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ORIGINAL RESEARCH ARTICLE

Use of earth observation images and GIS techniques for groundwater exploration in hard rock terrain

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ABSTRACT

It increased the demands on ground-water supplies that prolonged drought and improper maintenance of water resources. So it is necessary to evaluate ground-water resources in the hard rock terrain. In recent years, Remote-Sensing methods have been increasingly recognized as a means of obtaining crucial geoscientific data for both regional and site-specific investigations. This work aims to develop and apply integrated methods combining the information obtained by geo-hydrological field mapping and those obtained by analyzing multi-source remotely sensed data in a GIS environment for better understanding the Groundwater condition in hard rock terrain. In this study, digitally enhanced Landsat ETM+ data was used to extract information on geology, geomorphology. The Hill-Shading techniques are applied to SRTM DEM data to enhance terrain perspective views, and extract Geomorphological features and morphologically defined structures through the means of lineament analysis. A combination of Spectral information from Landsat ETM+ data plus spatial information from SRTM-DEM data is used to address the groundwater potential of alluvium, colluvium, and fractured crystalline rocks in the study area. The spatial distribution of groundwater potential zones shows regional patterns related to lithologies, lineaments, drainage systems, and landforms. High-yielding wells and springs are often related to large lineaments and corresponding structural features such as dykes. The results show that the combination of remote sensing, GIS, traditional fieldwork, and models provide a powerful tool for water resources assessment and management, and groundwater exploration planning.

Keywords: Remote Sensing; GIS; ETM+; SRTM; Groundwater Potential Zones

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1. Introduction

In recent years, remote-sensing methods have been increasingly recognized as a means of obtaining crucial geoscientific data for both regional and site-specific investigations. In the field of Groundwater exploration, various methods were followed but this study focuses on groundwater detection in hard rock terrain[1,2]. The remote sensing data should be acquired and integrated into the early stages of an investigation and used in conjunction with traditional mapping techniques. Hard rock terrain normally creates complex hydrogeology over a long period. Groundwater in hard rock terrain is present or stored in the confined fractures zones and weathered horizons. It is mainly due to the porosity nature of the rock and the fracturing zones, which causes the movement of the water into the hard rock. In India, about 65% of the country is underlined by hard rocks[3].

In this study various image processing techniques, DEM to derive the hard rock characteristics and various structures, to delineate the po-

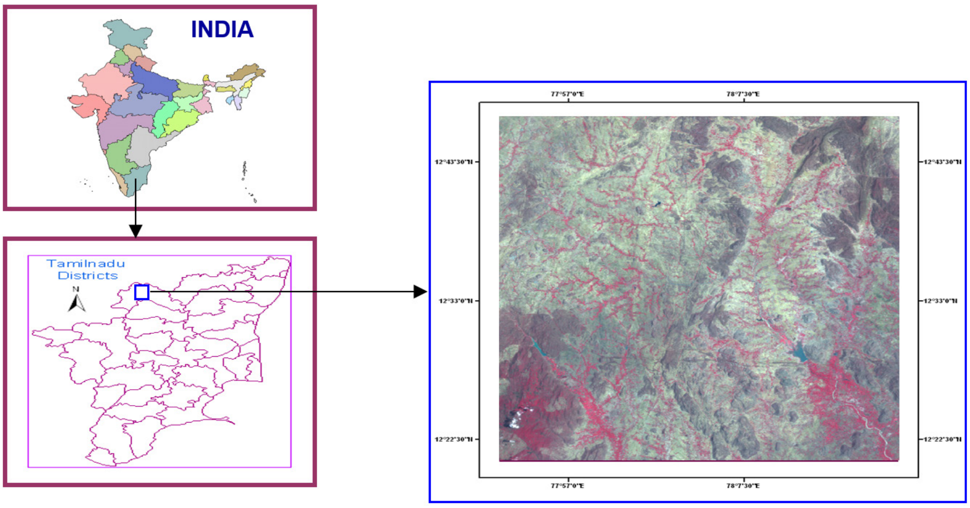

Figure 1. Location Map of the Study area**.**

tential zones of groundwater.

2. Aim and objectives

The overall objective of this study is to contribute to systematic groundwater studies utilizing Digital Image Processing, Digital Elevation Models (DEM) and Geographic Information Systems (GIS) in the assessment of groundwater resources.

