Geomatics Application for Assessment of Groundwater Prospective Zones: A Case study of Kanchi River Sub Basin, Khunti- Ranchi districts, Jharkhand.

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Abstract: Geomatic tools have emerged effectively in identifying and delineating the drainage character and assessment of groundwater prospective zones. This study highlights the likelihood of RS-GIS technique in hydrogeological studies, particularly for delineating the groundwater prospective zones in Kanchi River Sub Basin, Khunti- Ranchi, district, Jharkhand. Integrating various hydrogeological parameters such as lithology, slope, lineament, drainage, soil, and other allied features can be fruitful in assessment of the groundwater prospect of a large area. Geologically the study area is dominated by Precambrian lithounits such as granite gneisses, pelitic schists and quartzites showing multiple phase deformation and magmatism. In present study, seven major geotechnical elements were selected such as lithology, slope, lineament, soil, geomorphology, drainage, and LULC. The thematic maps were generated by Visual Image Interpretation techniques and were integrated in GIS environment. Sources for these data were existing thematic maps, satellite images -IRS-P6, LISS-III (Date of acquition-17th January, 2021), LANDSAT 8 OLI (Date of acquisition- 26th April 2022), SRTM (Date of acquisition – 2nd January 2015) and Survey of India toposheets at 1: 50,000 scale. Five Potential zones have been demarcated using AHP weighted linear combination of the various thematic layers. The hydrogeological parameter index of the present area indicates that regions having high lineament density within dissected hills and valleys are the most promising site for groundwater occurrence. The study emphatically suggests that about 50% of the study area falls under the category of moderate to high groundwater potential. The result obtained is in conformity with the published well yield data of watersheds of Jharkhand State. The present study highlights the importance and usefulness of weighted index as a model for identification of potential groundwater zones in similar hydrogeological conditions.

Keywords: Kanchi, RS-GIS, Groundwater Prospective Zones, Weighted Index.

1. Introduction

At the micro level, it is essential to enhance natural water resources within drainage basins. Identification of groundwater potential zone is important to understand the geotechnical behaviour of drainage basin which directly influences the socio-economical behaviour of the basin. In this regard, this study aims to identify the groundwater potential zones of Kanchi river sub basin, as for a larger part, the socio economy of rural regions of Kanchi river sub basin depends upon agriculture ecosystem and hence the challenge is to make water resources sustainable, more productive with eco-friendly exploitation methods.

The study area being hard rock terrain directly influences the rate of recharge, and several other factors such as lithology, lineaments, geomorphology, slope, drainage, soil and LULC have a direct influence on groundwater potentiality. Through conventional methods it is difficult to study the above said parameters for large areas and to identify the groundwater potential zones. In reference to the aforesaid, remote sensing (RS) and Geographic Information System (GIS) techniques have proved efficacious in water resource management, especially for identification of groundwater potential zones (Kumar U. et.al. 2013). Identification of groundwater potential zones requires an exhaustive study of satellite images through visual interpretation, extraction of geo-tectonic features, generation of thematic layers, and amalgamation utilizing GIS techniques, which gives powerful tools for processing and analysis of spatial data (Roy et. al. 2019).

2. Study Area

Kanchi river sub basin forms one of the sub-watersheds of Subarnarekha River. Administratively the watershed falls within the boundaries of Ranchi and Khunti districts and is well linked through metalled roads and railways. The study area lies between 85°13'15'' to 85°50'20'' Eastern longitudes and 23°11'30'' to 23°13'50'' Northern latitudes (Figure 1) occupying toposheet No 73 E/4, 73E/8, 73E/12 and 73E/16. The total area covered is 575 sq. km and is known for agricultural practices.

The area is predominated throughout the year by tropical climates with very little variation. The annual average rainfall is about 1300mm which is lower than the state average rainfall. The minimum temperature recorded is in month of December and January with a mean of 11°C and maximum temperature is recorded in the month of May and June with an average of 37.4° C. The study area represents a highly metamorphosed and deformed terrain in Chotanagpur gneissic complex. The lithounits are represented by schistose rocks, quartzites, isolated exposures of calc silicate rocks and different varieties of granite.

3. Data used and Methodology

The Survey of India topographic maps Nos. 73E/4, 73E/8, 73E/12 and 73E/16 on 1:50,000 scale were used for generation of base maps and for delineation of watershed boundary. IRS-P6 LISS III, 17th January, 2021 was used for preparation of various thematic layers. SRTM 30 m data was subsequently used for preparation of slope map (Figure 2).

