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Delineation of Groundwater Potential Zone in Baliguda Block of Kandhamal District, Odisha using Geospatial Technology Approach

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Abstract Assessment of groundwater potential zones is extremely important for protection of water quality and management of groundwater systems. Groundwater Potential Zones (GPZ) are demarcated with the help of geospatial techniques. The parameters, considered for identifying the GPZ such as geology, geomorphology, slope, drainage density, lineament density, rainfall, soil and landuse and land cover (LULC) are generated using satellite data and toposheet. Later, they are integrated with each other applying weighted overlay in ArcGIS. Suitable ranks are assigned for each category of these parameters. For various geomorphic units, weight factors are decided based on their capability to store groundwater. This procedure is repeated for all other layers and resultant layers are reclassified. The groundwater potential zones are classified into three categories like Poor, Good and Excellent. The use of aforesaid methodology is demonstrated in a selected study area in Baliguda block of Kandhamal district in Odisha.
Keywords *Groundwater Potential Zone; GIS; Lineament; rainfall*

1. Introduction

Groundwater is one of the most valuable natural resources, which supports human health, economic development and ecological diversity. Because of several inherent qualities, it has become an immensely important and dependable source of water supplies in all climatic regions including both urban and rural areas of developed and developing countries. The groundwater occurrence in a geological formation primarily depends on the formation of porosity. High relief and steep slopes impart higher runoff, while topographical depressions increase infiltration. An area of high drainage density also increases surface runoff compared to low drainage density area. Surface water bodies like rivers, ponds, etc., can act as recharge zones [1]. The remote sensing (RS) and Geographic information system (GIS) tools can open new paths in water resource studies. Analysis of remote sensing data supported by the survey of India (SOI) topographical sheets and collateral information with necessary ground truth verifications help in generating the baseline information for groundwater targeting [2]. The different hydrogeological themes can be used to identify the groundwater potential zones of the present area. Identification of groundwater occurrences using remote sensing data is based on indirect analysis of directly observable terrain features like geological structures, geomorphology, landuse and Landcover, drainage density, rainfall data and their hydrologic characteristics. Also lineaments play significant roles in groundwater exploration in all type of terrains. Application of RS and GIS can be utilized in as multi criteria analysis of resources evaluation and ground water Potential zone study. Integration of RS and GIS has proved to be an effective tool in determination of groundwater potential and other studied in various parts of the world [3; 4, 5; 6; 7; 8; 9; 10; 11]. Several studies have been made to delineate groundwater Potential zones using geospatial techniques. These methods utilize cost effective tools in producing valuable data on geological, hydrogeological and geomorphological parameters that help in delineating groundwater potential zones. The main goal of this study is to map groundwater potential zone based on terrain, hydrological and geological parameters employing multi criteria approach. These parameters are very closely associated with groundwater accumulation.

2. Study Area

The study area is a part of Kandhamal district lying between 19^0 34' to 20^0 36' north latitude and 83^0 34' to 84^0 34' east longitude. Kandhamal district is bound by Boudh district in the north, Rayagada district in south, Ganjam and Nayagada district in the east and Kalahandi district in the west. Kandhamal district is divided into 12 blocks and Baliguda block is one of them. The study area comprises an area of 812 km^2. Physiographically, the entire district is located on a high altitude zone with hill ranges and narrow valley tracks which ultimately guide the socioeconomic condition of the people. Almost 66 % of the land area is covered with dense forest. The maximum temperature recorded in this area is 45.5^0C and minimum temperature 2^0C. The annual average rainfall is 1163mm.

