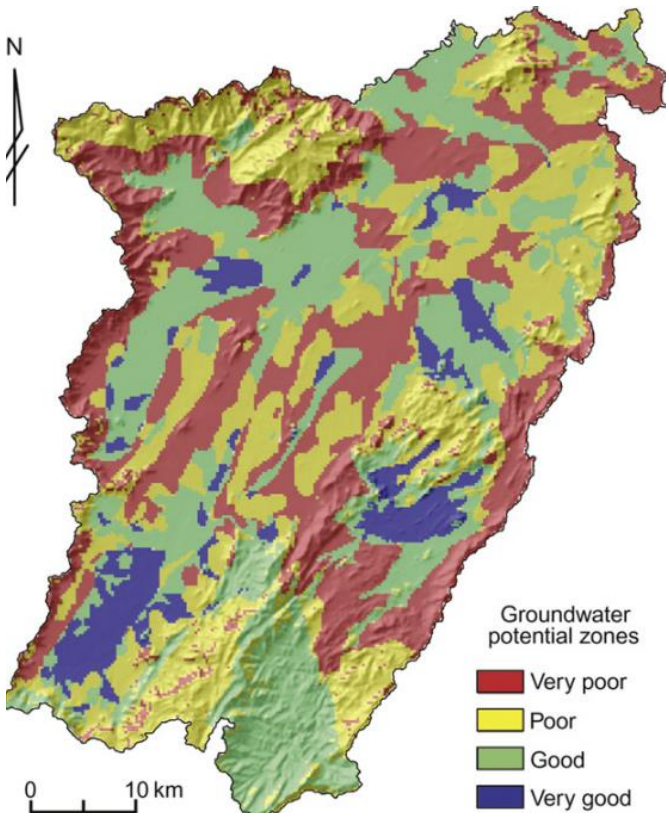


Fig 8: Ground water

Potential Map

Of study area.

6.7. Delineation of Groundwater Potential Zones in River Basins Using Geospatial Tools—an Example from Southern Western Ghats, Kerala, India

Authors: Hema C. Nair, D. Padmalal, Ammini Joseph & P. G. Vinod

Study Area: The study area—Ithikkara and Kallada river basin—lies between north latitudes 8° 45′–9° 15′ and east longitudes 76° 30′–77° 15′. The area is bounded by **Tirunelveli district of Tamil Nadu** in the east, Lakshadweep Sea in the west, Alappuzha and Pathanamthitta districts in the north and Thiruvananthapuram district in the south.

Methodology: The details of the materials and data sources for thematic layer preparation are Survey of India Toposheets for delineation of streams, **Shuttle Radar Topographic Mission (SRTM) 30-m resolution data source** (for digital elevation model, slope, topographic position index, topographic wetness index, roughness, curvature and dissection index), **LISS III image** (for geomorphology, land use/land cover and lineament), **Geological Survey of India map** (for geology), **NBSS and LUP soil map** (for soil) and **Central Ground Water Board** (for water level). **ArcGIS 10.1** and **ERDAS 9.2 software** were used for performing GIS and remote sensing applications. Drainage density and lineament density were prepared using the line density function of spatial analyst extension in GIS platform. Inverse distance weighted (IDW) interpolation technique was used for spatial modelling of groundwater level data. In IDW interpolation method, it is assumed that things that are close to one another are more alike than those are farther apart (Burrough and McDonnell 1998). Geomorphometry and Gradient Metrics Toolbox which is an ArcGIS Toolbox for Surface Gradient and Geomorphometric Modelling developed by Evans et al. (2014) is used for deriving dissection index, roughness and topographic wetness index. The topographic position index is derived based on Jenness algorithm (Jenness 2006). Curvature is derived using DEM Surface tools developed by Jenness (2013). The thematic maps of all the layers were prepared using natural breaks (Jenks) classification method and then by assigning weights for each class in GIS platform. After plotting the maps, the rank of each factor was given on the basis of its significance in groundwater potentiality. The groundwater potential zones were obtained by integrating all the thematic maps in a linear combination model using the Raster Calculator tool in spatial analyst extension of GIS software. Weighted overlay analysis is one method of modelling suitability. Each thematic layer which will be in a raster layer is assigned a weight depending upon their influence in groundwater potentiality. Values in the raster are then reclassified to a common suitability scale. Raster layers are overlayed, multiplying each raster cell's suitability value by its layer weight and totalling the values to derive a best suitable value. These values are written to new cells in an output layer. The symbology in the output layer is based on these values. Validation of the groundwater potential zone with field was done by ground truthing. The **GPS (Gramin eTrex 20) was used to locate high-yield wells and springs of the study area**. These locations were overlaid onto the groundwater potential zone map for validating the results