The specific objectives of the study are:

- ➢ To identify and suggest suitable digital enhancement techniques for extraction of groundwater controlling features, which is characteristic of hard rock crystalline formation, such as regional geology, geological structures and landforms.
- ➢ To prepare thematic maps of the area such as lithology, lineaments, landforms and geomorphology from remotely sensed data and other data sources like DEM.
- ➢ To assess groundwater controlling features by combining remote sensing, field studies and DEM.
- ➢ To identify and delineate groundwater potential zones through the integration of various thematic maps with GIS techniques.
- ➢ To make recommendations for future work and provide guidelines for groundwater prospecting.

2.1 Study area

The study area is situated to the north part of Dharmapuri district (upper Ponnaiyar Basin) and lies between Latitudes 12o 20” – 12o 45” N and Longitudes 77o 50” – 780 15” E and extends over an area of about 182 km2 covering 24 villages (**Figure 1**). The study area lies in hard rock terrain. Groundwater is available only in weathered and fractured zones. In this area assured surface water supplies are nominal and most of the farmers depend on groundwater for drinking and irrigation purposes.

2.2 Data used

In this study, a variety of data including satellite images, digital elevation models, geological maps, standard 1:50.000 scale topographic maps, and various thematic maps obtained from various sources have been used as data sources together with ground truth studies that have also been carried out. Different sets of data were used for the study like Landsat ETM+ 2015 data and SRTM data.

2.3 Methodology

The methodology employed is summarized in the flow chart in **Figure 2**. It involves digital Enhancement of Lansat ETM+ data for the extraction of lithological, structural and Geomorphological features and evaluation of digital elevation model (DEM) as well as field studies. The field studies are comprised of hydrogeological and structural investigations. The SRTM-DEM was used to extract lineaments and to map drainage systems and landforms. All data were integrated with a Geographic Information System (GIS) and analyzed to assess the groundwater controlling features. Finally, groundwa-

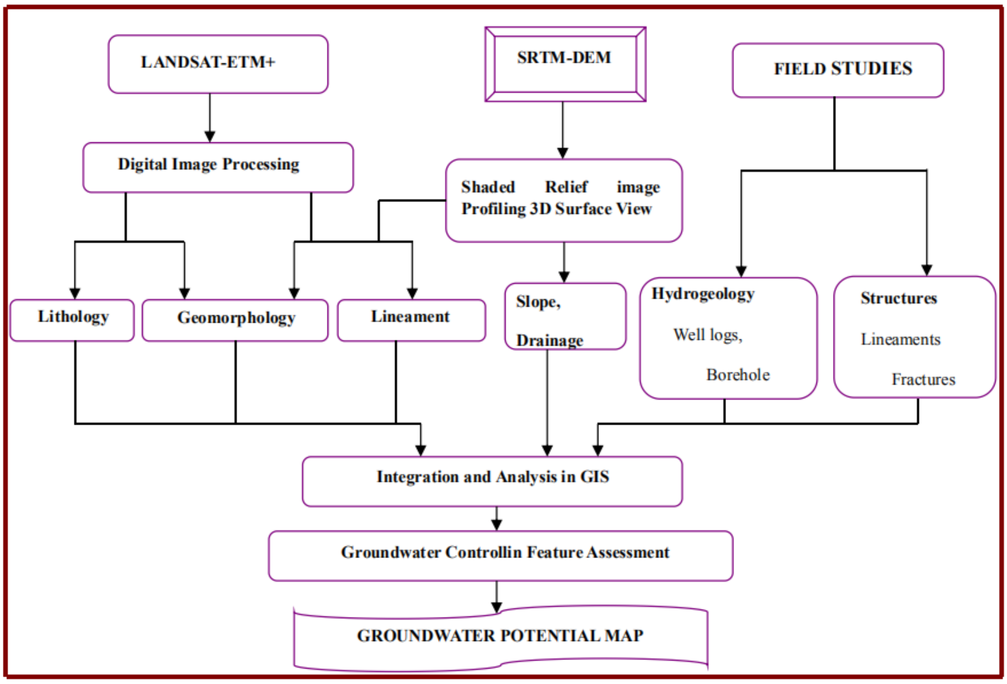

Figure 2. A flow chart depict the methodology adopted for preparation of Groundwater Potential Mapping.

ter potential maps were prepared based on the GIS analysis. The image processing software ERDAS (Earth Resources Data Analysis System) was used for the remote sensing data enhancements. ArcGIS 10.1 were utilized for GIS analysis. The geological, lineament maps and other collateral data were also made use of for the preparation of hydro geomorphological map. The hydro geomorphical map of the area was finalized after field checks with GPS at selected locations for verifying the doubtful units.