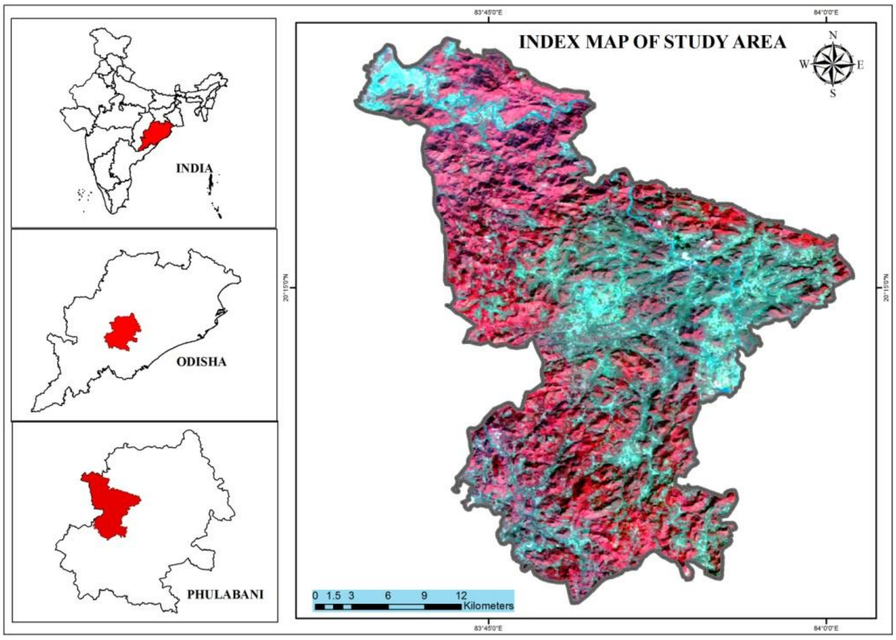

Figure 1: *Location map predicted the study area*

3. Materials and Methodology

For carrying out the present piece of work the open source Landsat data were collected from http//www.earthexplorer.usgs.gov site and has been analyzed to fulfill the objectives. Landsat 8 OLI data and SRTM DEM have been used for this study proposed. SOI toposheet number at 1:50,000 have also been used. The lithology map was collected from Geological Survey of India (GSI), Bhubaneswar and was later scanned, rectified and digitized on Arc GIS to prepare the of lithology thematic layer of the study area. The rainfall data was collected from regional office of Indian Meteorological Department, Bhubaneswar. The slope map was generated from SRTM DEM. The digital (FCC_S) of Landsat OLI were visually interpreted for preparing different thematic layers like Geomorphological map, Landuse and Landcover and lineament density map of Baliguda block. The drainage map was prepared from SOI toposheet and the drainage density map was prepared from Arc GIS software. In order to access groundwater Potential zones, different thematic layers Viz. Geomorphology, LULC, Drainage density, Lineament density, Slope, Soil and rainfall were generated from satellite imagery and the conventional data were in corporated with the help of Arc GIS 9.3 software. The methodology adopted flowchart for the present study is shown in Figure 2.