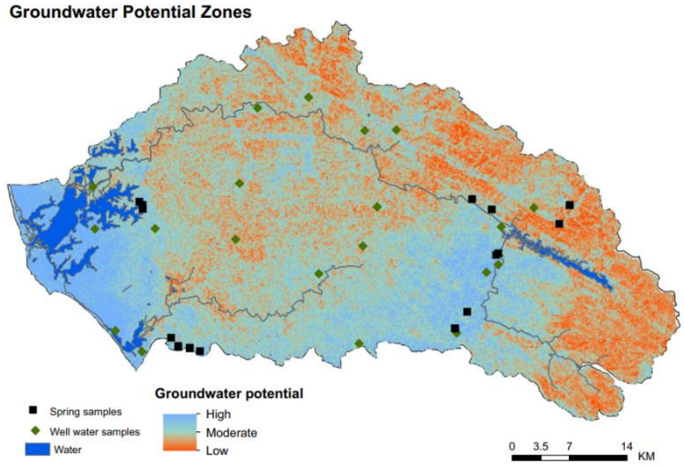


Fig 9: Ground water

Potential Map

Of study area

6.8. Delineation of groundwater potential zone in hard rock terrain of India using remote sensing, geographical information system (GIS) and analytic hierarchy process (AHP) techniques

Authors: Shashank Shekhar & Arvind Chandra Pandey.

Study Area: The Palamu district lies between latitude 23°50′ and 24°8′ N and between longitude 83°55′ and 84°30′ E. Palamu district are located in the **north-western part of the Jharkhand state**. Palamu district comprised an area of 5043 km^2.

Methodology: In the present study, the lithology map was collected from the Geological Survey of India, GoI, Jharkhand and was scanned, rectified and digitized in ArcGIS software to prepare the thematic layer of lithology. The soil map of the study area was procured from the **National Bureau of Soil Survey and Land Use Planning (NBSS&LUP**), Bihar. This map was also scanned, rectified and then digitized using ArcGIS software to obtain the digital soil map. The block wise rainfall data of 15 years (1986–2000) for the study area was collected from the Indian Meteorological Department, Pune. The slope map was generated from **Advanced Spaceborne Thermal Emission and Reflection Radiometer Digital Elevation Model (ASTER DEM**). A number of geomorphologic landforms were identified in the study area using **Advanced Wide Field Sensor (AWiFS) and LANDSAT image**. The satellite data of Linear Imaging Self Scanning Sensor (LISS) IV and AWiFS imageries of false colour composite were visually interpreted to identify and prepare the lineament map of the Palamu district. Reuter et al. 2009 evaluated the horizontal and vertical accuracy for ASTER GDEM using a variety of methods and investigated artefacts, blunders or gross errors, systematic errors or random errors. Based on their results, the average RMSE values of GDEM were between 18 and 29 m. The drainage map was prepared using the Survey of India topographical map and updated using high resolution LISS IV satellite image. The thickness of weathered zone in the study area was acquired from the Central Ground Water Board, GoI, Jharkhand. In order to assess groundwater potential in the study area, nine thematic maps, viz., **geomorphology (G), lithology (L), soil (S), slope (E), lineament density (LD), weathered zone thickness (W), drainage density (D), rainfall (R)** were generated using RS and conventional data with the help of **ArcGIS software (9.3).**

