Groundwater Exploration using Ground Magnetic Survey along the Contact of Crystalline and Sedimentary Rocks in Parts of Perambalur District, Tamil Nadu, India

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(Received on 24 October 2025; In final form on 10 April 2026)

DOI: https://doi.org/10.58825/jog.2026.20.1.296

Abstract: This study delineates groundwater potential zones along the contact between the Tiruchirappalli Cretaceous formations and the Archaean crystalline basement using ground magnetic surveys. Magnetic susceptibility data were collected with a Proton Precession Magnetometer along six NW–SE profiles at 1 km station spacing and 5 km profile intervals, covering key locations in Perambalur district, Tamil Nadu. A total of 60 measurements were obtained, with magnetic intensity values ranging from 967 to 7 gammas and averaging 297 gammas. Higher values were recorded in crystalline rocks (967–300 gammas) and lower values in sedimentary rocks (300–7 gammas), enabling the delineation of the basement–sedimentary litho contacts. Data processing in Geosoft and ArcGIS produced total magnetic intensity, reduction-to-pole, directional filter, regional, and residual maps, which highlighted lithological contacts and fracture systems. NE–SW fractures correspond to lithological contacts, while NW–SE fractures represent neo-tectonic structural elements. Groundwater potential zones were identified using rank and weightage method which shows that the possible potential zones are along the litho contact and the intersection of NW-SE fractures with litho contacts. The findings confirm that magnetic surveys are an effective tool for locating groundwater-bearing structures in basement–sedimentary terrains.

Keywords: Unconformity, Groundwater, Magnetic method, Radially averaged power spectrum

1. Introduction

Different geophysical methods like electrical, electromagnetic, gravity and magnetic are regularly used to identify subsurface structures, groundwater and minerals. Magnetic survey depends on the magnetic properties of the material to be surveyed. The intensity of magnetization varies with respect to the magnetic susceptibility of the material concerned. It is also used to locate and define the extent of sedimentary basins where the basement rocks are brought near to the surface. It is structural high, magnetic anomalies are large and characterized by strong relief. On the other hand, low magnetic values for deep sedimentary basin produce contours with a gentle gradient of magnetic maps (Adagunodo, 2015). Magnetic method is also used to delineate magnetic field intensity in an area underlain by different lithologies with varying magnetic mineral contents (Dransfield, 2018). Magnetic method also gives information about the depth to the basement rocks (Umeanoh, 2018). In groundwater resource studies, integrating remote sensing, geophysical data, and GIS tools play a critical role in monitoring, analyzing, and protecting groundwater resources for water resources development and management (Kamaraj, et al. 2023a; Kamaraj et al, 2023b; Ogungbade, 2022; Mohammed-Aslam, 2010). The effectiveness of remote sensing in the study of geotectonics and in groundwater explorationhas been demonstrated by several workers as (Akinluyi et al. 2018; Oyedele 2019; Al-Djazouliet al.2020).

Ground magnetic survey is an essential geophysical method employed in locating subsurface magnetic materials for possible exploration. In geophysics, the anomalous magnetization might be associated with local mineralization that is potentially of commercial interest (Joshua et al. 2017). The magnetic method also measures variations in the magnetic field to determine the location of subsurface features. Magnetic methods are sensitive to magnetic susceptibility in subsurface rocks and so are ideal for exploring the basement complex regions (Folami, 1998). This non-destructive technique has numerous applications in engineering and environmental studies, including the location of voids near the surface fault, igneous dikes, and buried ferromagnetic objects like storage drum pipes (Weymouth, 1985). It's also used in mapping geological boundaries between magnetically contrasting lithologies including faults (Telford et al. 2001; Muthamilselvan, 2017). Magnetic field variations can be interpreted to determine anomaly depth, geometry and magnetic susceptibility. Magnetic anomaly maps are used to aid geological interpretation. Magnetic survey was further used to locate groundwater potential zone (Sultan et al. 2015; Muthamilselvan, 2021; Muthamilselvan and Preethi, 2022; Muthamilselvan et al. 2022). According to Hansen et al. (2005), magnetic methods are widely used in almost all areas of near-surface geophysics. In the present study, magnetic survey has been used to locate groundwater potential zone in the unconformity region near Perambalur district of Tamil Nadu.

2. Study Area

The study area is situated southeast of Perambalur, Tamil Nadu, between 78°46'44" and 79°51'31" E longitude, and 10°59'49" and 11°19'48" N latitude. It falls in the toposheet numbers 58 I/15, 58 I/16, 58 J/13, 58 M/3, and 58 M/4. This region hosts some of South India's most well-developed Cretaceous sedimentary sequences, marking a significant period in India's geological history. Perambalur District, located centrally in Tamil Nadu, is about 267 km south of Chennai and spans an area of 1,757 sq. km. It lies between 10.54° and 11.30° N latitude and 78.40° and 79.30° E longitude. The district's primary mode of transportation is via roadways. The nearest seaport is Karaikal; 139 km away, while Tiruchirappalli International Airport, 67 km from the town, and is the closest airport. The district is drained by the Swetha, Kallar, and Vellar rivers. The Visvakudi Dam, situated in Visvakudi village, is built across the Kallar River, between the Vayalar Hills and Semmalai.

The district is situated in the southern plateau and hill zone of agro-climate regional planning, characterized by a semi-arid climate and renowned for its world-class black granite in the Pachai Malai hills. The soil mainly consists of red loamy and black soil. The district experiences an average annual rainfall of 908 mm, which is below the state average of 946.9 mm. Rainfall distribution is as follows: 52% during the northeast monsoon, 34% during the southwest monsoon, and 14% during the winter and hot weather periods. Groundwater is the primary irrigation source, with tube wells and wells supplying nearly 68% of the irrigated area. Major crops in the district include paddy, groundnut, sugarcane, millet, and cashew. Perambalur is responsible for about 24% of small onion production in Tamil Nadu, leading the state in this crop.