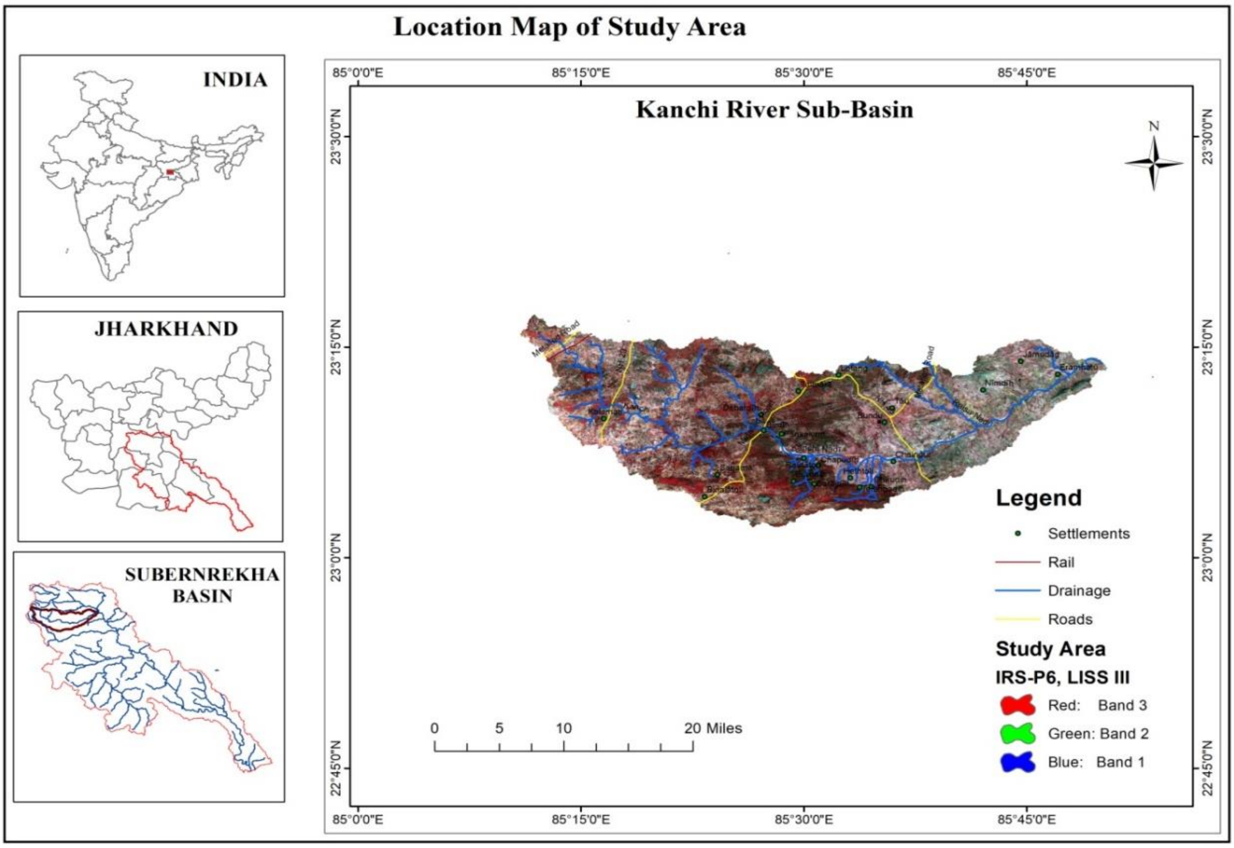

Figure 1. Location map of the study area

The lithology of the area was identified and extracted from published geological maps. The extracted lithological units were further verified in the field. The AHP weighted overlay criteria were used to delineate groundwater prospective zones. The suitability of infiltration and water holding capacity of aquifer depends on various factors such as lineament density, soil, drainage density, slope, geomorphology, lithology and LULC. Thematic layers were extracted and given weightage. ARCGIS 10.3v environment has proved beneficial for the extraction and analysis and overlay of raster data sets based on assigned weightage.

4. Results and Discussions

4.1 Lithology

Lithologically the study area represents a highly metamorphosed and deformed Archean hard rock terrain with predominant Chotanagpur gneiss along with varied types of granitic rocks, pegmatites, quartzofelspathic veins, schistose rocks and isolated exposures of calc-silicate rocks (Sengupta and Sarkar,1964; Ghosh,1983; Sanyal and Sengupta,2012). The lithounits of the area primarily comprises of pelitic, psammitic, and calcareous sediments, which have been affected by multiple tectonic activities, polyphase metamorphism and magmitism (Sinha, 1998). As per the groundwater province classification proposed by Singh R.L (1971), the above rocks are classified as crystalline formation with poor aquifer yield. The secondary porosity traversing the rock facilitates the groundwater recharge. Isolated patches of metapelites such as hornblende schist, mica schist, talc chlorite schist etc. are scattered within the gneissic complex and are considered to be poor aquifers. Exposure of schistose rocks are observed along western flank of the sub basin near Sonahatu area. The weathered mantle and joint patterns control the movement and occurrence of groundwater in these rocks. Biotite gneisses dominate within the central region and are exposed in Teladih, Dariguttu, Rabandag, Chanridih, Hesapirtoli areas. Exposure of mafic intrusives are present in the eastern flank of the basin (Figure 3).