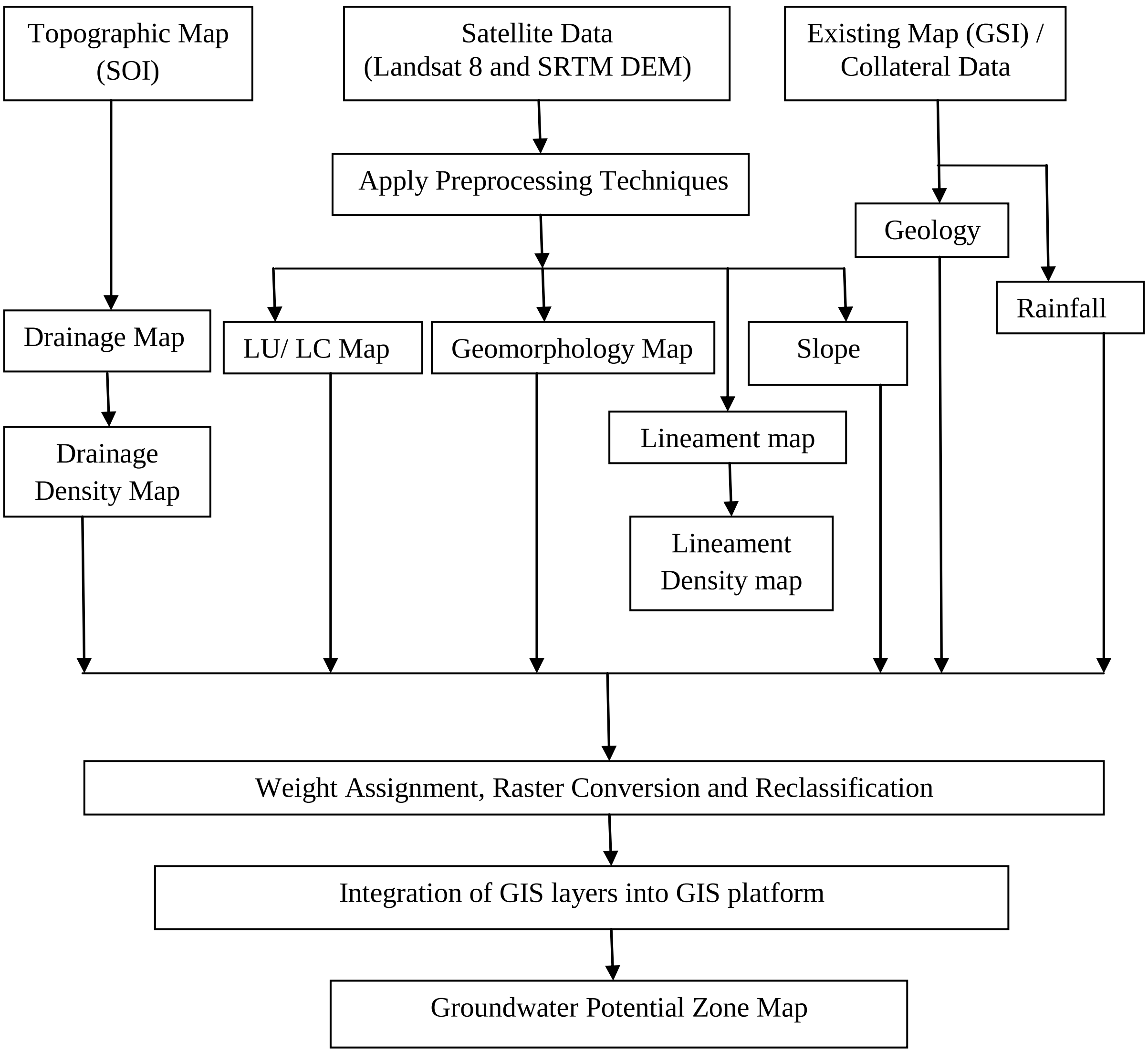

Figure 2: *Flow chart of the methodology of assigning the groundwater Potential of the study area*

GIS packages are used creation for digital data base, data integration and analysis. All thematic maps are digitized in continuous manner in vector format and the digitized values were then assigned. Different polygons in the thematic maps were labeled separately. Initially each one of the polygons in the final thematic layers was qualitatively visualized into one of the category Viz. (i) Excellent, (ii) good, (iii) moderate and (iv) Poor, in terms of their importance and occurrence of groundwater. Then suitable weights were assigned to each thematic feature after considering their characteristics. Knowledge based weight assignment was carried out for each feature and they were integrated and analyzed using the weighted aggregation method [12, 13]. In this method, the total weights of the final integrated polygon were derived as sum or product of the weights assigned to different layers according to their suitability. Finally the groundwater prospect or Potential zone map was generated.

3.1. Categorization of thematic layers

To assess the groundwater prospect of an area, it is necessary to understand different types of landforms, geology, soil characteristics, slope and recent land utilization of that area. The information in groundwater characteristic of the various parameters is initially generated in descriptive forms, which revels the parameters support the occurrences of groundwater. The criteria adopted for different thematic layers are given bellow.

3.2. Delineation of groundwater Potential zone

Considering all the themes and features in an integrated layer, the groundwater potential index (GWPI) is calculated as.

$$GWPI = GwGr + LwLr + DwDr + LIwLIr + RwRr + SwSr + GMwGMr$$

Where Gw represents weight of geology and Gr represents rank on the theme;
Lw represent weight of LULC and Lr represents rank on the theme;
Dw represent weight of drainage density and Dr represents rank on the theme;
LIw represent weight of lineament density and LIr represents rank on the theme;
Rw represent weight of rainfall and Rr represents rank on the theme;
Sw represent weight of soil and Sr represents rank on the theme;
GMw represent weight of geomorphology and GMr represents rank on the theme;

4. Results and Discussion

The occurrence of groundwater in an area is governed by several factors, such as topography, geology, geomorphology, landuse, soil, rainfall, drainage density, and lineament density for which thematic layers are prepared for their input into a GIS.

4.1. Geology

Lithology is a very important factor in predicting groundwater Potential zones. Three types of lithological units namely charnockite, sand and silt and sandstone are found in the study area shown in Figure 3. As sand and silt are under alluvium group, it has been given higher weightage as compared to sedementary rock like sandstone. Charnockite has lesser amount of porosity for percolation of groundwater in contrast to alluvium and sedimentary rock, so it has been given as less weightage. The weights assigned to different thematic layers and the derivation of weights for indivisual themes are shown in Table 1.

