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Identification of Groundwater Recharge Zones in Thirumanimuthuar Sub-Basin in Parts of Salem and Namakkal District, Tamilnadu, India

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Abstract: *The main objective of the study is to identify groundwater potential zones in Thirumanimuthar basin with an integrated approach using Remote Sensing and geographical information system (GIS). FCC Image of Landsat TM 30 m resolution data and topographic maps has been used to generate thematic maps like geology, geomorphology, lineament and lineament density, drainage, drainage density, and slope map of the study area. A number of geomorphic units such as Denudational hills, structural hills, Bajadas, Colluvial plain, Pediplain, Deep Pediment and Alluvial plains have been observed. A composite groundwater potential map has been generated as very high, high, medium, low and very low based on the groundwater availability area. The upper, middle and downstream of the basins have been identified as potential zones for groundwater exploration. The regions of lineaments and intersecting lineaments proved for groundwater potential zones. The data generated was validated with field checks and observed to be in conformity with the same.*

Keywords: *ArcGIS Software; Drainage; Drainage Density; Geographical Information System; Geology; Geomorphology; Lineaments; Lineament Density; Lithology; Prospect Map; Remote Sensing; Slope.*

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I. INTRODUCTION

1.1 General

Groundwater is an important natural resource in present day, but of limited use due to frequent failures in monsoon, undependable surface water, and rapid urbanization and industrialization have created a major threat to this valuable resource. A groundwater development program needs a large volume of multidisciplinary data from various sources. In order to ensure a judicious use of groundwater, its proper evaluation is required for optimal utilization. With groundwater occurrence being a subsurface phenomenon, its identification and location are based on indirect analysis of some direct observable terrain features like geology, geomorphology and their hydrologic characters. In the last few decades, Remote Sensing (RS) and Geographical Information System (GIS) techniques have been used in different field of sciences in which it provides an opportunity for better observation and more systematic analysis of various identification and demarcation of groundwater resources.

1.2 Remote Sesning and GIS

RS and GIS are playing a rapidly increasing role in the field of hydrology and water resource development. In developing accurate hydro-geomorphological analysis, monitoring, ability to generate information in spatial and temporal domain and delineation of land features are crucial for successful analysis and prediction of groundwater resources. However, the use of RS and GIS in handling large amount of spatial data provides to gain accurate information for delineating the geological and geomorphological characteristics and allied significance, which are considered as a controlling factor for the occurrence and movement of groundwater used IRS LISS II data on 1: 50000 scale along with topographic maps in various parts of India to develop integrated groundwater potential zones by qualitative analysis in terms (i.e., good to very good, moderate to good and poor), used GIS for the analysis of lineament data derived from SPOT imagery for groundwater potential mapping. For the assessment of groundwater resources of Northwest Florida, we took the advantage of GIS for spatial analysis and data visualization. Developed a GIS-based model for delineating groundwater potential zones of Marvdaiyar basin, Tamil Nadu, India, by integrating different thematic layers derived from remote-sensing data. Water resources in India are very unevenly distributed both spatially and temporally. Idiosyncrasies of monsoon and diverse physiographic conditions give rise to unequal distribution of water. Over the years, population growth, urbanization and agricultural expansion have exacerbated the situation. The aftermath of unscientific exploitation of groundwater is that we are moving towards the water shortage condition. Even now, some parts of the country are facing acute water crisis. Despite being a very important part of the nation's growth, water resource analysis has been fragmentary. An integrated study covering the aspect of identification of groundwater potential zones is a crucial requirement of the present day.

1.3 Need for Study

The efficiency and performance of planning, utilization, administration, and management of the groundwater resources is more important for human life. The present work is an attempt has been made to integrate RS and GIS-based analysis and methodology in groundwater potential zone identification in hard rock terrains. It is necessary to understand different types of landforms and their characteristics, rock types, geological structures and how they evolved with respect to each other, hydrological characteristics and slope in order to demonstrate the integrated remote sensing and GIS-based methodology for identification of groundwater potential zones, Thirumanimuthar sub basin, which forms the integral part of the Cauvery basin, has been taken as the study domain.

1.4 About the ArcGIS 10.1 Software

The release of ArcGIS 10.1 signals a major development in the way geographic information will be accessed and managed by GIS professionals and their organizations in the years to come. ArcGIS 10.1 gives GIS professionals a complete GIS that further integrates desktops and servers, as well as mobile and web applications. It provides organizations with the additional tools and infrastructure they need to extend the reach of their existing GIS. It also improves organizations ability to transition to next-generation GIS concepts and platforms without jeopardizing their current GIS investments.

