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Application of Remote Sensing, GIS and MIF technique for Elucidation of Groundwater Potential Zones from a part of Orissa coastal tract, Eastern India

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Abstract

With the advent of civilization and economic development of the country the demand for water has increased over the years. Therefore, evaluating the potential groundwater zone is very important for secured groundwater systems. Combination of remote sensing data and geographical information system (GIS) has brought a distinct path to study this kind of problems. Thus, the present study attempts to select and elucidate various groundwater potential zones for the assessment of groundwater availability in a coastal part of Orissa using remote sensing, GIS and multi-influencing factor (MIF) techniques. Survey of India Topo sheet and Satellite IRS-IC LISS III, Lands at TM digital and SRTM data are used to prepare various thematic layersviz., land use, geomorphological, geological, slope, drainage density and lineament density map. All these six layers are integrated using the Spatial Analyst Tool in Arc GIS 9.2 implying weighted overlay methods to delineate the Ground Water Potential Zones.In weighted overlay analysis each of these layers has been allotted fixed score and weight calculated from MIF technique on the basis of relative contribution of each of these maps towards groundwater potential. All the thematic maps are then enumerated with one another through ground control points and joined step by step using the normalized aggregation method in GIS for computing groundwater potential index. Finally, based on cumulative weighted value, groundwater recharges zones have been selected and classified into very good, good, poor, and very poor zones, respectively. The result depicts major portions of the study area have "Very Good" as well as "Good" prospect while a few scattered areas have very poor prospect. Thus, the results will be supportive for improved organization and supervision of ground water resources of the present area.

Keywords: Groundwater, satellite remote sensing, geographic information system, multi-influencing factor.

Introduction

Groundwater is one of the most precious natural resource, and has important impact on human life, economic development of mankind (mainly in agriculture, industries etc.) and ecological diversity. Groundwater is the primary source of freshwater[1]. Remarkable increase in the agricultural, industrial, population and domestic actions in recent years has increased the demand for good quality water to meet the growing needs. India is an agriculturally developed country and ~70 % of the total population depends on it. Thus, the agricultural over exploitation is an important factor for the declination of groundwater resources of the country[1,2,3]. India is the highest groundwater consumer in the world with annual extractions of 230 km[32]. The over exploitation and unjustified use of water as a result of rapid urbanization and population growth has also affected the ground water quality[4]. However, the groundwater is a finite and vulnerable resource which should be used properly, efficiently and ecologically for present and future generations. Therefore, assessment of potential groundwater recharge zone and proper management of ground water system is important for the water quality protection and increasing groundwater level. Poor knowledge, hidden nature and complex occurrence of this resource cause a hindrance to the efficient management of this important resource. The occurrence and movement of groundwater of an area is typically governed by the factors such as topography, lithology, geological structures, fracture density, aperture and connectivity, secondary porosity, groundwater table distribution, groundwater recharge, slope, drainage pattern, landforms, land use and land cover, climatic conditions, and the inter-relationships among these factors[5,6]. The same lithology forming different geomorphic units will have variable porosity and permeability thereby causing changes in the potential of groundwater. This is also true for same geomorphic units with variable lithology. However, groundwater supplies in the Indian subcontinent are difficult to quantify because of difficult hydrogeological formations, tectonic framework and considerable lithological and chronological variability complex, along with variations in hydroclimate and hydrochemical conditions[2]. Hence, identification and quantization of all these features are important in generating groundwater potential model of a particular area[7]. The conventional groundwater exploration methods such as field-based hydrogeological and geophysical resistivity surveys do not always account for the diverse factors that control the occurrence and movement of groundwater.

However, the image based remote sensing and GIS tools have brought a breakthrough in the groundwater resource management and land use studies. The main advantage of remote sensing is rapid acquisition of large and wide varieties data in both spatial and non-spatial domain over large and inaccessible areas even in areas where little geologic and/or cartographic information available[8-10]. Thus, the technique is ideally suited for regional studies[11-13]. Remote sensing data from satellite image offers an opportunity for improved observation and added systematic analysis of various factors affecting groundwater. Again GIS is one of the most important tools for integrating and analyzing spatial information and multidisciplinary database of any resource for planning of resource development environmental protection, scientific researchers and investigations. Investigation of remotely sensed data along with Survey of India Topographical and other relevantinformation's with essential ground check helps in generating the base line information for ground water targeting[11]. In the present study a part of the coastal area of the eastern margin of Orissa has been selected for qualitative assessment of ground water potential zones using remotely sensed data. Thus, the study indicates the need for integration of remote sensing and GIS to demarcate the groundwater potential zone.