4.2. Geomorphology

The hydrogeomorphology in hard rock terrain is highly influenced by the lithology and structure of the underlying formation and is considered as one of the most important features in evaluating the groundwater Potential and prospect [14]. Formations associated with river/water bodies and flood plains have higher water retention capability and therefore constitute the best landforms for higher groundwater Potential. The geomorphology of the study area is shown in Figure 4. The flood plain region of the study area, shown in green color receives good recharge and has excellent prospects. The pediplain region covers a majority of the study area and the groundwater reserve in these regions is very limited due to less recharge. The river channels and water bodies, characterized by highly porous and permeable materials perform as good groundwater prospects. The structural hills and denudational hills in the study area, shown in blue and yellow color comprise the runoff zones and are not suitable for groundwater.

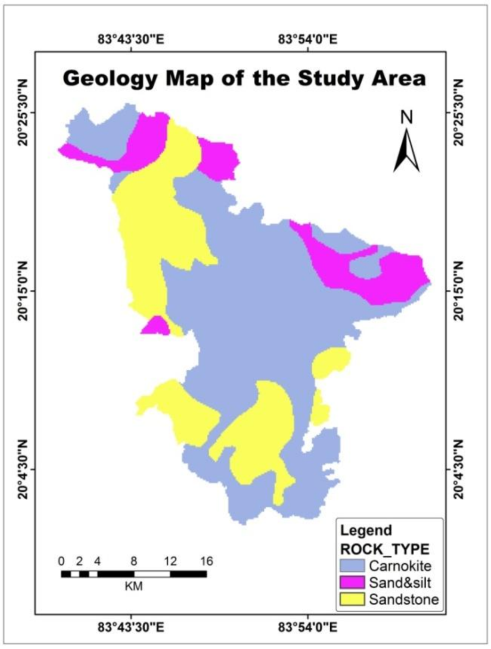

Figure 3: *Geology Map of the study area*

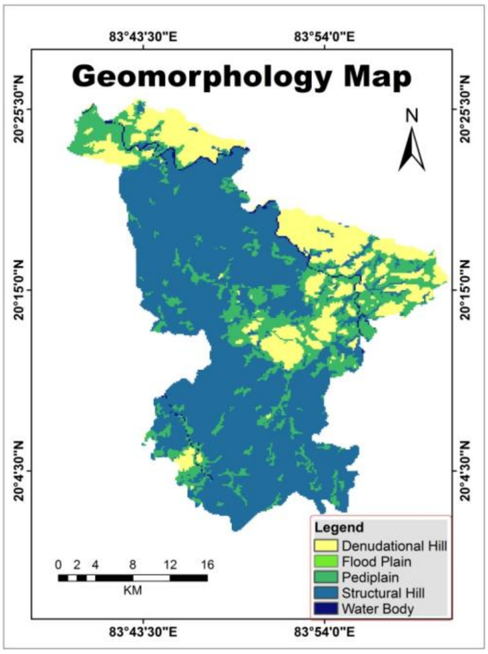

Figure 4: *Geomorphology Map depict the study area*

4.3. Soil

The soil of the study area are divided in to four main categories namely clay, sand, sandy loam and sandy clay loam are shown in Figure 5. Rank and weights have been assigned on the basis of infiltration or porosity rate of the soil. Sand and sandy clay loam have high infiltration rate and have been given high rank whereas most of the areas have been cover with sandy loam. It has been marked with low rank because sandy loam has low infiltration capacity. The last categories of soils are clay and it has also low infiltration capacity as compared to sandy clay loam.

4.4. Drainage density

Drainage density is an important parameter for evaluating groundwater prospects. The drainage map of the study area, shown in Figure 6 is used for the preparation of drainage density (Figure 7). High drainage density values are favourable for runoff low groundwater Potential zone. High ranks are assigned to low drainage density area and vice versa. Based on the drainage density value, the area was classified into seven group's viz. 0 - 59.86, 59.86 – 119.73, 119.73 – 179.60, 179.60 – 239.47, 239.47 – 299.34, 299. 34 – 359.21, 359.21 – 419.08 m/ Sq.km. Low drainage density causes more infiltration and the result is good water Potential as compared to high drainage density regions. Higher ranking were given to lower drainage density regions and vice versa.