New to ArcGIS Online is ArcGIS Online for organizations a customizable, web-based system designed for professionals who want to manage their organizations' geospatial content using cloud tools and infrastructure. It allows administrative control over data creation and access while making geographic information easily available to others within the organization, as well as beyond the organization in collaborative efforts with others. ArcGIS Online is now a fully integrated, easy-to-use portal for thousands of GIS professionals around the world. In addition to users, organizations can store and manage their maps, data, and other geospatial information on ArcGIS Online, as well as access thousands of free maps, datasets, services, and tools. ESRI continuously updates ArcGIS Online content to deliver new map, image, and task services so that users are always getting the latest, most accurate, and best cartographic base maps and GIS products available anywhere on the web.

At version 10.1, ArcGIS for Server runs natively on 64-bit Windows and Linux operating systems, providing users with high-performance web editing and map caching, on-the-fly analyses, and imagery exploitation capabilities, as well as additional choices for deployment. In addition to being fully certified on VMware and VCE's V-block platform, ArcGIS for Server can be deployed on Amazon Elastic Compute Cloud in both Windows and Linux. ArcGIS for Server includes new services, such as a print service that allows users to produce high-quality, large-format PDF maps directly from web maps.

Also new at 10.1, along with the ability to generate sophisticated GIS and mapping services with Standard and Advanced editions, all editions of ArcGIS for Server, including Basic, will provide simple mapping capabilities from a database resource, including maps, imagery, geo data, and tools, as a web service on both ArcGIS for Server and ArcGIS Online. Desktop users can also easily package their maps and layers and make that content available to staff, stakeholders, partners, or the public via online groups while maintaining complete control and ownership of their content. Mobile developers now have access to a suite of ArcGIS Runtime Software Developer Kits (SDKs) to create custom business applications for iOS, Android, and Windows Phone devices. Developers are able to create apps that use the powerful mapping and geocoding capabilities found in ArcGIS for Server and ArcGIS Online. These apps can be deployed within an enterprise environment or to the public via the Apple App Store, Microsoft Marketplace, and Android Market. In addition, a free, out-of-the-box ArcGIS application lets users explore map content, collect and edit GIS features, and use sophisticated geo-processing tasks. The ArcGIS app is available for download on all major mobile platforms.

At 10.1, developers will gain even greater access to the ArcGIS system via improved APIs and SDKs for web and mobile applications, configurable viewers, and the new ArcGIS Runtime. ArcGIS Runtime allows developers to create and deploy focused, stand-alone GIS applications for desktop users. The runtime is a small, lightweight deployment that, in terms of capabilities, FITS between ArcGIS Engine and the ArcGIS web mapping APIs. The new runtime is designed for both desktop and cloud development. It has a fast display and does not require installation; it can be run directly from a CD.

II. STUDY AREA

2.1 Location

Thirumanimuthar Sub-basin is a major tributary of river Cauvery, which lies between North latitudes 10˚58' and 11˚48' and East longitudes 77˚53' and 78˚21' (Figure 1). It originates at Manjavadi in Salem district and configures in river Cauvery at Paramathi velur in the Namakkal district of Tamilnadu. The river course is about 102 km with a total drainage of 2438 km^2. Thirumanimuthar forms an important groundwater province in south India, facing serious scarcity in groundwater quantity. The serious problem in the area is rapid growth population and intensive industries, and economic activity has increased. Generally, the basin is precarious for surface flow but receives meager flow during rainy season. It acts as a major sink for domestic and industrial effluents along with agricultural return flow. Thus, groundwater as the only water source has extensively been used to meet the increasing demand for domestic, irrigational and industrial requirements.

2.2 Aquifer Parameter

The Aquifer Parameter of Transmissivity (m^2/day) of Salem and Namakkal district, fractured aquifer is 1 to 265 and 2 to 106 respectively. The storativity of fractured aquifier is 9.6 x 10^{-5} to 4.3 x 10^{-2}, it same for both districts. The specific yield of Salem and Namakkal District is 0.015.

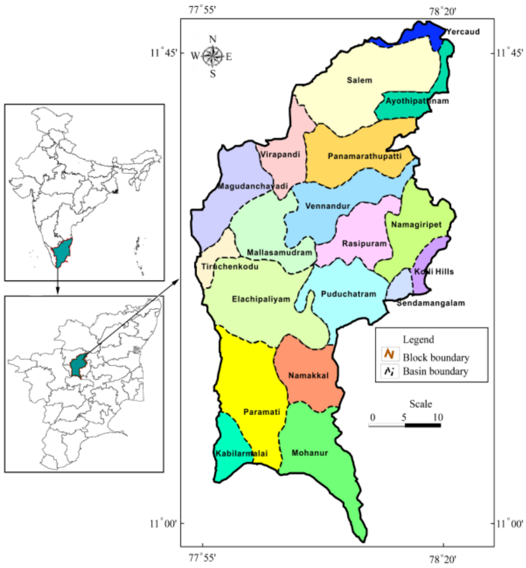

Figure 1: Location map of the study area

2.3 Lithology

The subsurface order of existence of different geological stratum in a particular locality is described with the term called as lithology. The study area consists of top soil, weathered and fresh stratums of geneiss, charnockite, and pyroxenite. The lithological details of the study area are known from the selected bore logs across the study area.