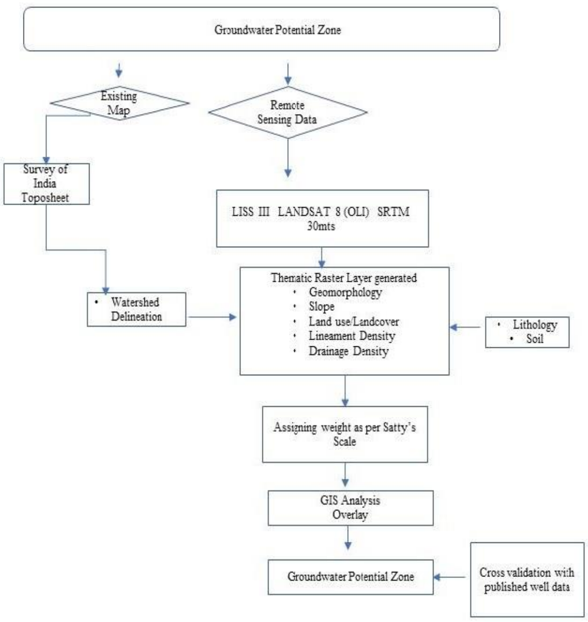

Figure 2. Flow Chart of methodology

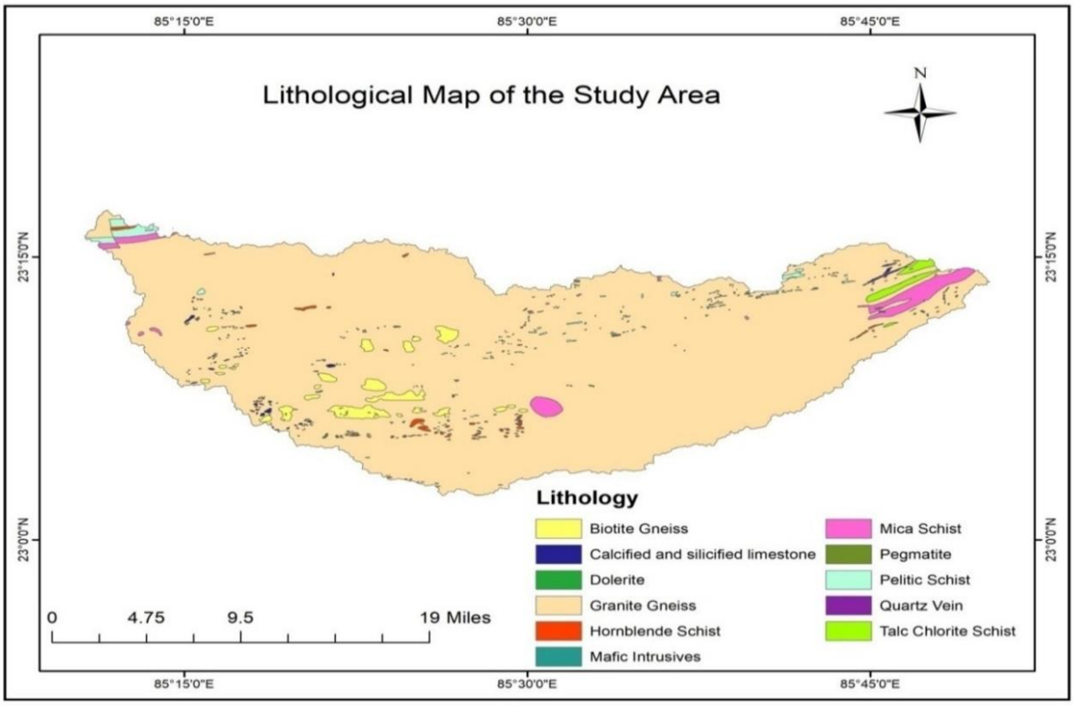

Figure 3. Lithological map of the study area

4.2 Lineaments

Secondary porosity has a significant effect on the presence and distribution of groundwater in hard rock terrain. Secondary porosity includes joints, fractures, fault planes, shear zones etc. Various studies have revealed that in compact impermeable rocks, lineaments are controlling factor for the occurrence of groundwater. Lineaments are surface indicators of subsurface fractures and other planes of weakness. Groundwater distribution in hard rock terrain is largely controlled by lineaments. Lineaments have been proved and used as indicator tool for detecting groundwater potential zones. Lineaments have been identified manually using visual image interpretation technique. LISS III imagery and SRTM DEM (30m) have proved their efficacy in identification of the lineaments. Google earth has been used for cross checking. Majorly the lineaments are oriented along NE-SW, E-W and NW-SE. The lineament density varies from 0.0 to 1.05 Km/Km^2 (Figure 4). High lineament density is result of interconnected fractures indicating high groundwater occurrence. The areas drainage is mainly controlled by structural and geomorphological lineaments.