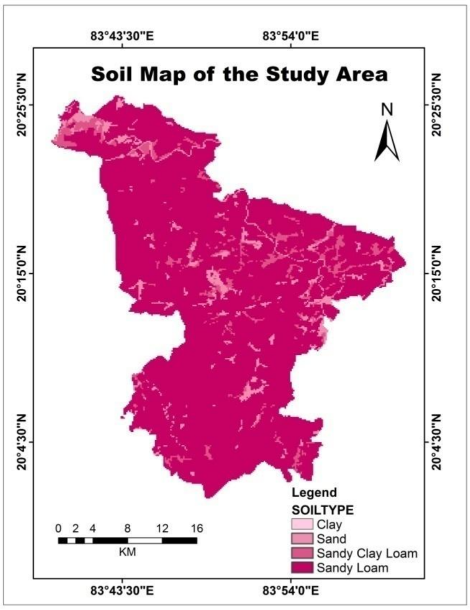

Figure 5: *Soil Map of the study area*

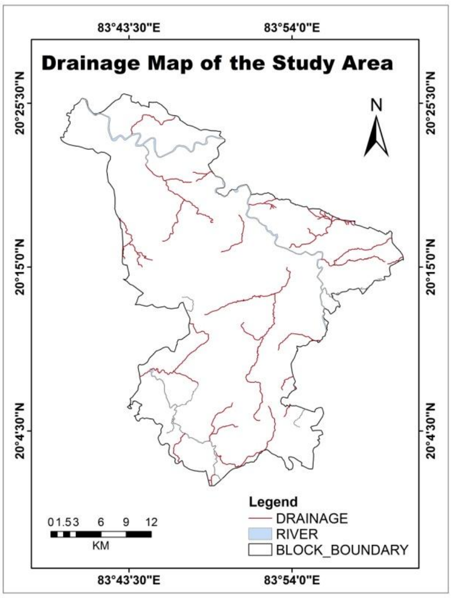

Figure 6: *Drainage map of the study area*

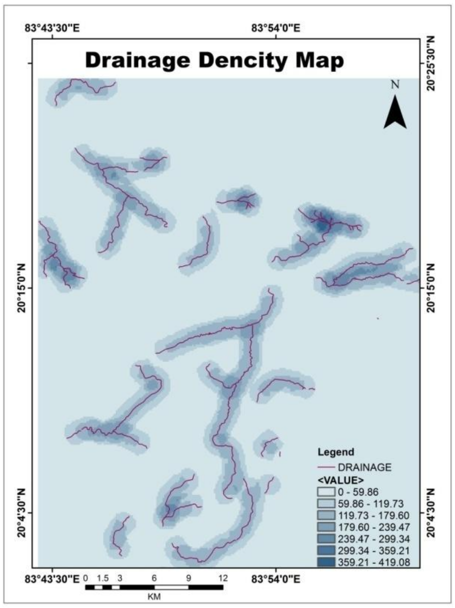

Figure 7: *Drainage density map of the study*

4.5. Lineament Density

The lineament is the result of faulting and fracturing and hence is the indicator of porosity and permeability of hard rock areas and it may be of significance in groundwater study. The geological linear features are assumed to be zones of fracture in bed rocks where prospects of more groundwater may be expected [15, 16]. Lineaments are normally shown in tonal, texture, relief drainage, vegetation linearity and curvilinearity in satellite data [17]. Accordingly, the lineament density map was prepared from the lineament map (Figure 8). The lineament density map shows (Figure 9) low density as compared to other parts of the study area. The minimum linear density was found in 0-42.06 and the highest density was 126.18 – 168.24 m/ km^2. Higher values of lineament density will have more recharge and hence better prospects for groundwater.