2.4 Ground Water Related Issues and Problems

The ground water development in the district of Namakkal and Salem, in general, is high when compared to many other districts in the state. 10 out of 15 blocks and 14 out of 20 blocks in the Namakkal and Salem district have been categorized as either 'overexploited' or 'critical' respectively. The trend analyses of historical ground water level data also indicate a long-term fall in a major part of the Namakkal and Salem districts. Based on the factors mentioned, it is inferred that a major part of the districts could be considered vulnerable to various environmental impacts of water level depletion such as declining ground water levels, drying up of shallow wells and decrease in yield of bore wells.

In Namakkal district, Incidence of fluoride in ground water in excess of permissible limits for drinking has been reported from parts of the district, especially from the fracture zone. Tamil Nadu Water Supply and Drainage (TWAD) Board have provided a number of villages in the district with fluoride-free drinking water supplies. Excessive use of fertilizers and pesticides in agriculture has also reportedly resulted in localized enrichment of nitrate and other harmful chemicals in the ground water, especially in the phreatic zone. Pollution of ground water due to Sago industry is also one of the issues in the district. The effluents from which have caused local pollution of surface and ground water resources. In Salem district, 12 Incidence of fluoride in ground water in excess of permissible limits for drinking has been reported from parts of the district, especially from the fracture zone. Pollution of ground water due to industrial effluents is another major problem in the district. A number of industrial units including textile units, sugar mills and sago factories exist in the district, the effluents from which have caused local pollution of surface and ground water resources. Excessive use of fertilizers and pesticides in agriculture has also reportedly resulted in localized enrichment of nitrate in the phreatic zone.

Ground water in phreatic aquifers in Salem district is in general colorless, odorless and slightly alkaline in nature. The specific electrical conductance of ground water in phreatic zone (in µ S at 250C) during October 2016 was in the range of 526 to 6040. In major part of the district the electrical conductivity is above 1000 µS/cm. In Namakkal district, ground waters are colorless, odorless and predominantly alkaline in nature. The specific electrical conductance of ground water in phreatic zone (in Micro Seimens at 250C) during October 2016 was in the range of 1300 to 7080 in the district. It is observed that ground water in the phreatic zone in Namakkal district may cause high to very high salinity hazard and medium to high alkali hazard when used for irrigation. In Salem district, Groundwater can be categorized as High Salinity on the basis of SAR. Proper soil management strategies are to be adopted in the major part of the districts while ground water for irrigation.

III. METHODOLOGY

For the groundwater resource development in an area, the following methodology may be undertaken which integrates remotely sensed data. The survey of India toposheets may be used for the preparation of the base map. The methodology of generation of thematic maps such as lithology, hydro-geomorphology, drainage and lineaments of the study area requires visual interpretation of satellite remote-sensing data. Identification and delineation of various units on the thematic maps are based on the colour, tone, texture, size, pattern and association. Survey of India (SOI) topographic maps (No. 58I/1, 58I/2, 58I/3, 58I/4, 58I/5, 58I/6, 58I/7, 58E/14, 58E/15, 58E/16 of scale 1:50000) were used for the preparation of base maps. Geology, geomorphology, drainage and lineament maps are generated from FCC Image of Landsat 7 TM. Drainage density, Lineament density and groundwater prospects maps were prepared by ARC GIS (Version 10.1) software. The methodology adopted is tabulated below (Figure 2).

All the thematic maps are verified through field checks. The thematic details thus finalized are transferred to the base map prepared from the survey of India toposheets. A typical method used in GIS modeling is to compute numerical values for each spatial feature in a theme and classify the numerical values on an interval basis known as Weighted Index Overlay Analysis. This method takes into consideration the relative importance of the parameters and the classes belonging to each parameter. There is no standard scale for a simple weighted overlay method. For this purpose, criteria for the analysis should be defined, and each parameter should be assigned importance. The result of the overlay analysis compared with manual evaluation has been made during the period of the study.

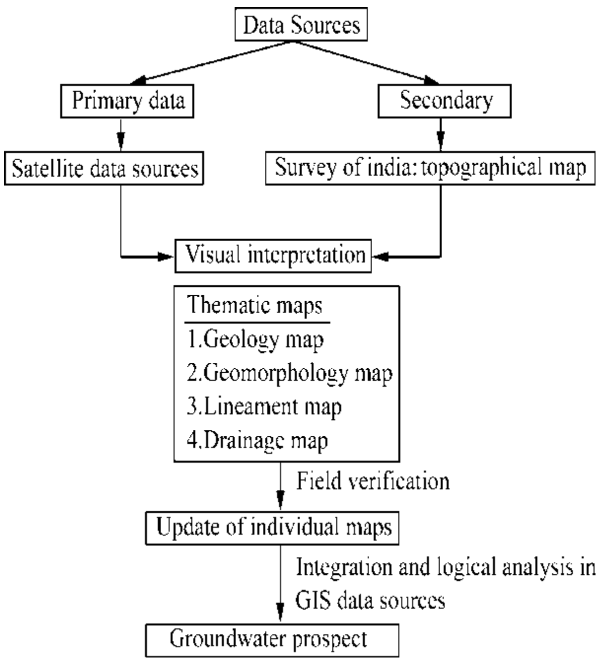

Figure 2: Flowchart for evaluating groundwater resources by Integrated Remote Sensing and GIS techniques