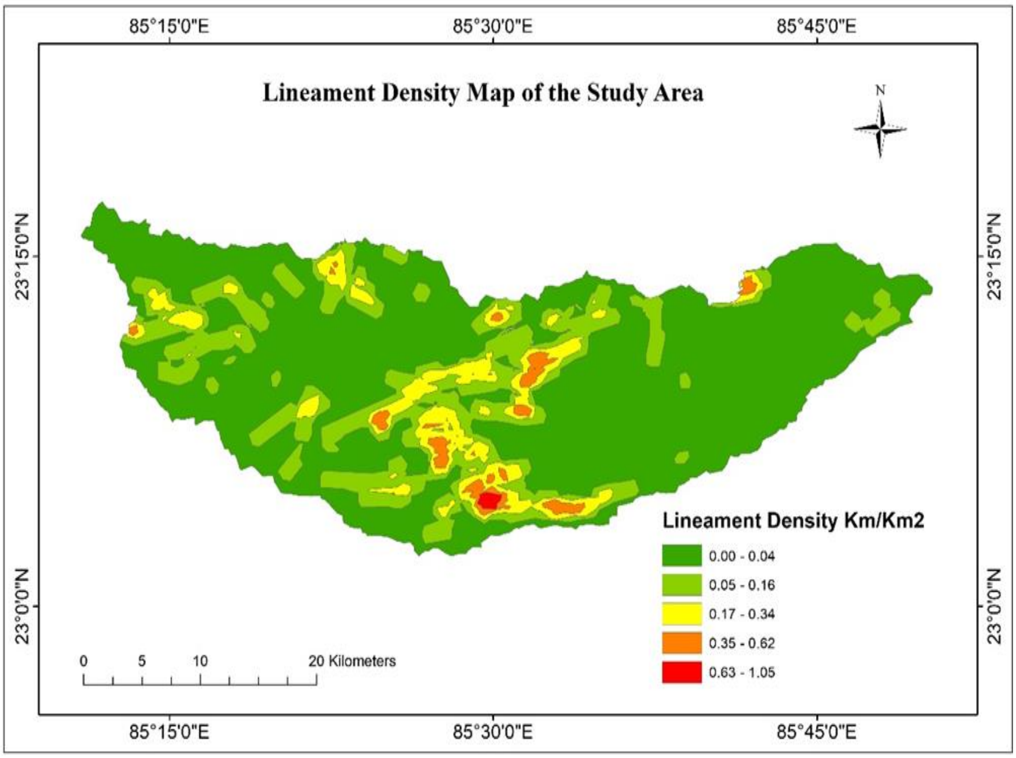

Figure 4. Lineament density map of the study area

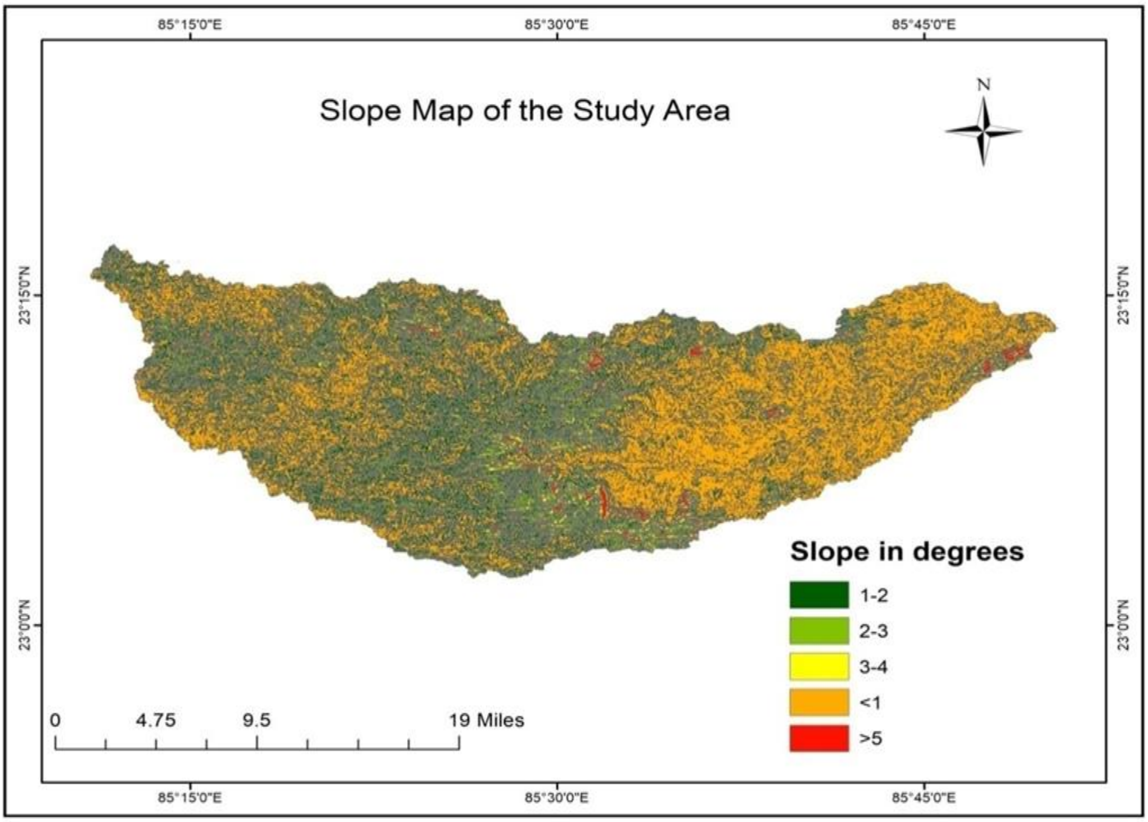

Figure 5. Slope map of the study area.