3. Geological Setting

The Tiruchirappalli Cretaceous Formation in the Ariyalur district of Tamil Nadu is among the well-developed sedimentary sequences in South India. This study area holds significant paleo geographical importance in the

Indo-Pacific region during the Cretaceous period. Blandford (1862) was the first to delineate the stratigraphy, dividing it into three groups: Uttatur, Trichinopoly, and Ariyalur. Sundaram and Rao (1984) later identified new formational units within the Uttatur and Trichinopoly Groups, including the Arogyapuram, Dalmiapuram, and Karai Formations of the Uttatur Group, and the Kulakkalnattam and Anaipadi Formations of the Trichinopoly Group. They maintained the classification of the Ariyalur Group (Sastry et al. 1972), which includes the Sillakkudi, Kallankurichchi, and Kallamedu Formations. The sedimentary sequence, which rests unconformably atop the Archean crystalline rocks, consists of formations that dip gently towards the east and southeast. The Upper Gondwana sediments, known as the Terani Formation (Sundaram and Rao, 1984), overlie these basement rocks and are categorized as the Sivaganga Formation (Banerji, 1982), regarded as non-marine and of Early Cretaceous age. The lithological boundary between the Archean and sedimentary rocks generally follows a NE-SW trend, which is also evident in the foliation of the crystalline rocks and the overall strike of the sedimentary formations (Figure 1).

4. Materials and Methods

4.1 Instruments

The Proton Précession Magnetometer (PPM) is an instrument designed to measure the scalar intensity of the local magnetic field. This well-established technique has been effectively utilized in classical proton precession magnetometers. The name "PPM" comes from its use of the precession of spinning protons or hydrogen nuclei in a hydrocarbon fluid sample to assess the total magnetic field intensity.

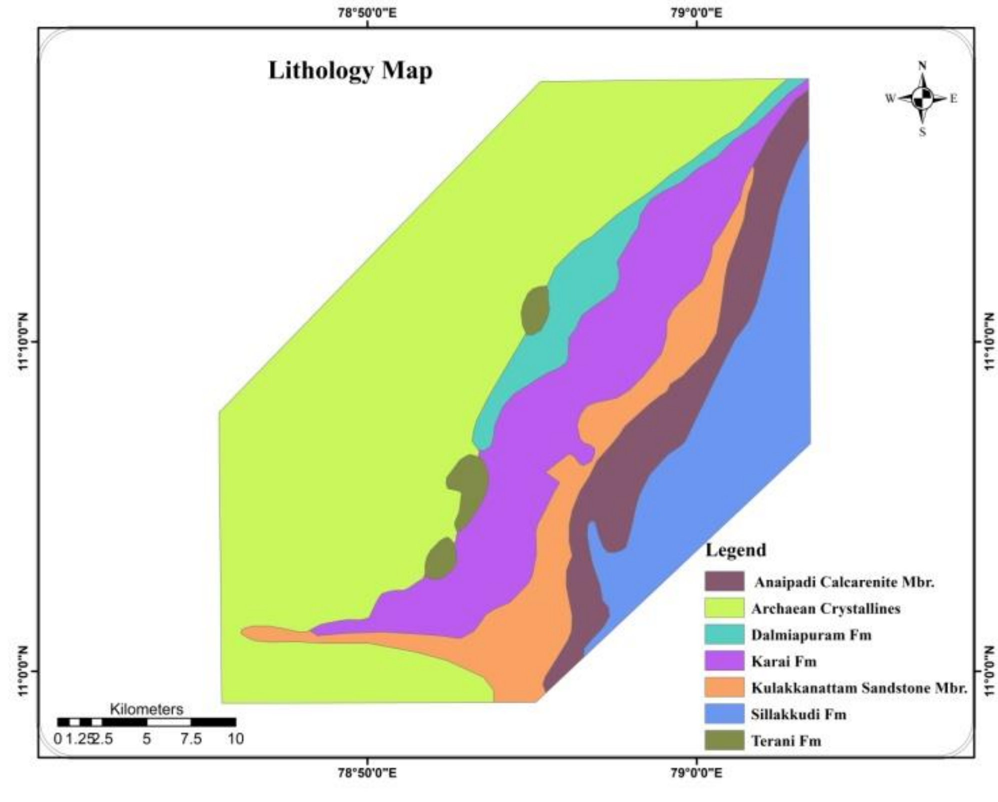

Figure 1: Lithological Map of the Study Area

In this process, the magnetic moments of the protons are initially aligned by a strong magnetic field generated by an external coil. When this magnetic field is abruptly turned off, the protons attempt to realign with the Earth's ambient magnetic field. Due to their spinning and magnetized nature, the protons presses around the Earth's field at a frequency that depends on the field's strength. The external coil detects a weak voltage generated by this precession. The period of the gyration is measured electronically with high precession, allowing for sensitivity levels between 0.1 and 1.0 nanotesla (Figure 2).

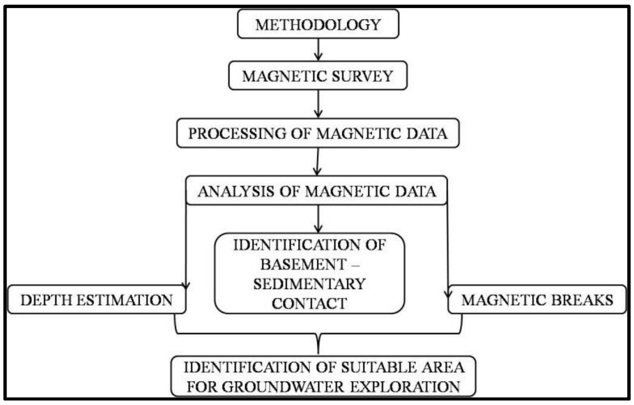

Figure 2: Methodology of Flowchart

4.2 Data Collection

A total of 60 samples were collected, with a 1 km sampling distance and a 5 km interval between profile lines. At each location, three magnetic readings were taken to enhance accuracy, and the averages of these values were used for analysis (Figure 3). The methodology flow chart is illustrated in Figure 2. Following the collection of magnetic data, a common processing technique involves removing diurnal variations, often utilizing base station data or International Geomagnetic Reference Field (IGRF) data. This study covers an area of approximately 500 sq. km, making hourly base station readings impractical. Therefore, the IGRF correction was applied to account for the Earth's main magnetic field. This method is typically used for extensive survey areas and is not employed for small-scale engineering and environmental surveys, as the Earth's magnetic variations can be as low as 0 to 2 gammas/km in the east-west direction and 2 to 5 gammas/km in the north-south direction. In this study, diurnal changes were addressed by considering IGRF values for the period between 2020 and 2025, using Geosoft Oasis Montaj software.