IV. THEMATIC MAP ANALYSIS

In order to demarcate the potential sites for artificial recharge in the study area 7 thematic maps are prepared viz.,Geology, Geomorphology, Lineament, Lineament Density, Drainage, Drainage Density and Slope.

4.1 Geology

The study area is entirely underlined by Archean crystalline metamorphic complexes. The rocks of this group are highly weathered, jointed and covered by recent valley fills and soil covers at some places (Figure 3). A wide range of rock types occurs which is found to be experienced by recurring tectonic and magmatic activities in Precambrian period which resulted in complicated structure and geology. The study area composed of many folds, faults, lineaments, shears and joints. The geology of the area is underlined by rocks representing metasediments of Achaean age with Charnockites, granitic gneiss, calcgranulites, syenites and ultra-basics as major exposures.

Meteorology and Hydrology

The area enjoys sub-tropical climate. The mean temperature varies from 33℃ to 45℃. The study area comes under a rain shadow region with an annual rainfall of about 1590 mm. The area receives major part of rainfall from southwest monsoon (47%), followed by northeast (33%), post monsoon (19%) and summer (1%).The mean annual temperature for the study area is 27.8℃. Relative humidity is generally higher during June to November. The evaporation varies from 7 mm to 9 mm /day in different months. Thirumanimuthar is a sub basin of Cauvery basin and is ephemeral in nature. Drainage pattern is dentritic to sub-dentritic. The groundwater in the study area therefore is restricted mostly to the zones of secondary porosity developed in these rocks due to fractures, joints and weathering.

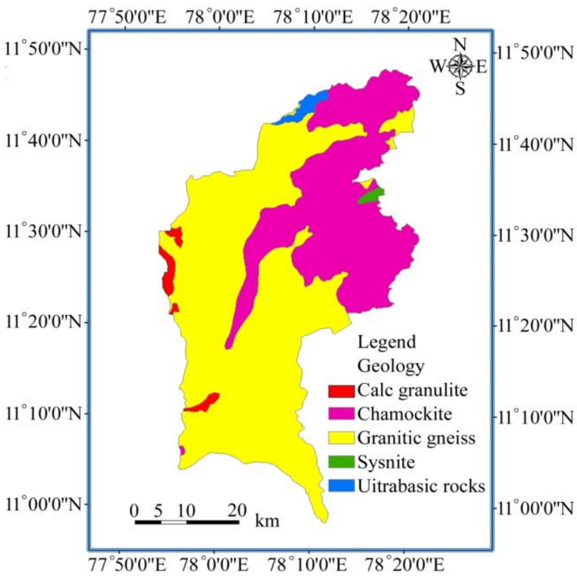

Figure 3: Geology map of the study area

From the hydrogeological point of view, the frequency and extent of jointing, fracturing and the flow contacts and weathering along them are the most significant parameters imparting permeability and porosity for forming suitable groundwater reservoirs in the deccan basalt terrain.

The occurrence and movement of groundwater in hard rock areas mainly controlled by the secondary porosity and groundwater occur under water table to semi confined conditions. Groundwater generally occurs in weathered portions of the rocks along joints and fractures. The occurrence and movement of groundwater in the study area are restricted to an open system of fractures like fissures and joints in unweathered portion and also the porous zones of weathered formations. The weathered layer in gneissic terrain of the study area varies from 2.2 to 50 m. In Charnockite, thickness was ranging between 5.8 and 55m. At contacts of gneiss and Charnockite, thickness ranges between 9.0 and 90.8 m indicating good groundwater potential zones. Groundwater fluctuation ranges from 0.2 m to 13.5 m BGL. It reaches the lowest level during summer (March-June), and after that, it starts rising till the end of the monsoon season (August-January). Groundwater flow was noted in the North East direction and, along with downstream flow, is due west to east which generally coincides with the topography of the study area. The study area falls under a semiarid climatic type and the areas over and adjacent to Shervaroy hills and Kolli hills are of dry to moist sub humid climatic types.

4.2 Geomorphology

Geomorphology is the scientific study of the origin &evolution of topographic and bathymetric features created by physical, chemical or biological processes operating at or near the Earth's surface. Geomorphologists seek to understand why landscapes look the way they do, to understand landform history and dynamics and to predict changes through a combination of field observations, physical experiments and numerical modeling (Table 1).