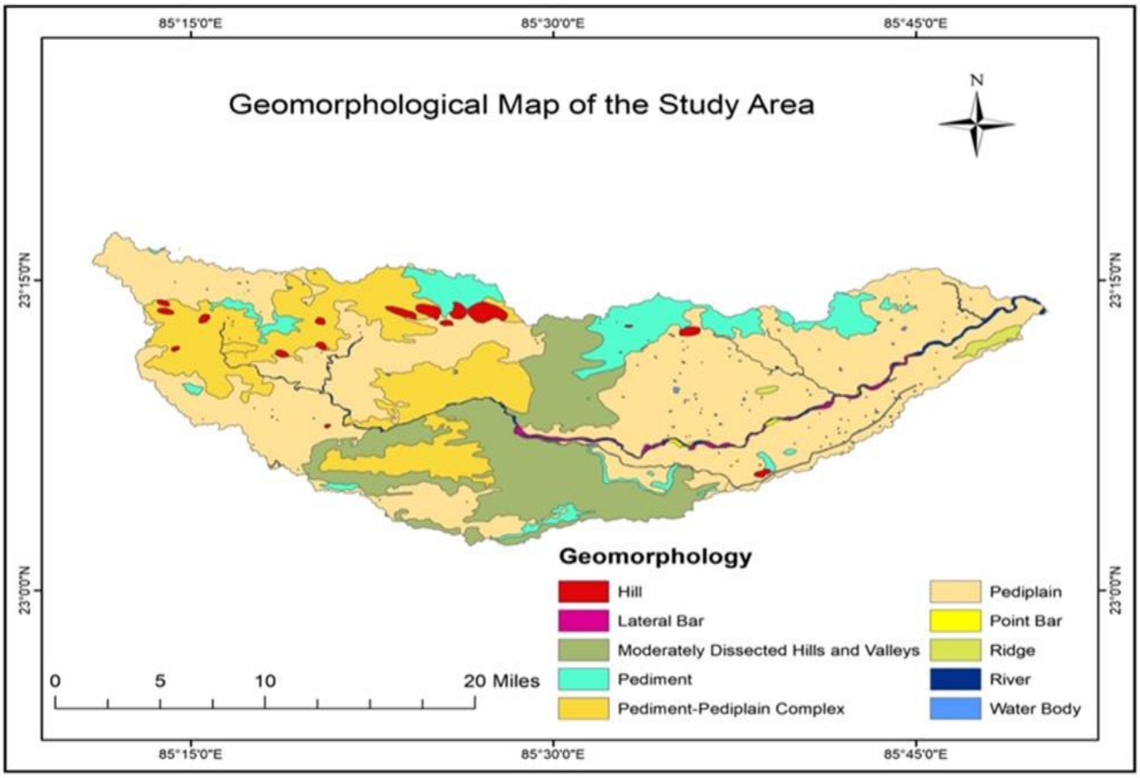

Figure 6. Geomorphological map of the study area

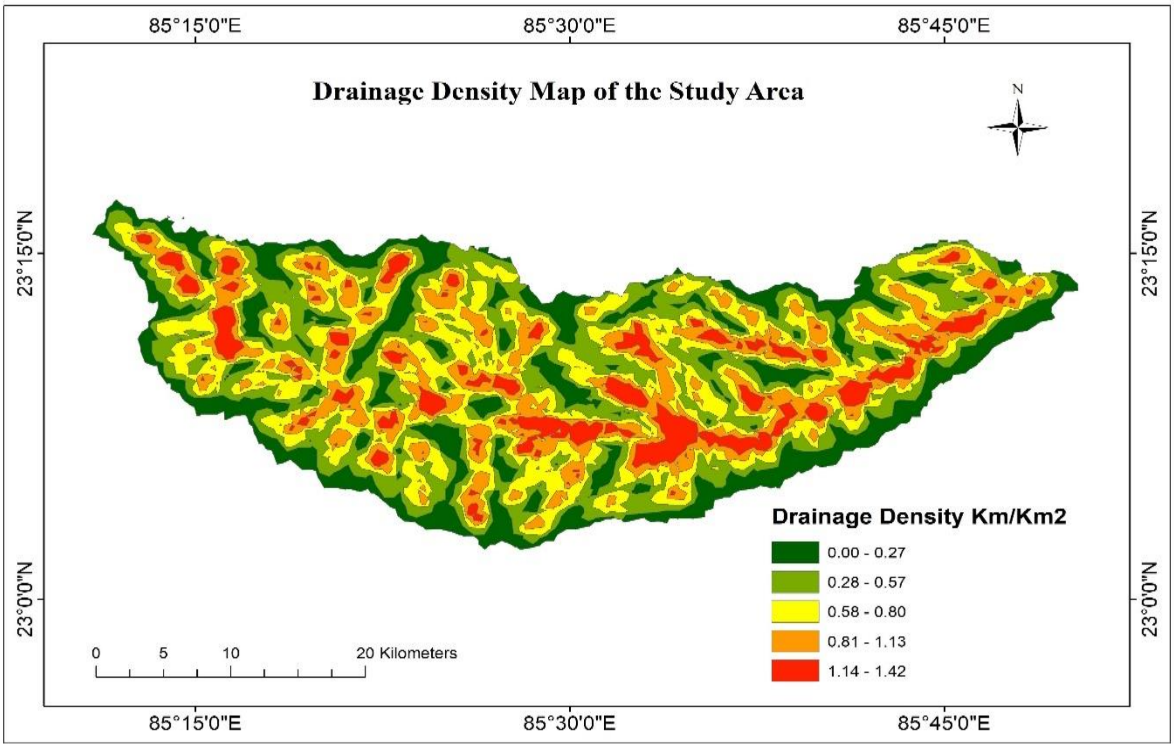

Figure 7. Drainage density map of the study area

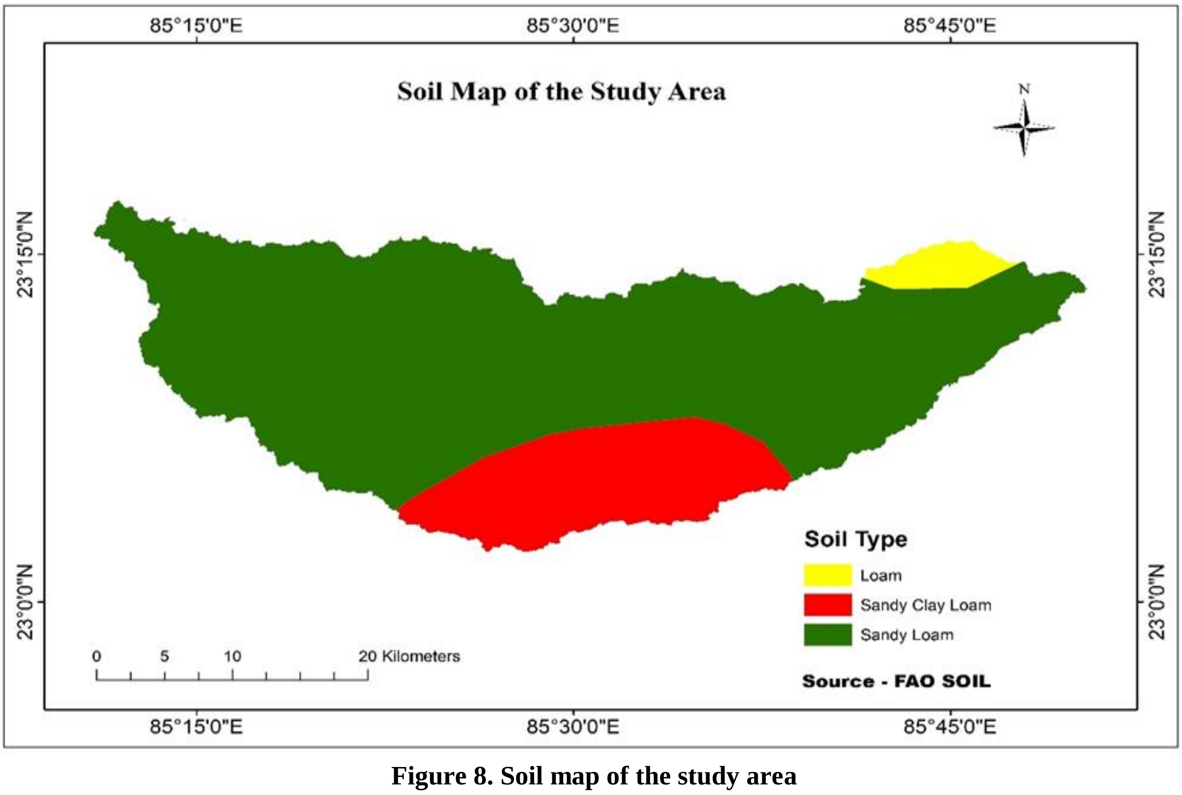

Figure 8. Soil map of the study area

4.3 Slope

The surface water flow is highly dependent on slope. Slope is the rate of change in elevation and controls the gravity effect on water movement. Gentle slopes are more favoured for surface recharge as compared to steeper slopes. The higher slope degree leads to rapid runoff, increased erosion rate, and limited recharge potential. Understanding slope distribution is crucial as it significantly influences the relationship between infiltration and runoff (Kumar U et al., 2013). Slope analysis has been done by ArcGIS v10 on DEM. Slope has been categorized into five classes based on their degree, as very gentle (<1), Gentle (1-2), Moderate (2-3), Steep slope (3-4), Very Steep slope (>5). Gentle to moderate slopes predominates (Figure 5) thus facilitating less runoff and more recharge.

4.4 Geomorphology

The study of geomorphology is vital in groundwater investigations. Landforms developed by geomorphological processes represent the surface features evolved with time and act as an indirect indicator for assessment of groundwater potential zones. Typical geomorphological features associated with hard rock terrain such as hills, ridges, moderately dissected valleys, pediment- pediplain complex, pediments etc are observed. The pediplains occupy majority of study area indicating pediplantation through time and considered to be moderate to good potential zones. The point and lateral bars are also good sites of recharge as compared to hills and ridges. The geomorphological map (Figure 6) was prepared by digitizing the areas based on Bhukosh-GSI, toposheets and was further upgraded using LISS III image.