After correction, the magnetic data was gridded, contoured, processed, and analyzed. Various maps were generated, including the total magnetic intensity map, reduction to the equator, regional and residual maps, analytical signal maps, directional cosine filter maps, and a magnetic breaks map. These were created to identify groundwater potential zones at the unconformity contact between the crystalline basement and the Tiruchirappalli Cretaceous formations. All maps were produced using the WGS84 ellipsoidal datum with geographic latitude and longitude projections. Interpretations from these maps were used to pinpoint the litho contact and unconformity between the basement crystalline and sedimentary rocks, as well as to identify subsurface structural features within the study area. Finally, suitable sites for groundwater exploration were recommended.

5. Results and Discussion

5.1 Total Magnetic Intensity Map

The magnetic data was gridded using the minimum curvature grid method within the Geosoft environment to create a total magnetic intensity (TMI) map of the surveyed area (Figure 4).

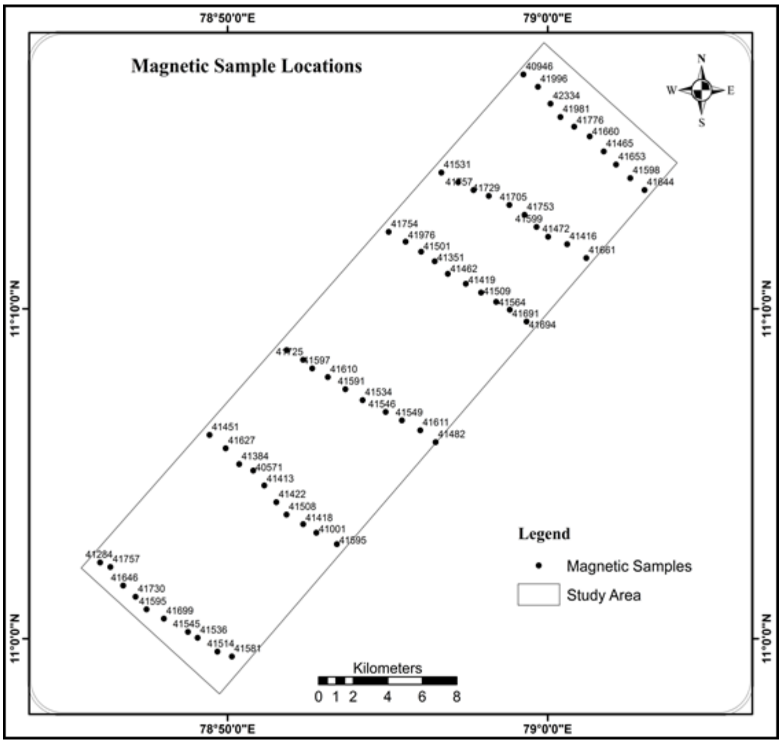

Figure 3: Magnetic Data Collection

This map reveals significant variations in magnetic intensity, reflecting differences in lithology. In the surveyed area, sedimentary rock exhibit lower susceptibility compared to the crystalline basement. The TMI map shows a maximum magnetic field intensity of 42,334 nT in the Archaean terrain, while the minimum is 41,334 nT in the sedimentary formations. After IGRF corrections, the magnetic anomalies range from 967 nT to 7 nT, with magnetic values decreasing from the northwestern to the southeastern part of the area. The TMI map displays a high intensity range of approximately 960 to ~301 nT (indicated in pink to red) in the northwest, following a NE–SW trend, while lower magnetic intensities of 300 to7nT (shown in green to blue) are observed in the southeast, maintaining the same trend.

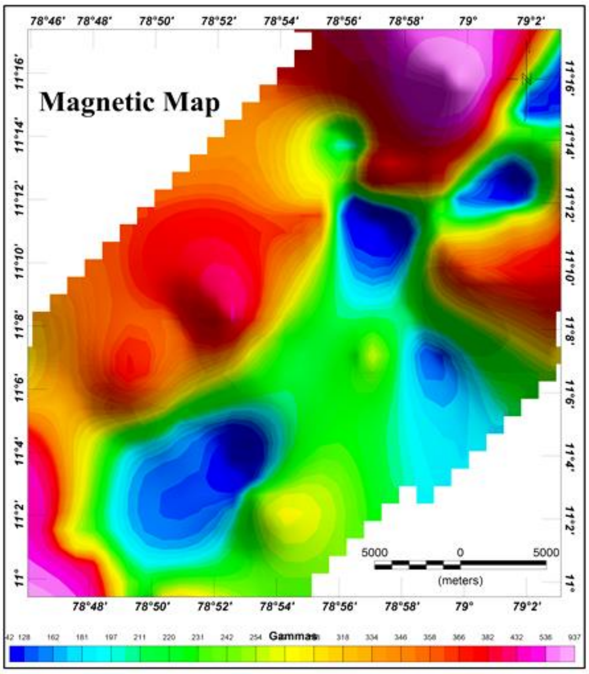

Figure 4: Total Magnetic Intensity Map

5.2 Reduction to Magnetic Equator

To accurately position the causative body, the total magnetic intensity map was adjusted to account for latitude effects, ensuring that the magnetic anomalies are symmetrically centered over their respective sources, especially since the study area is near the equator. A standard phase shift operation known as Reduction to Pole (RTP) is typically performed on the observed magnetic field to enhance anomaly interpretation (Figure 5). However, in regions close to the magnetic equator, where the inclination is less than 15°, RTP tends to be unstable and cannot be reliably derived, as it results in a north-south alignment of anomalies, leading to unstable data. A similar instability occurs when the magnetic field is reduced to the equator (RTE) rather than to the pole, depending on the study area's latitude. After reducing the field to the equator, the regional magnetic field becomes horizontal, and most source magnetizations will also be horizontal.