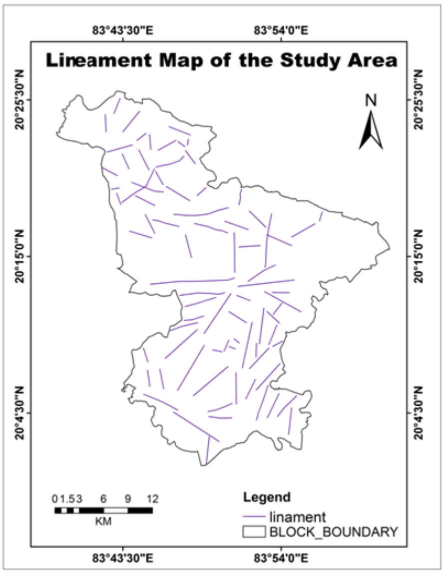

Figure 8: *Lineament map of the study area*

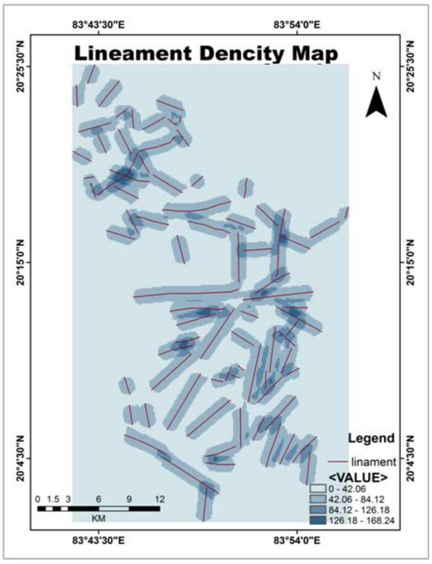

Figure 9: *Lineament density map of the study*

4.6. Landuse / Landcover

The study area consists of agricultural lands, built up land, scrub, forest, wasteland and water bodies are shown in (Figure 10). From the landuse point of view agricultural lands are Moderate sites for groundwater exploration. The areas occupied by water bodies are coming under Very High categories and the Reserve Forests are coming under Moderate categories. Lands which are not used for any purpose are treated or classified as wasteland and hence it is categorized as Poor for groundwater prospects. Lands with scrub are categorized as Low Moderate categories.

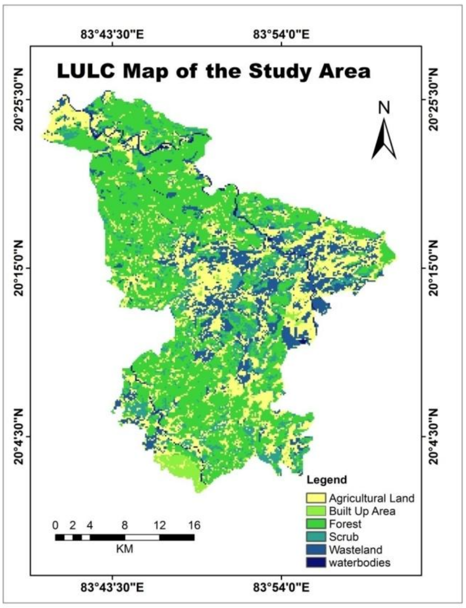

Figure 10: *LULC map of the study area*

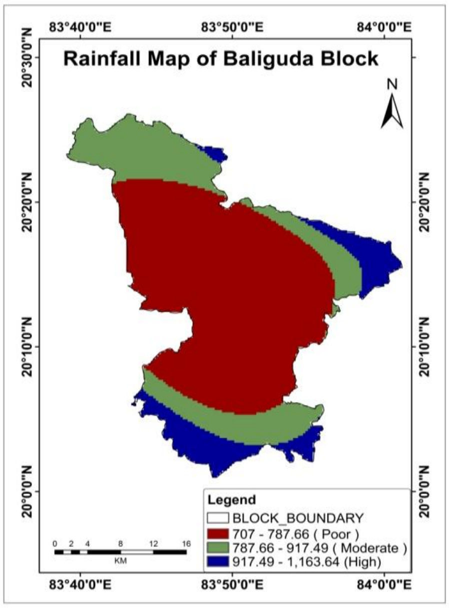

Figure 11: *Rainfall map of the study area*

4.7 Rainfall

Rainfall is the main source of groundwater recharge. In the present study, the thematic layer of rainfall has been developed on the basis of 12 points data by the use of Inverse Distance Weighted (IDW) method in Arc GIS platform. Figure 11 illustrates the rainfall map of the study area. The total area is depicted as coming under three rainfall zones. The area 707-787.66 mm rainfall falls into Poor for groundwater storage categories. The areas with 787.66 – 917.49 mm rainfall are considered as Highly Moderate categories. The area having a rainfall of 917.49 – 1163.64 mm are slotted under relatively High category for groundwater recharge