3. Integrating remote sensing and GIS in groundwater studies

3.1 Digital image processing and image interpretation

Image enhancement techniques are used in this study utilized the procedures that made the georeferenced images clearer and more interpretable for hydrogeological analysis. To extract the Lithological, Structural and Geomorphological features and from satellite images that cannot be clearly detected in a single band, the spectral information of the lithological and structural features recorded in multiple bands are utilized. The geological structures, especially the fractures that are considered to be one of the high ratings of groundwater controlling parameters, have been clearly brought out during the digital image enhancement techniques. The integration of Landsat ETM+ images with high-resolution PAN data provides complementary information with respect to the discrimination of major geological features and allows lineament extraction in detail. The selection procedure using the statistical techniques was applied in ETM+ data that covers the most prominent rock types in the study area. Principal component analysis (PCA) was performed with the six reflective bands of ETM+ and a number of different three-band PC color composite combinations were created and analyzed for their content (**Figure 3B**). The Decorrelation stretch (DS) conducted on ETM+ bands 4, 5 and 2 is shown in (**Figures 3C** & **D**) better lithological and geomorphological contrast was obtained when compared, for instance, with the standard band combination of PCA and FCC images. Moreover, most of the lithological units in the study area are discernible in the image. In general, the decorrelation stretch proved to be the most effective in accentuating colors, thus facilitating visual discrimination of various hydrogeological features. This is because the technique removes the high correlation commonly found in multispectral data sets and thus produces more colorful composite images[4-5].

3.2 Evaluations of SRTM Data

The evaluation of digital topographic data is of great importance as it contributes to the detection of the specific geomorphologic/ topographic settings in rougher terrain. Data of the Shuttle Radar Topography Mission (SRTM) are used to provide digital elevation information (90 m spatial resolution). SRTM DEM data are used for lineament analysis. The primary method used for the interpretation of the SRTM DEMs was to extract lineaments through the creation of hill-shading DEMs. Hill-shading DEMs with different azimuth directions and sun angles are used in this study (**Figure 4. A & B**). This technique is effective in creating images that enhance geomorphic features. The result shows that the shaded relief image can provide good enough geological information. Subsurface structures such as fault zones can be derived by geomorphologic analysis (drainage pattern) and the identification of linear tonal anomalies on the imageries. Linear morphologic features (lineaments) as visible on hillside maps and LANDSAT imageries are often related to traces of faults and fractures in the subsurface influencing groundwater permeability (**Figure 4C**).