The RTE grid ideally exhibits the same frequency distribution as the original TMI grid while retaining geological strike and dip information, effectively removing the influence of magnetization direction. This allows for mapping of structures and rock types. The RTE results clearly highlight two distinct rock types trending in a NE-SW direction. The yellow to pink colors on the RTE map indicate high magnetic susceptibility, suggesting the presence of crystalline rocks in the Archaean area. In contrast, green to blue colors represent various sedimentary rocks from the Tiruchirappalli Cretaceous formations. The litho contact identified between these rock types in the middle of the map indicates unconformity relationships and highlights a weak zone where groundwater potential is likely high, making it a suitable area for exploration.

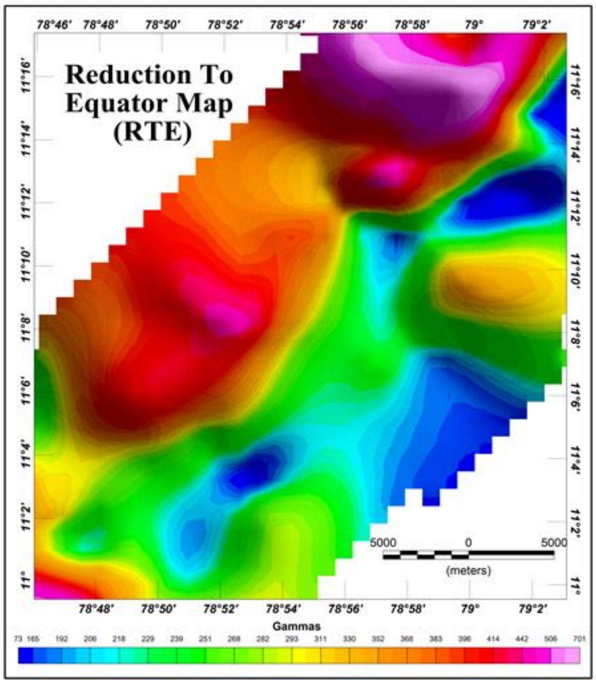

Figure 5: Reduction to Equator Map

5.3 Regional and Residual map

Regional and residual anomaly maps were created using Gaussian Regional/Residual filters in the Geosoft Oasis Montaj environment (Figures 6 and 7). These maps are designed to delineate both shallow and deep causative bodies within the study area. Deeply buried magnetized bodies generate magnetic anomalies with long spatial wavelengths, referred to as regional trends, while shallow magnetized bodies produce anomalies with short spatial wavelengths, known as residual trends. When focusing on shallow structures, long-wavelength anomalies are considered noise and filtered out. Conversely, if the interest lies in deeper structures, short wavelengths are treated as noise and removed.

The regional anomaly map was generated using a cutoff wavelength of 10,000 m^{-1} in the Geosoft environment. This map effectively reveals the contact relations between two distinct rock types trending in a NE-SW direction and indicates that the unconformity contact extends in depth, as it was derived using a low-pass filter that emphasizes deeper sources. For the residual anomaly map, the same cutoff wavelength of 10,000 m^{-1} was applied. This map clearly separates individual causative bodies and highlights shallow features. The elongated, oval, and semicircular shapes of magnetic highs in the residual anomaly maps suggest the presence of granitic and Charnockite rock.

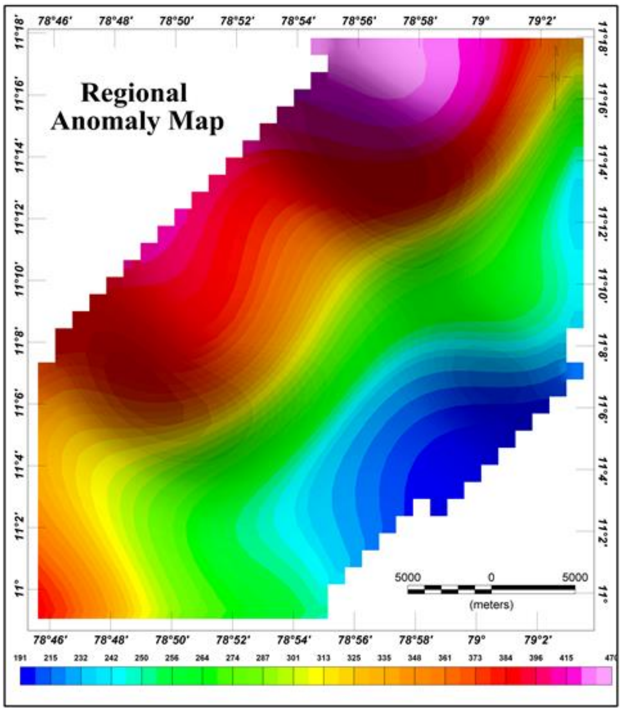

Figure 6: Regional Anomaly Map

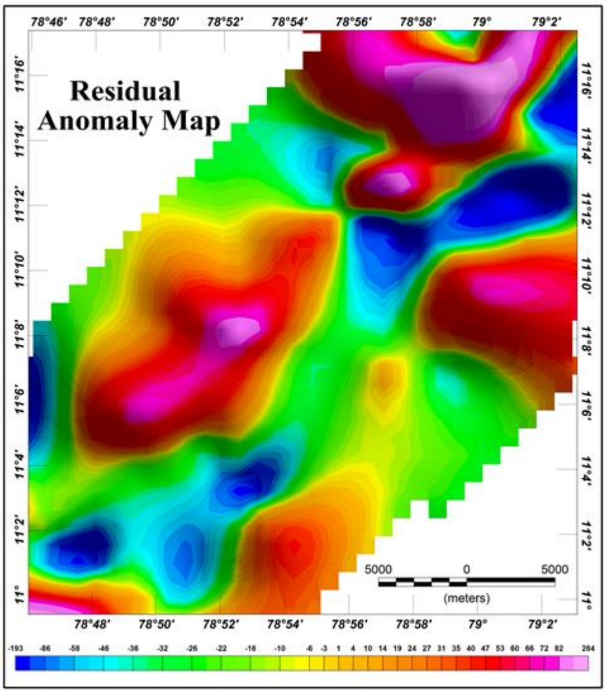

Figure 7: Residual Anomaly Map

5.4 Cosine directional filter

The Directional Cosine Filter (DCF) is a spectral domain grid filter that selectively rejects or retains components of the observed data based on a user-specified azimuth. Unlike conventional directional filters, the DCF produces a smooth curve in Roll of Range, which helps to eliminate shorter wavelengths (Serguel et al. 2000). This filter was applied to the total magnetic intensity data to enhance the visibility of structural elements trending in the NE-SW direction. To extract these NE-SW linear features, an azimuth of 45° was utilized with a cosine function degree of 2. The results from the directional filter clearly highlighted NE-SW structural