4.8 Slope

Slope is one of the most significant parameters for groundwater exploration. Slope of any area affects the runoff and recharge of surface water. In terms of groundwater recharge, an area with flat terrain topography falls into Very Good category and has relatively more infiltration rate. Figure 12 illustrate the slope map of the study area. Topographically, the area is categorized into plain to steeply sloping hills. The slope varies from 00 to 9.260. On the basis of degree of slope, the study area has been classified into four slope classes. The area having 0 0 – 1.16 0 falls into High for groundwater storage categories because of the nearly flat terrain and relatively high infiltration rate. The areas with 1.160 – 2.430 slopes are considered as Good due to slightly undulating topography. The area having a slope of 2.430- 3.810 cause relatively high runoff and low infiltration and hence categorized as Poor and the area having 3.810 – 9.26 0 are considered as very poor due to high slope and runoff.

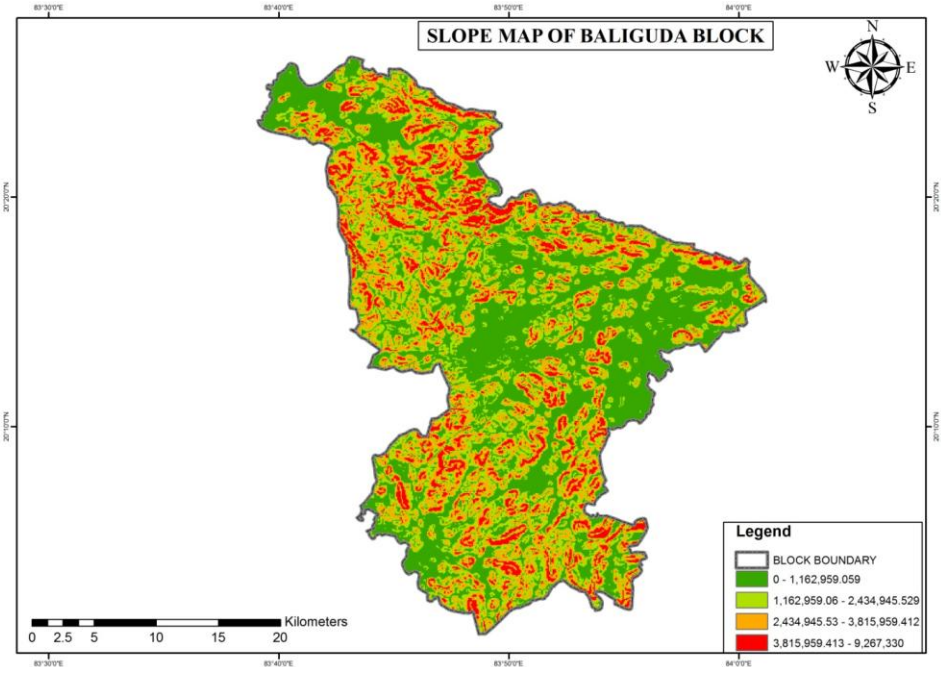

Figure 12: *Slope map of the study area*

4.9. Integration of thematic layers using weightage overlay analysis Model

Depending on the groundwater potentiality, each class of the main eight thematic layers (Geomorphology, Geology, LULC, Soil, Drainage Density, Lineament Density, slope and rainfall) are qualitatively placed in one of the categories viz. Very High, High, Highly Moderate, Moderate, Poor and Very Poor. The weights and ranks have been chosen basing on the judgment of works carried out by researchers or knowledge of expert gained through similar work on groundwater potentiality mapping [18; 19; 20; 21]. All the thematic maps are converted into raster format and superimposed by weighted overlay method (rank and weight wise thematic maps and integrated with one another through in GIS software). For assigning the weight, the geomorphology and geology were assigned higher weight whereas the drainage density and lineaments were assigned lower weights. After assigning weights to different parameters, individual ranks were given for sub variable. The maximum value is given to the feature indicating highest groundwater potentiality and the minimum given to the lowest groundwater potentiality. In LULC, the highest rank values are given to water body and low rank values are assigned to build up area. Similarly in geology, highest values are assigned to charnockites and lowest values to sand and silt. Among the various lineament density classes, the very high lineament density categories are assigned higher rank values as this category has greater chances of groundwater infiltration. In landforms, water body has highest rank 9 and structural hill has lowest rank 1. The overlay analysis is tabulated in Table 1. All the thematic maps have been integrated using Groundwater Potential Index (GWPI) formula in GIS. A final groundwater Potential map (Figure 13) is prepared based on the above technique. In the present study, the groundwater Potential zones have been categorized into three type's viz. Excellent, Good and Poor. Table 2 gives the upper and lower limits of weights considered for demarcating these three types of groundwater prospective areas.