Table 1: Different Hydro geomorphological Units, their Characteristic and Groundwater Potentiality

Hydro geomorphic units	Area (m^2)	Description	Soils	Drainage	Lineament	Groundwater Availability
Alluvial plain (AP)	184.85 (7.58%)	Level plain, gently sloping with slightly undulating land surfaces.	Gravel, sand, silt and clay materials.	Medium	Nil	Very high to high
Bajadas (B)	2.69 (0.11%)	It is formed by series of stream deposition along the foot hill.	Thin layer of soil and gravel	Medium	Nil	High to low
Colluvial plain (CP)	354.8 (14.55%)	Any material that has been transported for short distances from the source essentially by gravity and especially near the foot hills is considered as Colluvial deposit.	Sandy-silty-gravel in different proportions	Medium to Poor	High	Medium to high
Deep pediment (DP)	394 (16.16%)	Gently sloping topography; very deep	Sand, sandy silt and clay	Moderate to good	High	Very low to medium
Denudational Hills (DH)	267.73 (10.96%)	Fractured rocks covered with big pebbles	Sand, silt, clay and Hill soils	Good	Low to High	Moderate to poor
Pediplain (P)	1,172 (48.07%)	Moderately sloping plain with <10m thickness of weathered zone	Shallow weathered Granitic and Charnockite	Medium	High	Medium to high
Structural Hills (SH)	61.93 (2.57%)	The linear or arcuate hills exhibiting definite trend lines and Charnockites, Granitic gneiss formations.	Hill soils	Very good	Low	Low to very Low

Alluvial Plain (AP)

AP is defined as a level plain, gently sloping with slightly undulating land surfaces. It is encompassed of alluvial type of deposits like sand, silt and clay materials. These are the fluvial depositional plains built on either side of a river course due to the shifting of the river course during its long geological history. AP is marked as a zone of good groundwater prospects because of their good recharging capacity. The APs are identified as small pockets along the middle and down course of the study area with invariably good groundwater potential zones.

Bajadas (B)

Bajada represents geologic conditions that are excellent for obtaining groundwater in large quantities from wells. Water infiltrates readily in the coarse materials at the heads of the fans and moves down the bajada under a hydrostatic head. Bajadas are the main geomorphic units that are present very close to the foot hills of the study area. Generally, the bajada zone is excellent for groundwater targeting especially in the hilly region. Bajadas are located along the Eastern side, and it has occupied a very small portion of the area.

Colluvial Plain (CP)

Any material that has been transported for short distances from the source essentially by gravity and especially near the foot hills is considered as colluvial or colluvial deposit. CP is composed of sandy, silt and gravel in different proportions. The CP slowly merges with the river built plain, and the zone of contact of the two is often found to be a transitional one. CP is identified in the foot hill area along the north-eastern part of the study area with very high groundwater availability.

Deep Pediments (DP)

Deep pediments are mainly due to high weathering of the Granitic gneisses under semi-arid climatic conditions. It is characteristically defined as a gently sloping topography; when deep, its infiltration is moderately good. The thickness of the weathered zone varies from 10 m to 20 m and favors a good amount of water to circulate within this zone before reaching the deeper fracture zone. Deep pediments are found as a detached unit throughout the study area. The groundwater potential zone is good to moderately good.

Hills/Denudational Hills (DH)

The denudational hills (Figure 4) mainly consist of highly fractured rocks covered with big pebbles and sparse vegetation occurring superficially due to the accumulation of moisture holding soils. The badland topography of this region is due to the erosion of fine material from the bottom of the denudational hill to the plain region, leaving the rock exposed. This zone has geological potential for groundwater because of occurrence of fractured rocks through which rainwater percolates and groundwater is recharged. But the groundwater flows away towards the adjacent plains. Therefore, groundwater prospecting is less feasible than in the surrounding plains. Thus, the groundwater potential is moderate to poor.

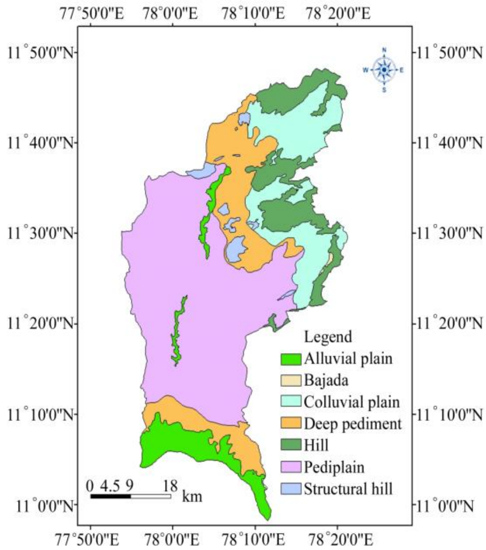

Figure 4: Geomorphology map of the study area

Pediplain (P)

Pediplains are developed by continuous processes of pedimentation. Pediplain with meta-sedimentary rock exposures (Granitic Gneiss and Charnockite) is to be found in the central part of the area. This is formed due to intensive weathering of rock materials under semi-arid climatic conditions, representing the final stage of the cyclic erosion. In the study area, 48.07% of the area is mainly covered with Pediplain. Groundwater prospect in a pediplain region is good when associated with lineament interaction.Pediplains with lineament interaction have been identified in the centre of the study area.