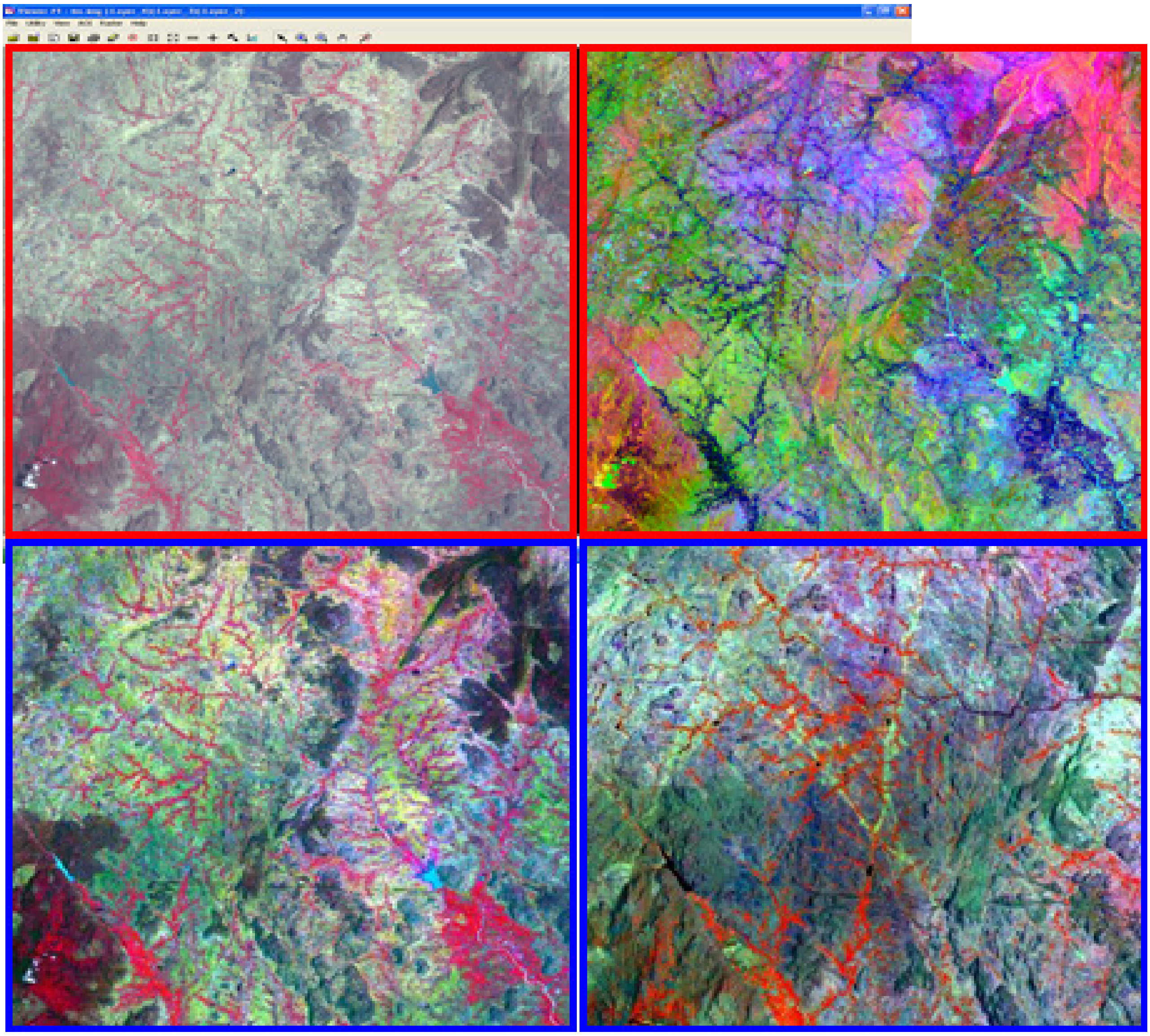

Figure 3. Enhanced Landsat-ETM+ images. A. FCC (4-3-2). B. PCA (4-3-2). C. Decorrelation Stretched (4-3-2). D. Subset image highlight the various hydrogeological features**.**