4.5 Drainage density

The study area belongs to part of Chotanagpur plateau which represents highly undulating and forested track. Drainage system of an area forms the drainage patterns irrespective of whether they are occupied by permanent streams, thereby indicating the surface and subsurface conditions. Drainage patterns are largely governed by the structure and litho –units and morphology of the area. The surface flow is from west to east and shows dendritic to sub- dendritic and parallel patterns indicating a uniform lithology and gentle slope. The drainage density value ranges in between 0.0 to 1.41 Km/Km^2. The drainage density map (Figure 7) was generated in Arc GIS using line density and values were obtained by grid indexing method. Drainage density is inverse of infiltration capacity. Groundwater potential is high in areas having low to moderate drainage density.

4.6 Soil

Soil is a natural body made up of mineral and organic components, with a distinct genesis and nature of its own. Soil forms the controlling parameter for infiltration and surface water flow and is a function of climate, parent material, relief, organism and time. Soil texture is fairly fertile and sandy loam occupies the larger part indicating better drainage and infilteration capacity. Distribution of soils is evident in divergent physiographic units such as rolling hills, pediplains, gently sloping lands etc. The soil type map (Figure 8) is prepared with the help of FAO (Food and agriculture organization). Three classes of soil type are observed which includes sandy clay loam, loam and sandy loam. Sandy clay loam occupies the southern part, Loam is present in the north-eastern and sandy loam predominates .

4.7 Landuse - land cover

Land use refers to the use of land, while land cover refers to the materials present on its surface. Land and water resource management depends significantly on continuous observation and mapping of LULC.

It is especially significant for hydrogeological studies since it has a direct impact on evapotranspiration, groundwater infiltration, and surface runoff during and after precipitation. The LULC cover map (Figure 9) has been identified by employing maximum likelihood algorithm in the supervised classification scheme on LANDSAT 8 (OLI). LULC information has great importance in storage and recharge (Singh A., 2014). Six categories of LULC cover are identified which are water bodies, Mixed Forests, Crop Land, Shrubland, Built-up Land and Bare Ground (Figure 10). As per controlling factor the LULC classes are put as mixed Forest > shrubland > cropland > bare ground. Mixed forests and shrubland are good sites for holding moisture because of greater depths of major root zones. Vast cropland indicates presence of good groundwater potential.