Structural Hills (SH)

Structural hills are the linear or arcuate hills exhibiting definite trend lines and Charnockites and Granitic gneiss formations. These hills are structurally controlled with numerous joints/fractures which facilitate some infiltration and mostly act as run-off zones. The structural trend of the hills ranges in the southwest to northwest direction with slight deviation towards the eastern part of the study area. The slope of the hills ranges from 2° to 4°. The distribution of lineament is comparatively less, and hence, the groundwater availability is moderate to poor.

4.3 Lineaments

A lineament is defined as a large-scale linear feature, which expresses itself in terms of topography of the underlying structural features and relatively straight tonal alignments visible in satellite images. Remote sensing data i.e. satellite images of an area are useful to map lineaments. For better interpretation of lineaments, the images are digitally processed using image processing software. Further high spatial resolution and multi-spectral data (with color composites suitable for particular application) make the marking of lineaments much easier, accurate and reliable. The satellite data of Landsat TM Image of FCC (False color Composites) have been visually interpreted to identify the lineaments of the basin. The data have been checked by field studies, and they act as pathways for groundwater movement in hard rock areas. In general, lineaments are considered as good potential zones for groundwater targeting, as they reflect high porosity and hydraulic conductivity of the underlying materials. Most of the lineaments are confined to the locations where Pediplain, Deep Pediment and Colluvial Plain are exposed. The lineaments trending NNE-SSW, NE-SW, NW-SE and NS are identified in the study area indicating regions of good groundwater availability (Figure 5).

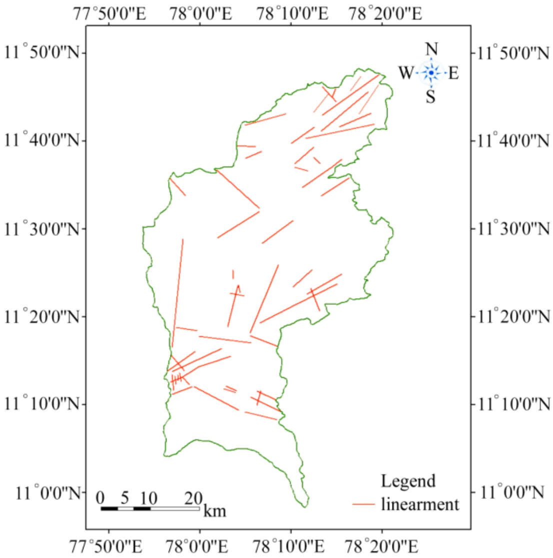

Figure 5: Lineament map of the study area

Magnitude of lineaments all lineaments are also classified based on their length into the following two types. A. Minor lineaments- For quantification purpose, lineament with length < 3 km is classified as a minor lineament. B. Major lineaments- Lineament with length > 3 km is classified as a major lineament. Lineament studies have vast applications in different disciplines of geosciences for example identification of tectonic features, recognition of folds and faults, exploration of mineral deposits, petroleum prospects and groundwater.

4.4 Lineament Density

To determine the lineament density in the study area, the total study area is subdivided in a number of grids of dimension 1 km × 1 km. The density of the lineaments of a single grid is obtained from the values of the total length of the lineaments in a single grid (ΣL). Calculation of the density of the lineaments in the area involves the ratio of ΣL to A. By calculating the value of $\Sigma L/A$ for each grid and locating the value at the centre of that grid, the density of the lineaments of the study area is calculated. These values are joined by isolines to prepare a lineament density map using GIS software. High lineament density (Figure 6) is observed in over the hilly terrain, pediplain and deep pediment and moderate-to-low lineament density over the colluvial plains. This shows that the hills are structurally controlled. Lineament interceptions were observed at a few regions in Pediplain with potential zones for groundwater (Table 2).

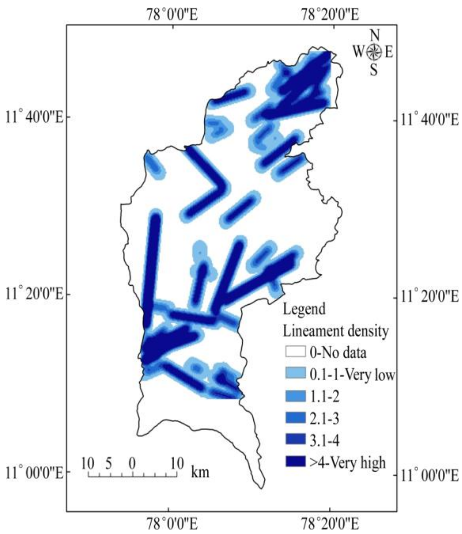

Figure 6: Lineament density map of the study area

Table 2: Lineament Density Category

Class	Ranges	Lineament Density Category
1	0	No Data
2	0.1 1	Very Low
3	1.1 2	Low
4	2.1 - 3	Moderate
5	3.1 - 4	High
6	Greater Than 4	Very High