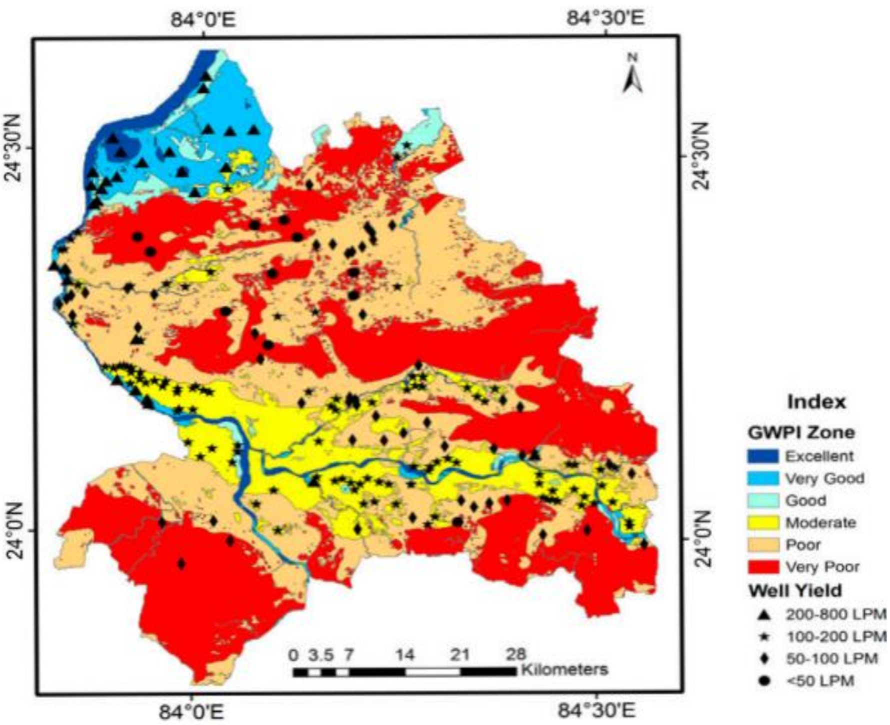


Fig 10: Ground water

Potential Map

Of study area

6.9. Groundwater exploration using fuzzy logic approach in gis for an area around an Anticline, Fars Province

Author: S. Rafati, M. Nikeghbal

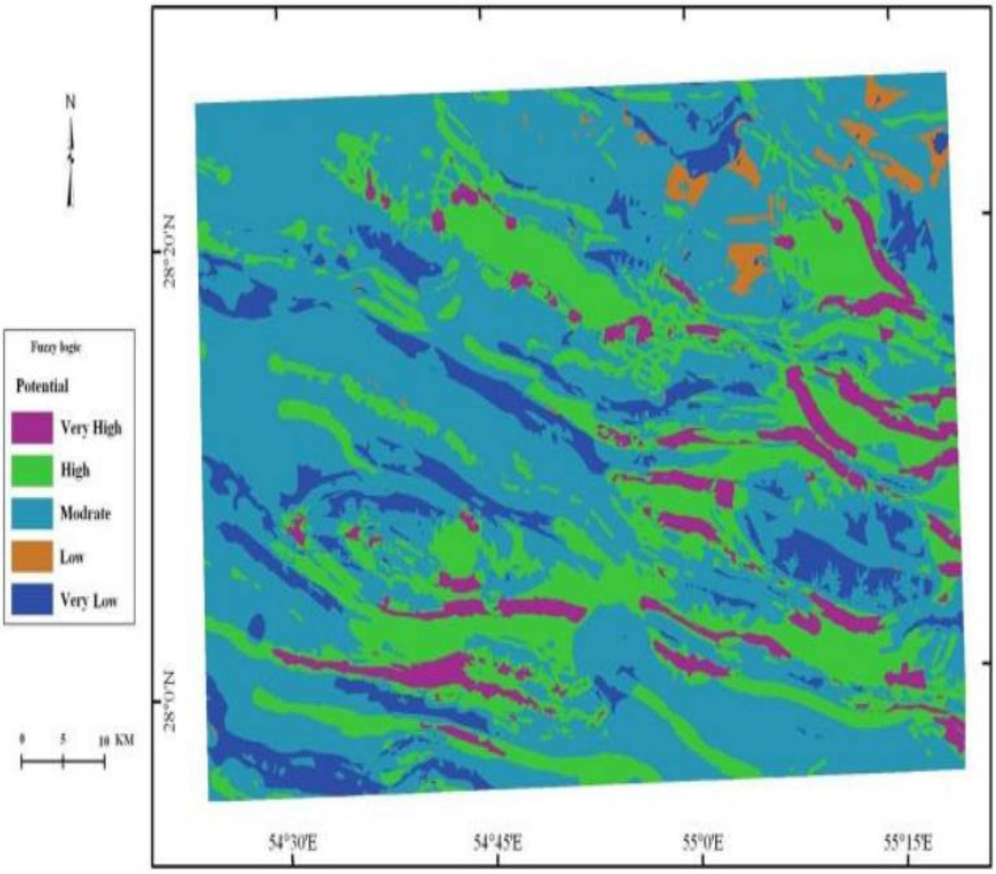
Study area: The study area is the region around an anti-cline which located in the 15 kilometre of southeast of Haji Abad city in the Fars province. The area is bounded by latitude 27°55' to 28°25' N and longitude 54°24' to 55°20'E.

Methodology: In this paper**, Fuzzy logic approach** was used in a suitable combination **of slope, elevation range, drainage density, fracture distance and lithology layers** to ground water exploration. To combine various spatial data, we applied fuzzy product and sum operators. Also, the fuzzy γ operator with the value of γ = 0.95 was tested.

Fig 11: Ground water

Potential Map

Of study area



7. Conclusion

The mapping of groundwater resources has assumed importance in recent years because of increased demand for freshwater for various purposes. The present study reveals that remote sensing and GIS are important tools for groundwater resource assessments. It is an essential tool for **ecological monitoring, climatic situation, geographical, geomorphologic mapping, vulnerability management, resource estimation, urban planning** and to study the farming practices. In the studies, numbers of thematic layers have been utilised for identifying the potential zones for groundwater. From the analysis, the groundwater potential zones in terms of high, moderate and low have been delineated. The groundwater potentiality maps derived from the studies are validated using the available **secondary data of springs and wells**. In this way, accuracy of the research works is found.

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