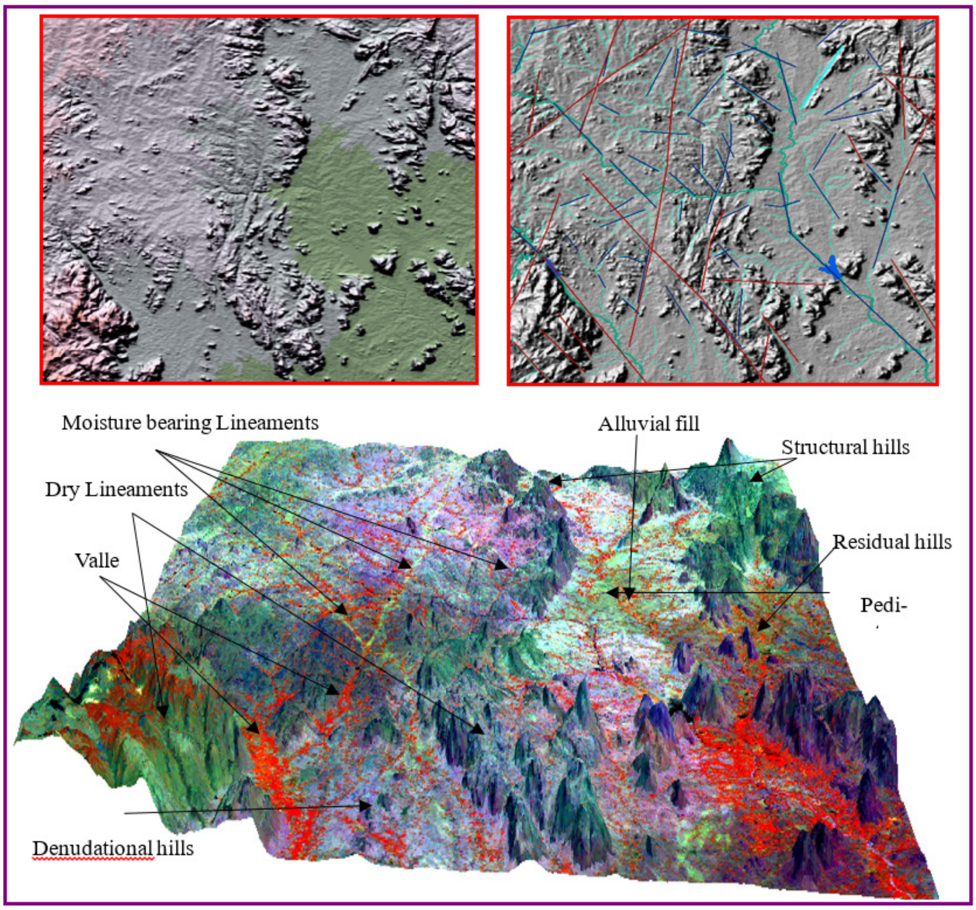

Figure 4. A. Shaded relief image with varying sun azimuth and angle that can enhance the structural features in the study area. B. Shaded relief image with overlay in drainage and lineaments. C. 3D perspective view of the study area created from SRTM hill-shading DEM along with the Hydrogeological interpretation.

3.3 Spatial analysis

Spatial analysis was performed in GIS to assess terrain features, e.g., water bodies, stream networks, faults, rock type, elevation, land-use classes and vegetation cover. GIS-RS spatial analysis was used to generate land surface statistics and to assist in the study of spatial relationships between terrain elements for image enhancements.

4. Result and discussion

4.1 Geology

Igneous and metamorphic rocks are closely interspersed throughout most of the Region. Igneous rocks are predominantly granite; subordinate amounts of dolerite are widespread. Metamorphic rocks, chiefly Charnockite, Migmatite, gneiss and schist are common and tend to be folded and faulted extensively. The rocks are broken and displaced by numerous faults and zones of shearing, some of which are many miles long. Fortunately, indirect evidence of the degree of fracturing of a particular rock may be derived from terrain analysis, chiefly soil thickness and topographic expression. In most places, massive granite and gabbro have thin soils and are poorly fractured, whereas gneiss and schist have thicker soils and moderate to relatively high fracture densities.

4.2 Structure

The geological structure normally encountered in hard rock areas of places such as India is granite or granite gneiss overlain by a variable thickness of weathered material[6]. Since identification and demarcation of moisture-laden fractures in the crystalline rock formation will aid quick exploration of groundwater, a detailed analysis has been done (**Figures 5 & 6**). The analysis of pre-monsoon data through the digital enhancement technique offered a differentiation of moisture-bearing lineament with dry lineament based on land use/land cover along the fracture zones. While the moisture-bearing lineaments in this terrain signify a promising groundwater occurrence at a shallow depth, the dry lineament signifies an unpromising shallow groundwater occurrence[7]. It is generally accepted that lineaments analysis alone cannot be used for borehole siting. Remotely sensed data along with hydrogeological data, when integrated with statistics and GIS techniques, may provide a valuable tool to help in the selection of successful borehole sites in areas that consist of crystalline rocks and have a semi-arid terrain[8,9].

4.3 Drainage

According to El-Baz, the coincidence of drainage with structural features, as well as the channels that drain into fractures, provides the ideal fluvial-structural configuration for groundwater accumulation. So, these features are valuable for groundwater exploration in the study area. Intersecting drainage patterns, indicative of subsurface structures suitable for groundwater occurrences.

4.4 Geomorphology

The geomorphology of an area is highly influenced by the lithology and structure of the underlying formations[10]. So hydro geomorphological units have a direct relation to groundwater. Hydrogeomorphologically, the study area is classified into different zones covered by Denudostructural hills; Denudational hills, Residual hills, Alluvial plain, Pediment, peneplain and Valley fill (**Table 2**). The delineation of hydrogeomorphic zones aims at demarcating areas of groundwater recharge/discharge and potential zones for development.