Study Area: The study area is a part of a coastal tract situated on the eastern margin of India (figure 1). It lies between (Lat-19°10'-19°30'N and Long-84°45'-85°10'E) and covers an area of about 750 sq. km. The breadth of the coastal area varies from 8 to 12 km and extends for a length of around 70 km.

Geology and Geomorphology: Major parts of area are underlain by hard crystalline rocks of Archaean age. Sediments of Recent to sub-recent age occupy narrow discontinuous patches along the Rushikulya River and Bahuda River and also in the coastal tract. Sometimes laterite occurs as the capping over the older formations i.e. Khondalites. The Archaean crystalline of the Eastern Ghat Group comprises of Granite and Granite gneiss, Khondalite suite, Charnokite suite, Pegmatite and Quartz vein[14]. The arearepresents a unique physiographic setting with highly rugged mountainous region in the West, North, Central, and Northern part and with dense forest covered and gently undulating plains and isolated hillocks in the eastern part. The average altitude in the hilly terrain ranges between 300 m to 700 m above mean sea level, with the highest of 949 m.

The low-lying flood plains of the Rushikulya River and the intermontane valleys are characterized by gently undulating topography, scattered hills and mounds with an average altitude between 40 m to 140 m above mean sea level. The geomorphic units of the area are broadly classified[15] as: Structural Hills, Denudation Hills, Residual Hills, Inselberg, Linear Ridges, Pediment, Intermontane Valley, Pediment Inselberg Complex, Buried Pediplain (Shallow), Buried Pediplain, Buried Pediplain (Moderate), Buried Pediplain (Deep), Flood Plain, Coastal Plains and Sand Dunes.