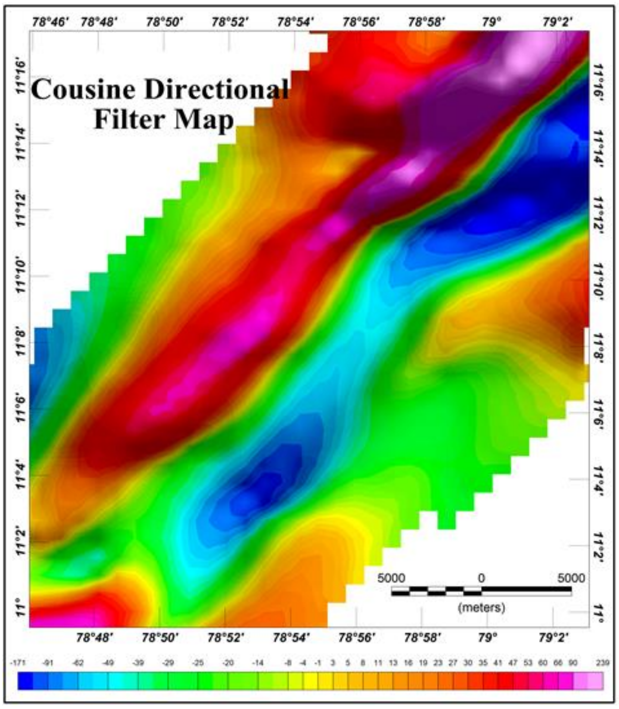

Figure 8: Cosine Directional Filter Map

elements, representing the unconformity contact between the crystalline basement and sedimentary rocks (Figure 8).

5.5 Depth Estimation: Radially averaged power spectrum

The radially averaged power spectrum is a magnetic method employed to determine the depths of both shallow and deep sources, as well as the basement-sedimentary complex and subsurface geological structures. Various authors have detailed the spectral analysis technique (Spector and Grant, 1970; Garcia and Ness, 1994; Tatiana and Angelo, 1998). In this study, the fast Fourier transform (FFT) was applied to the RTE magnetic data to calculate the energy spectrum within the Geosoft environment. The resulting diagrams (Figure 9) from the radially averaged power spectrum indicate the average depth levels of the deep and shallow segments. The depth of the causative body was determined by calculating the slope of the profile and then applying the formula $h=s/4\pi$ where (h) represents the depth and (s) denotes the slope obtained from the profile. The power spectrum reveals residual anomalies extending up to 1200 m in depth and regional anomalies around 2200 m. The profile displays two slopes from which these depth estimates were derived, and it also aids in visualizing the litho contacts. The litho contact is identified at the point where the two slopes intersect.

5.6 Discussion

Swerves in the contour lines and variations in colour intensity observed on the Reduction to the Pole (RTE) magnetic map were employed to accurately map magnetic breaks representing both surface and subsurface fractures within the study area. Three distinct sets of magnetic breaks, oriented NE–SW, NW–SE, and E–W, were delineated, each indicating key surface and subsurface