4.5 Groundwater Potential zones

By integrating both hydrogeological and hydrogeomorphological details derived through the visual onscreen interpretation of different enhanced products, a groundwater prospective zone map of the study area was prepared **Figure 7**. The groundwater conditions of the study area have been arrived at by incorporating the details obtained through ground surveys with a groundwater prospective zone map **Table 2**. The various geomorphic units are classified as favorable, moderately favorable and poor zones of groundwater[11,12].

Groundwater development is promising in the floodplains, alluvial plains and valley fills that are associated with thick alluvium and weathered material that has high porosity and permeability charac-

Table 2. Geomorphic Units for Hydrogeomorphological Mapping in the Study area

S.No	Geomorphic units	Structures	Lithology	Groundwater Conditions
1.	Structural hills	Lineaments, Joints, Fractures etc.	Charnockites, Kondalites etc.	Mainly act as a run-off zone, not suitable for groundwater prospecting.
2.	Residual hills	Joints, Fractures etc.	Charnockites, Granites etc.	Mainly act as a run-off zone. Fractures and intersection of fractures are promising zones for groundwater extraction.
3.	Pediment	Fracture controlled	Gneisses, Granite, Charnockite etc.	Sporadically distributed in the study area. Moderate to poor groundwater prospective zones.
4.	Pediplain	-	Gneisses, Granite etc.	Mainly covered by red soil. The weathered thickness range from 1–7 m. The occurrence of groundwater is in unconfined condition within weathered and fractured layer. Moderate groundwater prospective zone.
5.	Valley fills	Fracture controlled	Recent alluvium, colluvium, clay, sand, silt etc.	Fine/medium grain unconsolidated sediments with thickness of 1–5 m. Most of the wells drilled in this zone are high yielding. Good/excellent groundwater prospective zone.
6.	Alluvial plain	-	Recent alluvium, colluvium, clay, sand, silt etc.	Fine/medium grain unconsolidated sediments with thickness of 1–10 m. Most of the wells and dug wells drilled in this zone are high yielding. Excellent groundwater prospective zone.

teristics. Only a small area is occupied by these landforms, and hence favorable zones of groundwater are very limited in the basin area. A large part of the area is occupied by pediments, peneplains, structural hills, which do not favor much infiltration and hence are generally not favorable for groundwater exploration. The study reveals that a large part of the area has good to moderate groundwater producing potential.

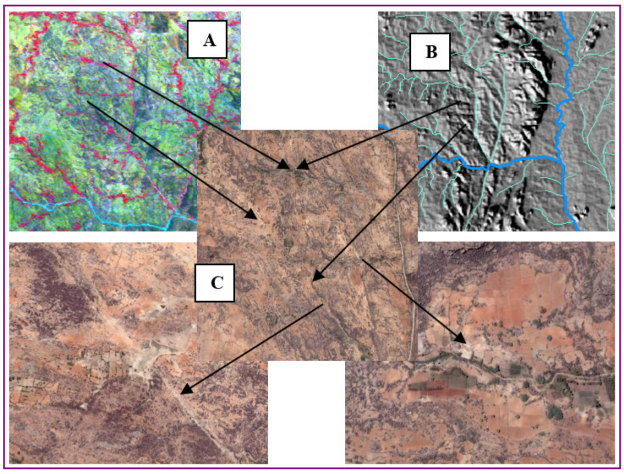

Figure 5. A. A lineament detected on contrast-stretched DS image. B. The same lineament detected on a Shaded relief image. C. Field photographs of an NW-SE trending fault trace that corresponds to the lineament.

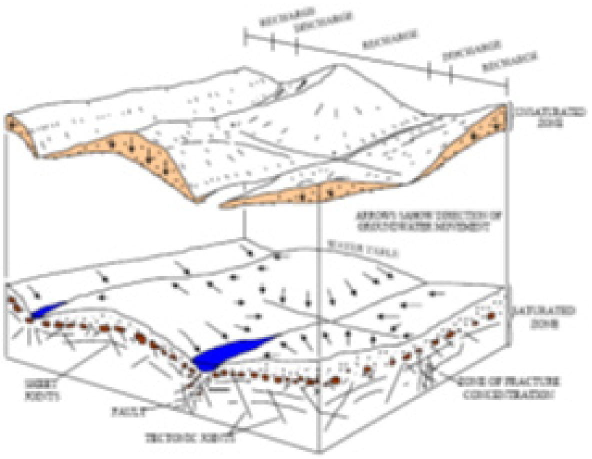

Figure 6. Block diagram of fracture zones and groundwater movements associated with surface fracture traces.