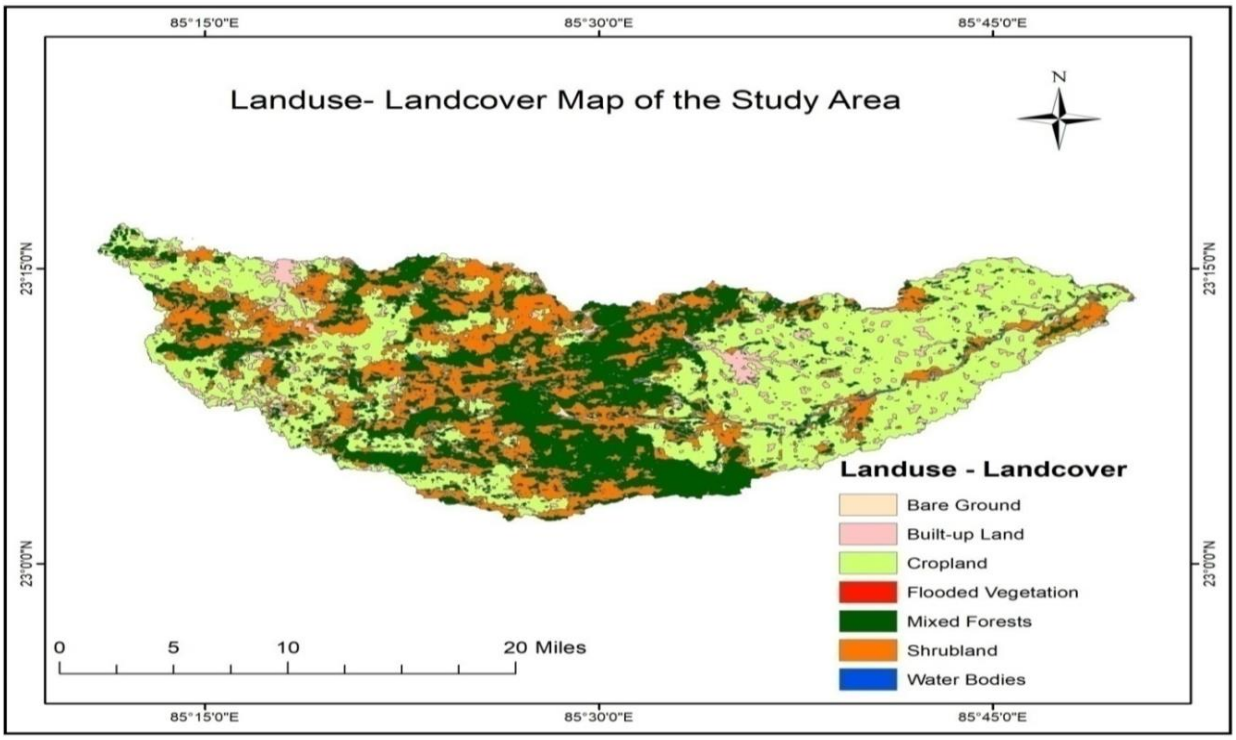

Figure 9. LULC Cover map

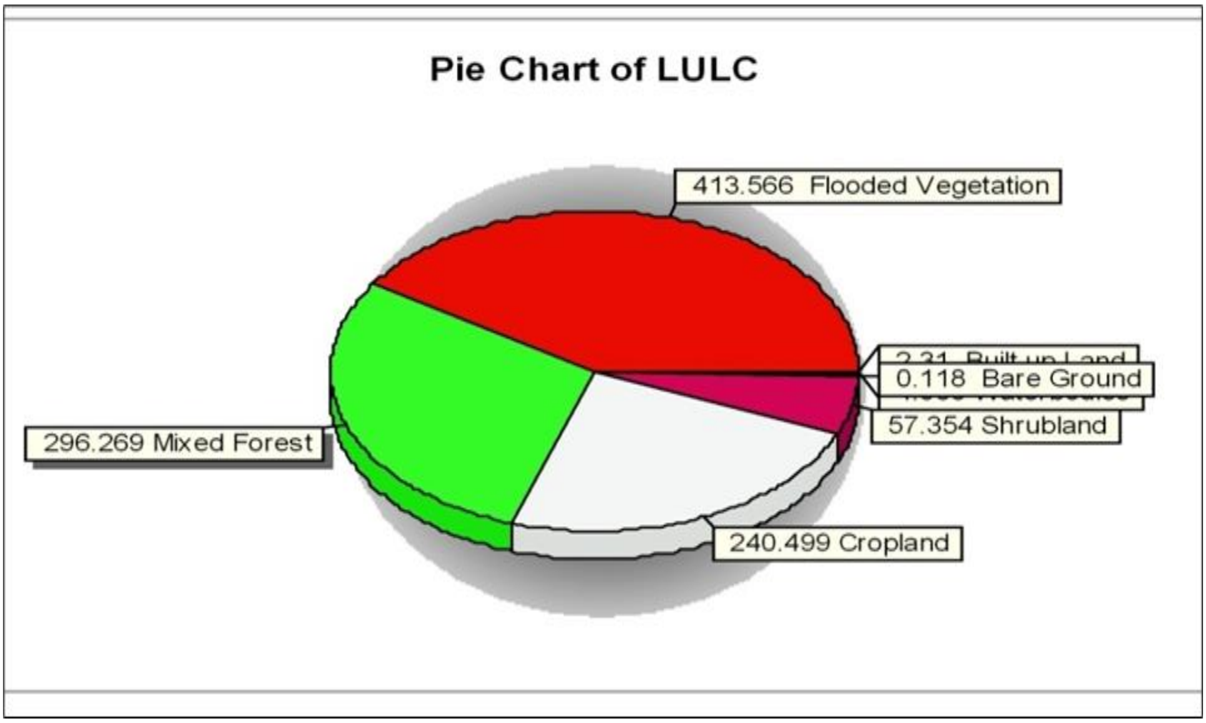

Figure 10. Pie Chart of LULC map of the study area

4.8 Groundwater prospect and validation

GIS analysis can be used to integrate various thematic layers extracted from satellite and collateral data to accurately assess groundwater potential zones. RS-GIS techniques have proven effective in identifying groundwater potential zones by integrating factors like geological structures, lithology, geomorphology, slope, soil, and LULC (Manjunath M.C et.al. 2015.). In the present investigation, the groundwater potential map is prepared by integrating different thematic maps using weighted overlay method in ArcGIS software. GIS- based multi-criterion on decision making using Saaty's Analytical Hierarchy Process (AHP) was employed for pairwise comparison (Table 1) and due weights were assigned. The consistency ratio (CR) value found is 0.09 which is less than 0.1 hence the pairwise comparison judgement is acceptable for thematic layers (Saaty 1980). It is observed that the factors which mostly govern the potentiality includes lineament density (38.5%), geomorphology (19.1%) and lithology (12.8%) respectively as per given in table 1. The other four factors have low influence on the occurrence. Finally, the groundwater potential zone (GWPZ) was derived using the overlay spatial operations of weighted thematic raster layer. The formula used for computing GWPZ is given below:

$$GWPZ = \sum_{w=1}^{m} \sum_{j=1}^{n} W_{\mathrm{j}} * \mathrm{X_i}$$

Where, Wj represents the normalized weight of jth parameter obtained by AHP, Xi is the weight of the ith class of the parameter, m denotes the number of parameter or thematic layers and n denotes the total number of classes or rank within specific parameter or theme. The groundwater prospect map of the study area was finally established by the AHP weighted linear combination of the seven thematic layers and reclassified into five zones as very low, low, moderate, high and very high classes (Figure 11). High potential zones fall in highly fractured zones where lineament density is maximum and is also characterized by highly dissected hills and valleys geomorphological class. It is also in agreement with low to moderate slope and loamy soil accrediting higher recharge.

Table 1. Pairwise comparison matrix for thematic layers

	Lineament Density	Geomorphology	Lithology	Slope	Soil	LULC	Drainage Density	weight	Wt.x100
Lineament Density	9	8	7	5	4	3	1	0.385	38.5
Geomorphology	9/2	8/2	7/2	5/2	4/2	3/2	1/2	0.191	19.1
Lithology	9/3	8/3	7/3	5/3	4/3	3/3	1/3	0.128	12.8
Slope	9/4	8/4	7/4	5/4	4/4	3/4	1/4	0.096	9.6
Soil	9/5	8/5	7/5	5/5	4/5	3/5	1/5	0.079	7.9
LULC	9/6	8/6	7/6	5/6	4/6	3/6	1/6	0.070	7.0
Drainage Density	9/7	8/7	7/7	5/7	4/7	3/7	1/7	0.051	5.1