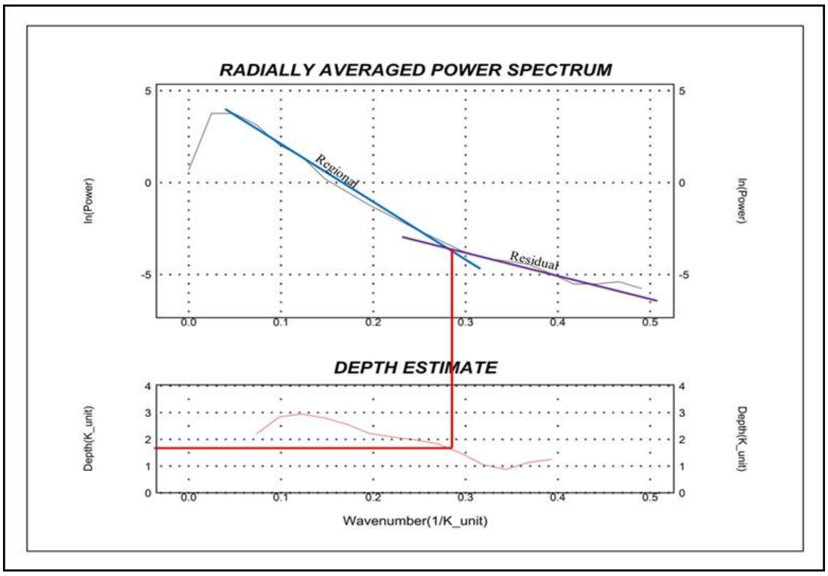

Figure 9: Radially Averaged Power Spectrum

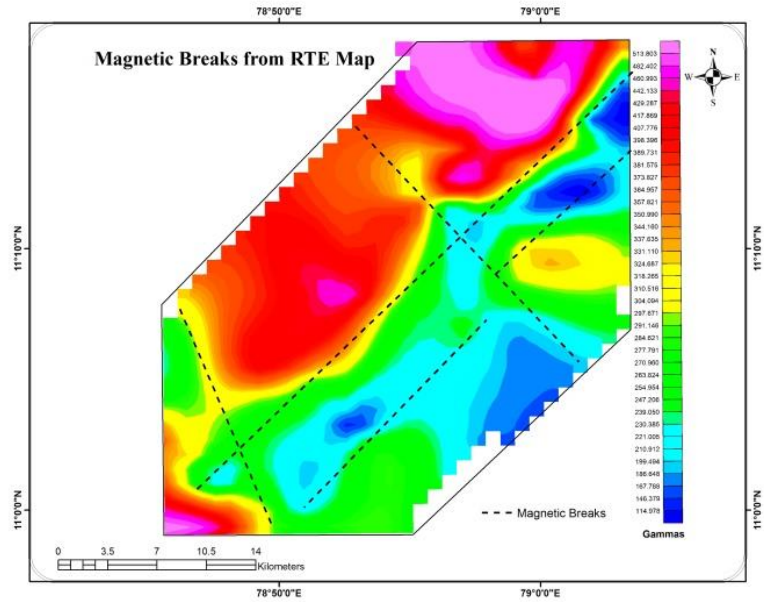

Figure 10: Magnetic Breaks from RTE map

structural elements including faults, shear zones, (Figure 10) and lithological contacts. Notably, the NE–SW trending breaks are especially prominent on the RTE map, extending from the southwestern to the northwestern portion of the region and demarcating unconformity contacts between crystalline and sedimentary rocks. Within the context of groundwater occurrence in Tamil Nadu particularly in hard rock regions fractured aquifers are the principal water sources. It is noteworthy that the intersection points of NE–SW, NW–SE, and E–W magnetic breaks are considered highly significant for groundwater exploration. The regional anomaly map revealed the depth continuity of NE–SW trending magnetic breaks, which extend from the southwestern to the northeastern sections of the study area. In addition, the RTE image was instrumental in delineating the contact zone between Archaean crystalline basements and overlying sedimentary rock formations.

Structural elements, including fractures and unconformities, were identified using a suite of magnetic methods and subsequently incorporated into an ArcGIS environment to assess potential sites for groundwater exploration. Magnetic breaks were interpreted from various geophysical maps, such as the magnetic map, reduced-to-equator (RTE) map, cosine directional filter map, regional and residual maps, alongside lithological contact zones, which are considered structurally weak (Figure 11). Buffer analysis was performed by generating ring buffers of 250 m, 500 m, and 750 m around these weak zones using the ArcGIS ring buffer tool. Zones encompassed by 250 m buffers on either side of the magnetic breaks were interpreted as areas with maximum groundwater potential, while zones within the 750 m buffers were considered to have minimum groundwater potential. To prioritize favorable sites for groundwater exploration, thematic layers were assigned specific weightages and ranks, facilitating effective delineation of high-potential zones. (Figure 12). The final ground potential map is shown in Figure 13.