4.6 Conclusion and recommendations

The different types of digital enhancement techniques, such as linear stretching, band combination, PCA and filtering, hill shading techniques using DEM are found to be useful for extracting the various groundwater controlling features in typical hard rock terrain. The integration of the details derived from digitally enhanced ETM+ and DEM products with GIS has helped in the preparation of a groundwater potential zone map. The occurrence of groundwater is controlled by rock type, structures and landforms as revealed from GIS analyses and field investigations. High-yielding wells and springs are often related to large lineaments, lineament intersections and corresponding structural features.

In metamorphic and igneous intrusive rocks with rugged landforms, groundwater occurs mainly in drainage channels with valley-fill deposits. Zones of very good groundwater potential are characteristic for alluvial/colluvial layers overlying crystalline rocks, flat topography with dense lineaments and structurally controlled drainage channels with valley-fill deposits. The overall results demonstrate that the use of Digital Image Processing, DEM and GIS provide potentially powerful tools to study groundwater resources and design a suitable exploration plan.

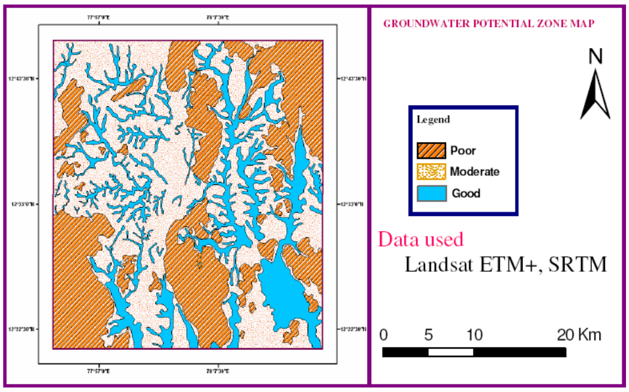

Figure 7. Groundwater potential map of the study area.

5. Recommendations

Several approaches were applied to understand the hydrogeological conditions of the hard rock aquifers in parts of Tamilnadu. Because of the inhomogeneous nature of hard rock aquifers, it is crucial to use investigation techniques that maximize the information from various sources. An attempt was made to optimize the available data using methods that have proved to be successful in hydrogeological studies in other parts of the world. The following recommendations are given.

➢ Geospatial data are powerful tools to improve our understanding of groundwater systems. While not directly measuring hydrogeological properties, they provide continuous detailed terrain information and allow the mapping of features significant to groundwater development. Various satellite data with different spectral and spatial resolutions coupled with digital image processing techniques help to accurately produce detailed maps. Ground verification is crucial to increase the accuracy of the interpretation results.

➢ Geographic Information Systems are very time and cost-effective once the database is created and provide many advantages over traditional approaches. Integration of different data layers such as remote sensing, geomorphology and field data in a GIS environment provides means to unravel the nature of hard rock aquifers. Spatial and statistical analysis allows understanding the correlation between different parameters. This integrated approach of groundwater potential assessment in a GIS is highly recommended.

➢ Structures are assessed at the outcrop scale to decipher the nature of lineaments interpreted from remote sensing data. Field investigations of well sites in relation to location, topography and structures as well as subsurface information such as pumping test and lithological log data are most valuable to improve our understanding of the hydrogeological conditions (**Figure 8**).

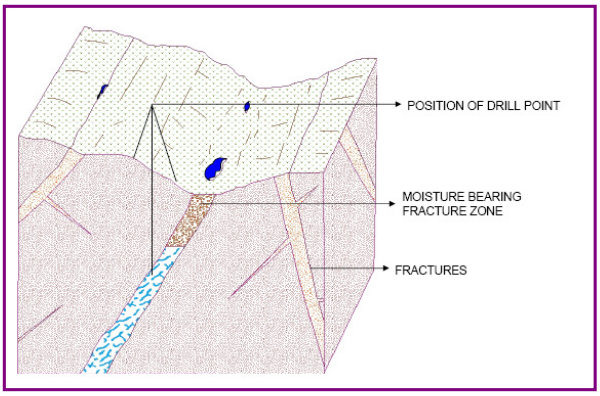

Figure 8. Correct positioning of rig**.**

Conflict of interest

The authors declare that they have no conflict of interest.

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