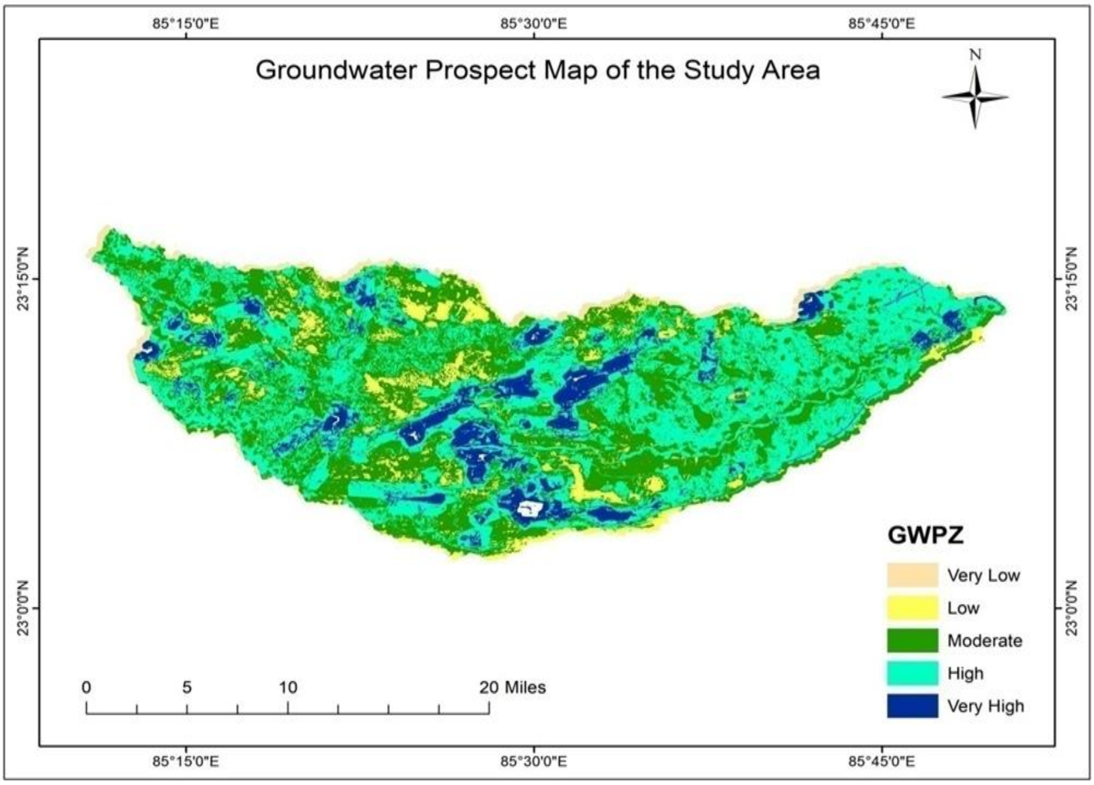

Figure 11. GWPZ map of the study area

Conclusion

The present investigation reveals the competency of advance geospatial techniques in establishing the groundwater prospective zones in hard rock terrain which is carried out in Kanchi River sub-basin of Subarnarekha river basin, Jharkhand, India. This paper intends to assess the cost effectiveness of RS and GIS for mapping and evaluation in terms of time and resource. The variable parameters governing the potential of groundwater occurrence were lineament density, geomorphology, lithology, slope, soil and LULC however all factors don't hold equal weightage. The most significant factors in determining potentiality are lineament density, geomorphology, lithology and slope having weighted values of 38.5%, 19.1%, 12.8% and 9.6% respectively. The prospect map indicates that most promising sites are ones having high lineaments within dissected hills and valleys. This suggests that the study area is structurally controlled and emphasizes the importance of lineaments and geomorphology on groundwater investigations. Moderate to high prospect zones are noticed in areas having high lineament density, croplands and Pedi plains having loamy soil. The evidence of good groundwater occurrence is also evident by developed massive cropland which implies favourable recharge sites.

Low prospect zones are present along the hills, ridges, pediments, steep slopes and high drainage density which facilitates runoff.

It can be inferred that the about 50% of study area manifest moderate to high potential, occupying the central and western part of study area. Water yield is 50-100lpm for depth<30m and 400-800lpm for depth 30-80mts for moderate to high zones (Source- JSAC/TECH-REP/RD-GOJ/WSMIS-JRD/09-10/07). The groundwater prospect map created by integration using geomatics application might prove informative in efficient future planning, development and management for water reservoirs both surface and underground present in a given watershed.

References

Ghosh N.C. (1983). Geology, tectonics and evolution of Chhotanagpur Granite Gneiss Complex, Eastern India; Structure and Tectonics of Precambrian rocks of India; Hindustan Publ. Corp. 10, pp. 211-247

Kumar U., B. Kumar and N. Mallick (2013). Groundwater Prospects Zonation Based on R.S. and GIS using Fuzzy algebra in Khoh River watershed, Pauri-Garhwal District, Uttarakhand, India. Global perspectives on geography (GPG), Vol 1, Issue 3, pp. 37-45.

Manjunath M.C., H. T. Basavarajappa and H. Basavaraj. (2015). Spatial data integration and mapping of groundwater potential zones of Precambrian Terrain of Hassan District, Karnataka, India using Geomatics Application. International journal of civil engineering and Technology (IJCIET), Vol 6, Issue 5, pp.123-134

Prioritization of watershed of Jharkhand State (Based on IWMP criteria and satellite derived Parameters) (JSAC/TECH-REP/RD-GOJ/WSMIS-JRD/09-10/07).

Roy A., T. Keesari, and U. K. Sinha (2019). Delineating groundwater prospect zones in a region with extreme climatic conditions using GIS and remote sensing techniques: A case study from central India. J Earth Syst Sci 128, 201. https://doi.org/10.1007/s12040-019-1205-7

Saaty T. L. (1980). The analytic hierarchy process. MsGraw-Hill, New York, p278.

Sanyal S. and P. Sengupta (2012). Metamprphic evolution of the Chotanagpur Granite Gneiss Complex of the East Indian Schield: current status. Geological Society, London, Spec. Pub. 2012, V. 365, pp. 117 -145. Doi: 10.1144/SP365.7

Sengupta D.K. and S. N. Sarkar (1964). Structure of the Granite rocks and associated metamorphites of the area around Muri-Silli-Jhalida, Ranchi and Purulia Dist. India. 22nd Int. Geog. Cong. Vol 4., PP 374-389.

Singh A. (2014). Groundwater resources management through the applications of simulation modelling; a review. Sci Total Env.499, pp 414-423.

Singh R. L. (1971). India, A Regional Geography,NGSI, Varanasi, Res. Pub.6.

Sinha J., U. Kumar and S. P. Singh (1998). Petrogenesis of the amphibolites of chuttupalu area, Ranchi (Bihar). Quaternary Journal of the geological association and research centre. Vol 6, No. 3, pp 64-69.Subbarao N. (2006). Groundwater potential index in a crystalline terrain using remote sensing data. Environmental Geology, Vol. 50, pp.1067-1076.