4.5 Drainage

A drainage map is a plan of all streams or river systems in a drainage basin. Drainage analysis involves a detailed examination of the drainage patterns, drainage texture and stream patterns. The drainage pattern map has been prepared from a survey of India toposheets. The drainage type is mainly dentritic, and a few locations have the trellis type. It is also observed that, in almost all watersheds, new drainages have come up, and a stream has changed its course in the southern side of the study area. Stream orders are classified on the basis of its origin. The main stream has the highest order from river-mouth to the head of a stream, and the largest tributary has lower stream order by 1 than the stream. Generally, stream order increases, the numbers and the mean gradient of streams decrease in an inverse geometric ratio and the mean length of streams and the mean area of drainage basin increase. The study area streams have the shortest, and the steepest streams have the smallest drainage basins. A first-order stream network was observed in the majority of the area (Figure 7).

A hilly terrain with closeness in the drainage pattern is proved as zones of poor groundwater potential, as a major part of the water poured over them during rainfall is lost as surface runoff with little infiltration. On the contrary, a low drainage density area permits more infiltration with greater potential for groundwater. The structural analysis of a drainage network helps to assess the characteristics of the groundwater recharge zone. Drainage is noted more in the hilly regions when compared with the rest of the area, indicating poor groundwater potentials. But along the northern side of the area lineaments are more, indicating favorable locations for groundwater potential zones.

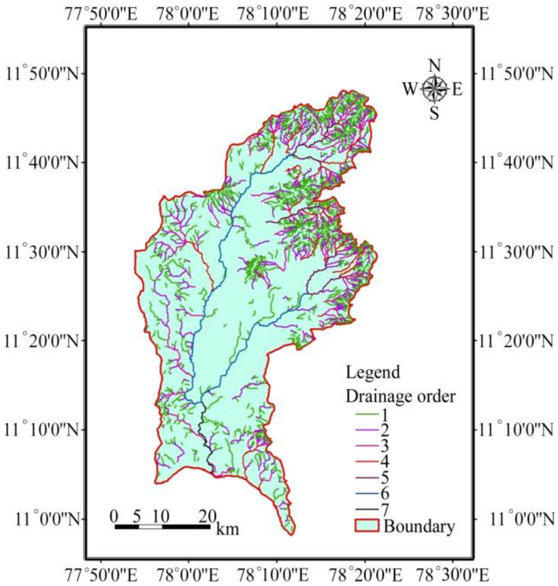

Figure 7: Drainage map of the study area

4.6 Drainage Density

It is noted as one of the prime indicators for the location of groundwater potential zones in hard rock terrains like the study area. It is also an indirect measure of porosity and permeability of a terrain. DD is defined by the total length of the streams in a given drainage basin, divided by the total area, indicating an expression of the closeness of spacing of channels. DD provides a quantitative analysis of the average length of stream channels stretching the entire part of the basin. The DD values were grouped into eight categories with value ranges from 0 to 550 (Figure 8). Higher values are confined to the hilly terrains with low groundwater availability; the higher value is noted from the hilly terrain. Hence, in this region, groundwater availability may be very low. Drainage density indicates closeness of spacing of channel as well as the nature of surface material, thus providing a quantitative measure of average length of stream channel for whole basin.

It has been observed from drainage density measurement made over a wide range of geologic and climatic type that a low drainage density is more likely to occur in region and highly resistant of highly permeable subsoil material under dense vegetative cover and where relief is low. High drainage density is the resultant of weak or impermeable subsurface material, sparse vegetation and mountainous relief. Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture. The drainage density characterizes the runoff in an area or in other words, the quantum of relative rainwater that could have infiltrated. Hence the lesser the drainage density, the higher is the probability of recharge or potential groundwater zone.