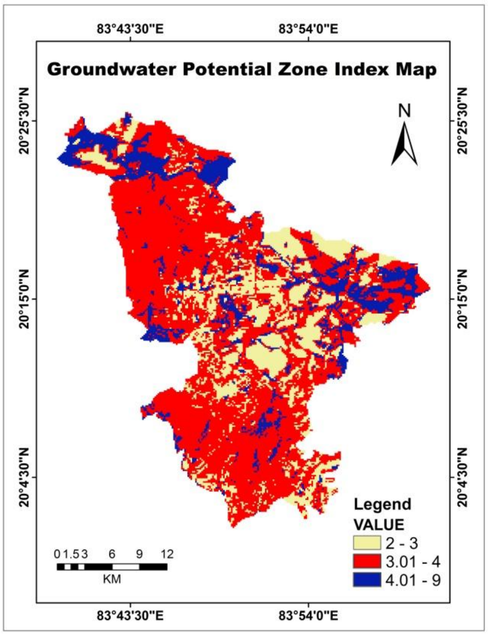

Figure 13: *Groundwater Potential Index map of the study area*

Table 1: *Thematic Map Weight and Feature Ranking*

Theme	Sub-Classes	Category	Rank	Influence (weight) %
Geomorphology	Water body	Very High	**9**	**25**
	Structural hill	Very poor	**1**	
	Denudational hill	Poor	**2**	
	Pediment	Moderate	**4**	
	Flood plain	High	**8**	
Geology	Sand and silt	High	**8**	**18**
	Sand stone and conglomerate	Highly Moderate	**6**	
	Charnockite	Poor	**3**	

LAND USE/ LAND COVER	Agricultural land	High	**8**	**8**
	Built Up land	Very Poor	**2**	
	Forest	Highly Moderate	**6**	
	Scrub	Low Moderate	**5**	
	Wasteland	Poor	**3**	
	Water Body	Very High	**9**	
Soil	Sandy loam	Poor	**3**	**15**
	Sandy clay loam	High	**8**	
	Clay	Highly Moderate	**6**	
	Sand	Very High	**9**	
Drainage Density	0-59.86	Poor	**3**	**6**
	59.86-119.73	Highly Moderate	**6**	
	119.73-179.60	High	**8**	
	179.60-419.08	Very High	**9**	
Lineament Density	0 - 42.06	Poor	**3**	**7**
	42.06 - 84.12	Highly Moderate	**6**	
	84.12 - 126.18	High	**8**	
	126.18 - 168.24	Very High	**9**	
Slope	0^0 - 1.16^0	High	**8**	**12**
	1.16^0- 2.43^0	Highly Moderate	**6**	
	2.43^0-3.81^0	Poor	**3**	
	3.81^0- 9.26^0	Very poor	**1**	
Rainfall	707 – 787.66	Poor	**3**	**9**
	787.66 - 917.49	Highly Moderate	**6**	
	917.49 -1163.64	High	**8**	

Table 2: *Weightage Range of Groundwater Potential Zone*

Groundwater Category	Weightage Table
Excellent	>4.01
Good	3.01- 4.0
Poor	<3.01

5. Conclusion

In this study it has been established that geospatial technology can provide appropriate platform for convergent analysis of large volumes of multidisciplinary data and decision making for groundwater studies. These techniques have been successfully used and demonstrated for evaluation of groundwater potential. The weightage Index overlay model has been found very useful in the mapping of groundwater prospective zones. This groundwater Potential information will be useful for identification of suitable location for extraction of water. From this study it is observed that remote sensing and GIS technique can be used effectively to delineate groundwater recharge potential zones map, which can be used for improvement in the groundwater recharge and holding for the study area and later on may be for various purposes like identification of location of structures for artificial recharge, locations of new tube wells and efficient groundwater management for betterment of the society.

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