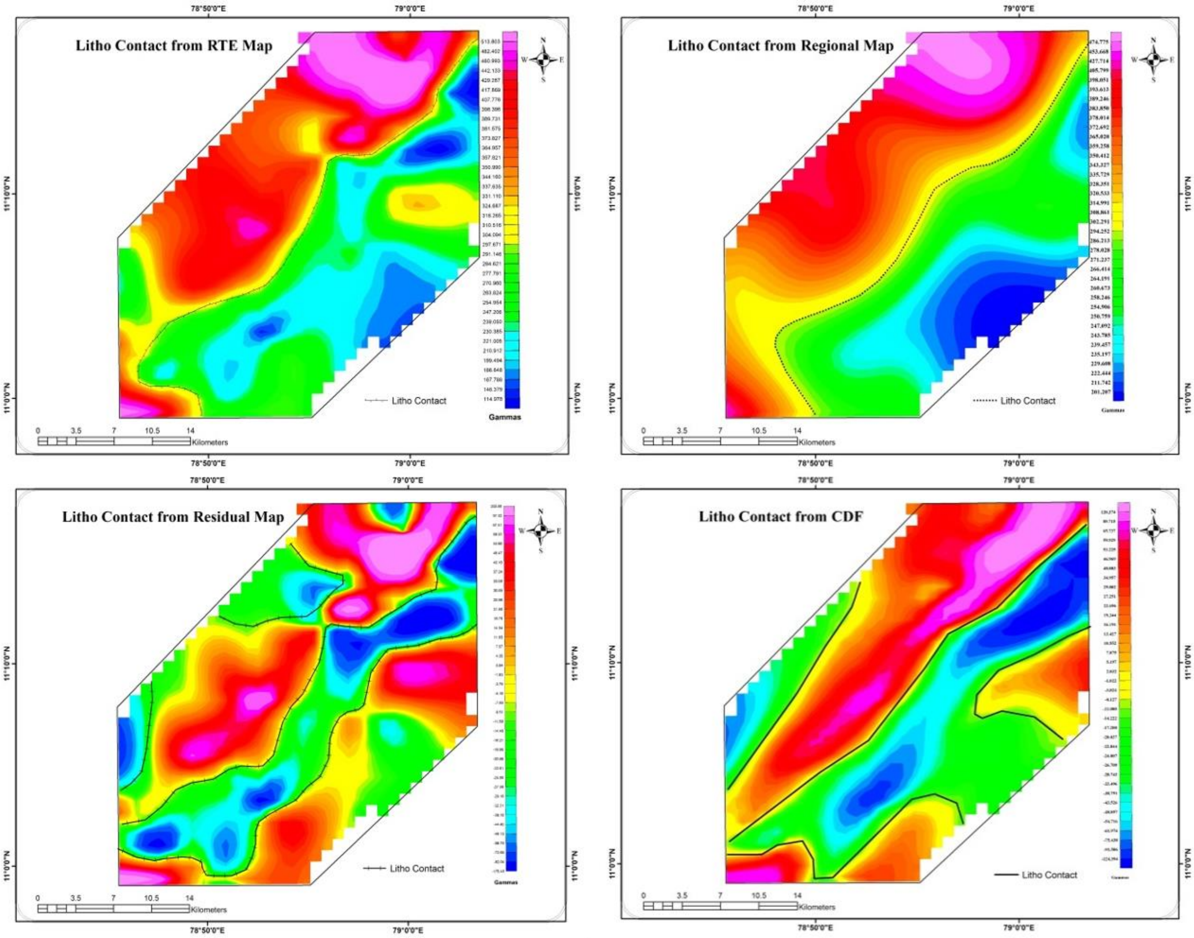

Figure 11: Maps Showing Litho Contact from RTE, Regional, Residual and CDF

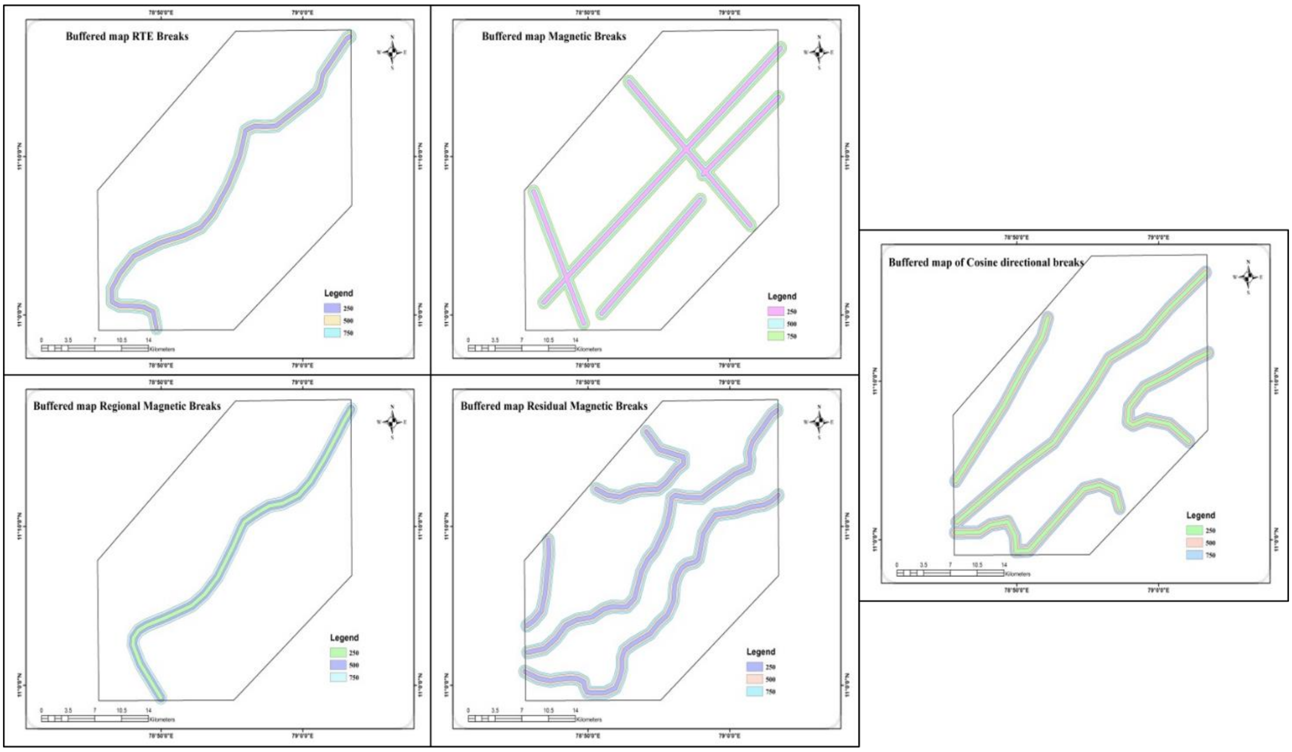

Figure 12: Maps Showing Buffered map for Thematic layers

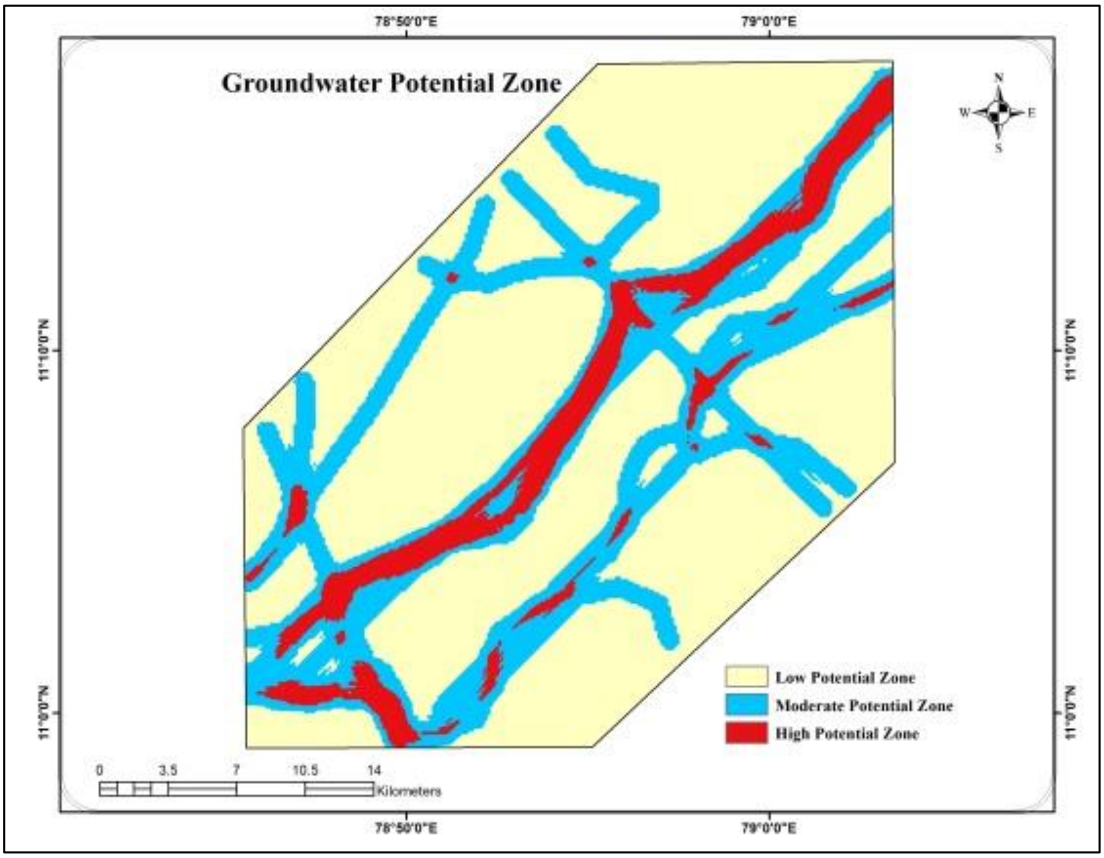

Figure 13: Groundwater Potential Map

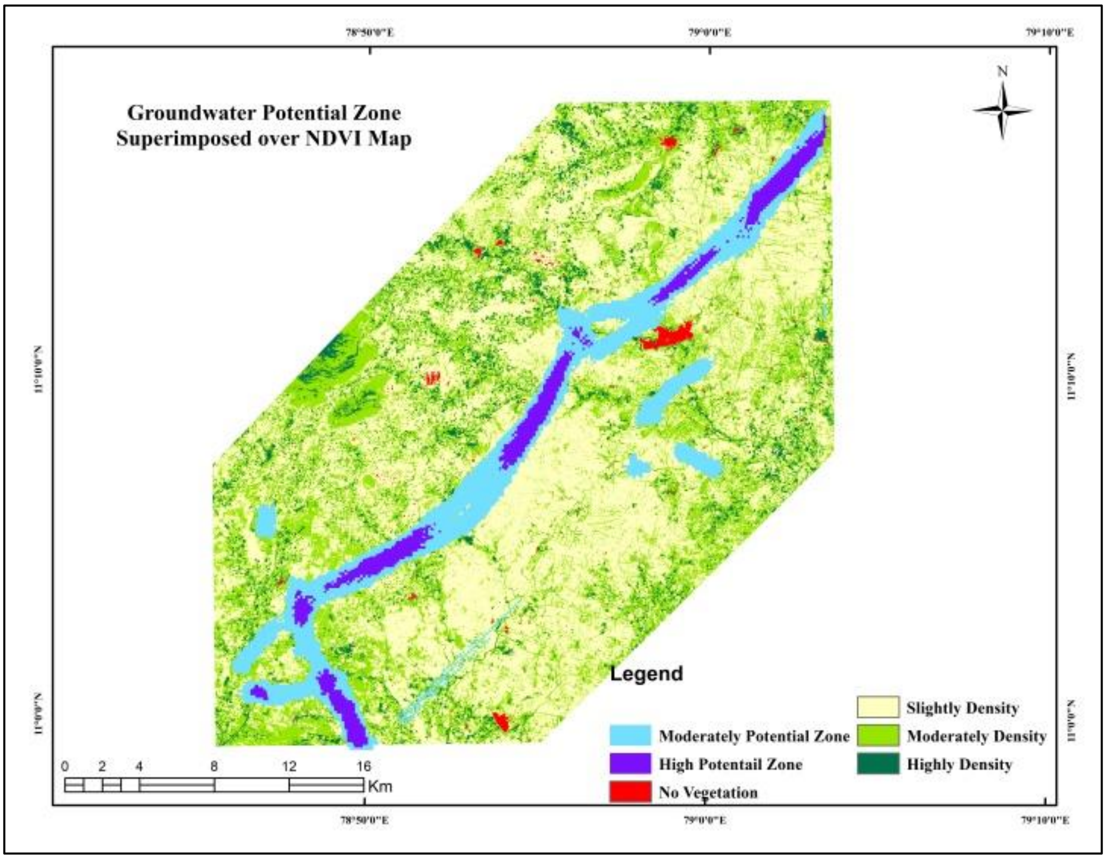

Figure 14: Validation of Groundwater Potential Zone using NDVI

5.7 Validation using NDVI

The Normalized Difference Vegetation Index (NDVI) was calculated to map vegetation distribution and density in the study area for May 2025 Landsat 9 data. NDVI, a widely used remote sensing tool, assesses vegetation health by comparing red and near-infrared reflectance. Healthy vegetation absorbs red light and reflects near-infrared radiation, resulting in high NDVI values, whereas built-up areas, barren land, and water bodies exhibit low or negative values (Rouse et al. 1974).NDVI was computed using the standard formula: NDVI = (NIR − RED) / (NIR + RED). The resulting NDVI values were classified into four categories: no vegetation, slightly dense vegetation, moderately dense vegetation, and highly dense vegetation.

The NDVI map shows a gradual decrease in vegetation density from crystalline rock regions toward sedimentary terrain. Furthermore, groundwater potential zones categorized as moderate and high were overlaid on the NDVI map to validate the zones delineated from the magnetic survey. The results from the magnetic survey do not perfectly correspond with areas of high vegetation density. This discrepancy may be attributed to differences between surface information derived from remote sensing and subsurface data obtained through the magnetic survey (Figure 14).

6. Conclusions

The results of this study demonstrate that ground magnetic surveys are highly effective tools for delineating potential groundwater exploration zones within parts of Perambalur district. Observed variations in magnetic susceptibility allowed for precise identification of contacts between basement crystalline rocks and overlying sedimentary formations. A significant magnetic contrast of approximately 700 nT was detected between the Archaean crystalline basement and the Cretaceous formations in the Tiruchirappalli region, facilitating the clear demarcation of lithological boundaries. These contacts, commonly regarded as structurally weak zones, are further intersected by neo-tectonic fractures trending NE–SW and NW–SE, which collectively enhance the region's groundwater potential. Buffering, Weightage and ranking analysis of the thematic layers indicated notable groundwater prospects, especially along unconformity contacts between basement and sedimentary units. Overall, the findings reinforce that magnetic methods remain among the most efficient geophysical approaches for identifying favorable zones for groundwater exploration.

Acknowledgements

The author wishes to express gratitude to the Department of Remote Sensing at Bharathidasan University for providing a magnetometer and for their ongoing support and encouragement in research activities.

Conflicts of Interest

The authors declare that they have no conflicts of interest

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