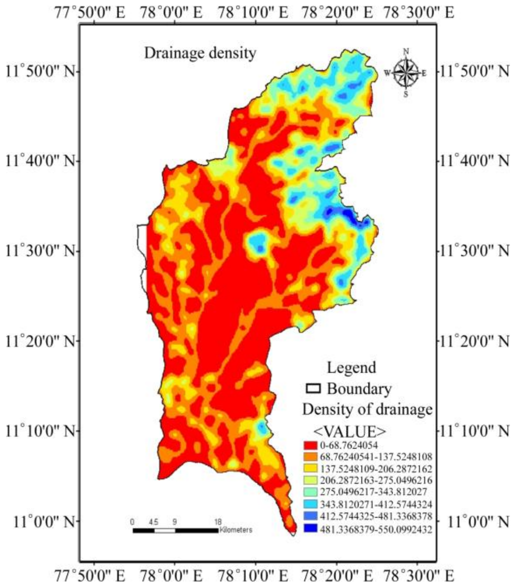

Figure 8: Drainage Density Map of the study area

4.7 Slope

Slope is also a crucial parameter for occurrence and recharging conditions of groundwater in a particular area. The slope is measured in degrees using the method proposed. A layout grid of 2cm has been prepared and overlaid on the topographic map, and the average slopes have been delineated. General slope track is NE-SW direction of the study area (Figure 9). The identified slope categories vary from 1° to more than 85° in the study area (Table 3). Slope degree has been classified on the basis of water availability in the study area. On the basis of the above classification, 0° to 1° and 1° to 3° are observed along the direction. 5° to 10° degrees is noted in upstream and middle of the basin which indicates good potential is present in the area. A high degree (V 35°) is confined to the hilly region which, in turn, indicates that groundwater availability is poor to nil.

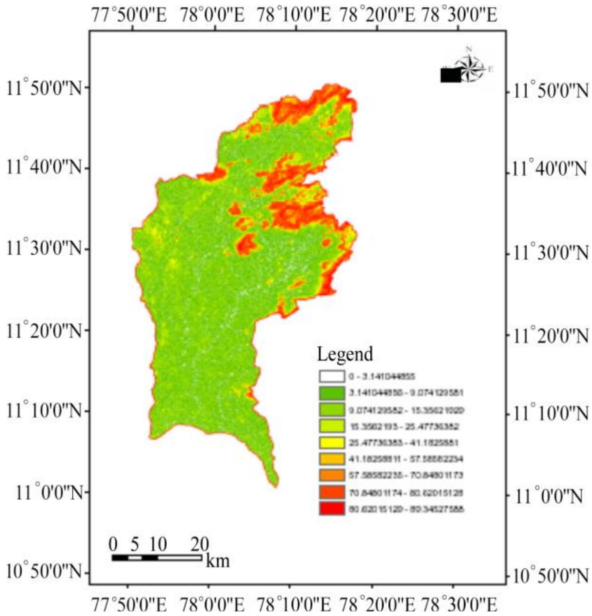

Figure 9: Slope map of the study area

Table 3: Classification of Slope Degree on the basis of Ground water availability

Slope Degree in Range	Category
0° - 1°	Excellent
1° - 5°	Very good
5° - 10°	Very good
10° - 15°	Good – moderate
15° - 35°	Moderate to poor
> 35°	Poor to nil

V. RESULT AND DISCUSSION

Generation of Groundwater Prospect Map

Finally, the groundwater prospect maps (Figure 10) have been prepared by integrating information from all the thematic maps like geomorphology, lineament and LD, drainage, DD and slope. In this method, the total weights of the integrated polygons that were ultimately formed were derived as a sum or product of the weight that had been assigned to the different layers according to their groundwater suitability. Then the polygons of the final integrated layer were reclassified as very high, high, medium, low and very low/not suitable based on the weight ranges obtained from logical conditions that had been established. Very high and high zones are observed in regions of colluvial plains, high drainage density, and lineament density and along the lineament interaction indicating the availability of water in the subsurface. Medium zones are confined to 70% of the study area with low drainage density and with meager or absence of lineaments. Low and very low zones are confined to the hilly regions, scarp slopes, pediments, pediplains and structural hills which do not favor much infiltration and with less groundwater availability.

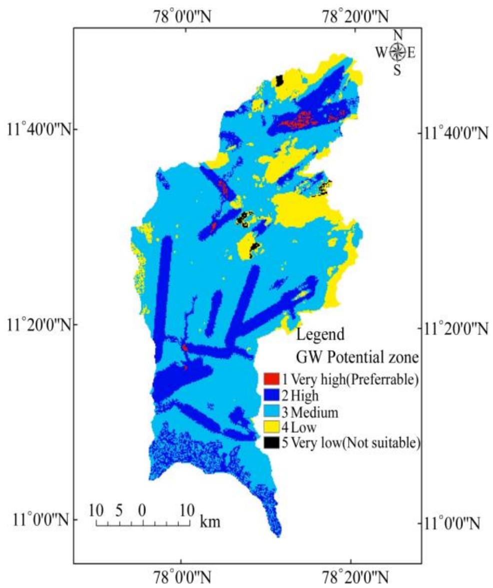

Figure 10: Groundwater prospects map of the study area

VI. CONCLUSION

Mapping of groundwater resources has been increasingly implemented in recent years because of increased demand for water. The importance of the study is, instead of taking only one characteristic to identify potential groundwater zones, integrating the thematic maps prepared from conventional and remote sensing using GIS gives more and accurate results. Presence of colluvial plain, high drainage density and interaction of lineaments were identified as prospective zones for groundwater exploration and development in the study area. The presence of intersecting lineaments in the area enhances the potential of groundwater.

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