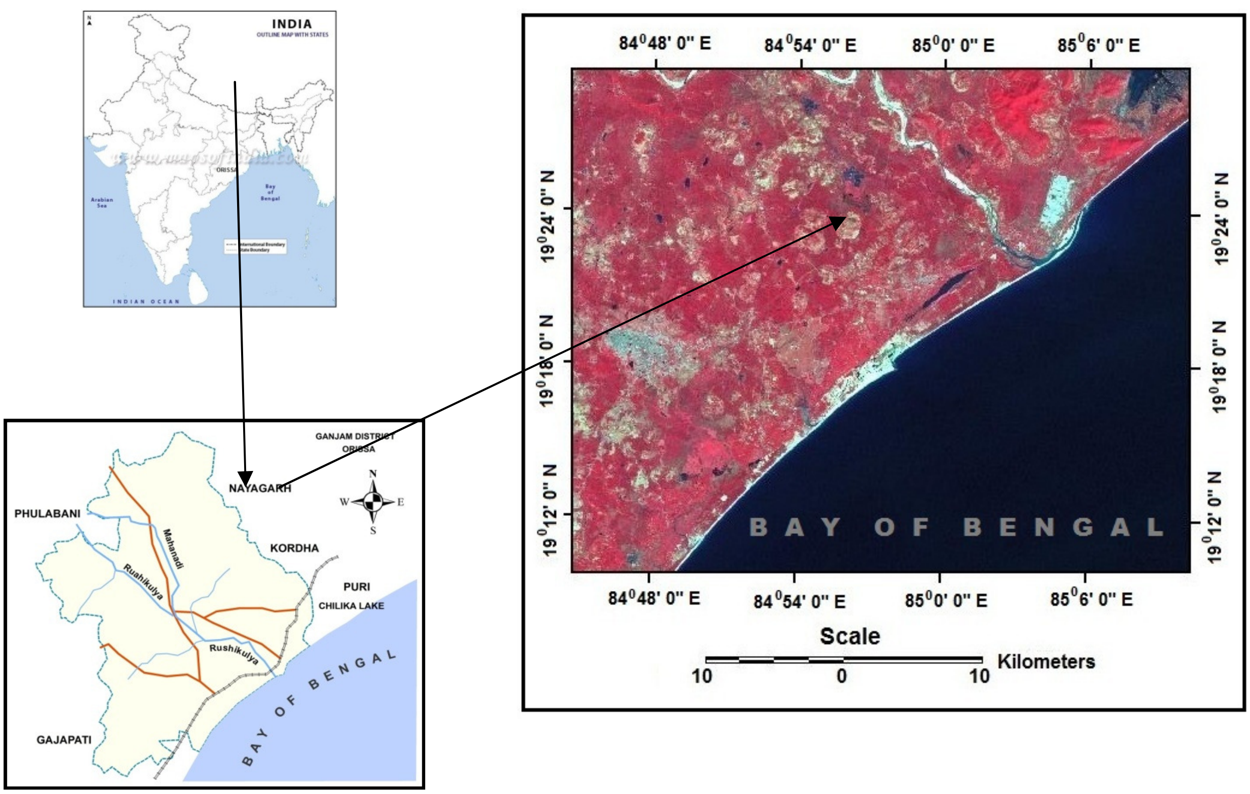

Figure-1
Location Map of the Study Area

Material and Methods

The Landsat TM data (Path-140/ Row-047) and IRS-IC LISS-III Digital data images (Path-106/ Row-058) and SRTM (DEM) are used in the present study. Survey of India (SOI) Toposheet (No. 74E/3, 74A/15, 74A/16) at 1:50,000 scales are also used. Geographic Information System and Image Processing (ARC VIEW, ARC GIS and ERDAS IMAGINE software) are used for analysis and mapping of the individual layers as described in the flow chart (figure 2). Initially, all the images were rectified using the SOI Toposheet. This was followed by processing the digital images using the various processing techniques, viz., enhancement, filtering, classification and other GIS processes[16]. Subsequently, selective field checking was carried out. All the accessible spatial data is accumulated in the digital form and properly registered to make sure the spatial component overlaps appropriately. Digitizing of all the maps and collateral data, followed by transformation and conversion from raster to vector, gridding, buffer analysis, box calculation, interpolation and other GIS processes were undertaken.

The influencing factors for groundwater are shown in table 1. The effects of each major and minor factor are assigned a weightage of 1.0 and 0.5 respectively. The cumulative weight of both major and minor are considered for calculating the relative rates. Again, the rate is further used to calculate the score of each influencing factor. The score for each influencing factor is calculated by the formula[17].

$$\left[\frac{(A+B)}{\sum(A+B)}\right] * 100 \qquad (1)$$

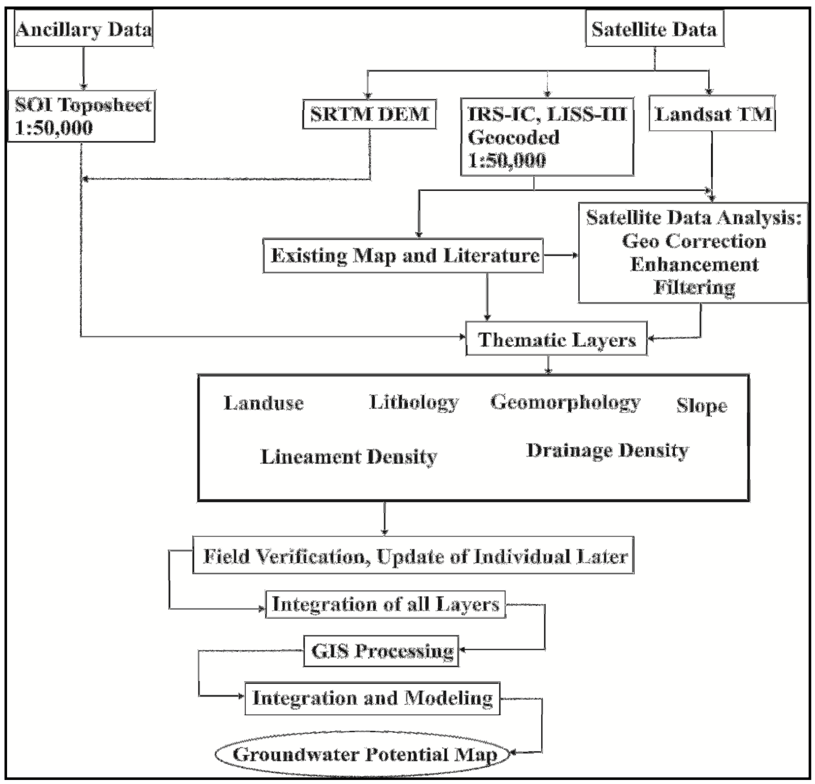

Figure-2
Flow Chart for Elucidating Groundwater Potential zones

Table-1
Influencing factor, relative rates and score for each groundwater potential factor

Factor	Major Effect (A)	Minor Effect (B)	Proposed Relative rates (A+B)	Proposed Score of each influencing factor
Landuse	1+1	0	3	22
Lithology	1+1	0	2	15
Geomorphology	1+1+1	0	3	25
Drainage Density	1	0.5	1.5	10
Lineament Density	1+1	0	2	13
Slope	1+1	0.5	2.5	15
			∑14	∑100

This stage produced the resulting layers such as Landuse, Geomorphology, Lithology, Drainage density, Lineament density, Slope etc. the entire input layers derived from above process and were processed to extract the spatial features which are relevant to the groundwater zone. This stage includes various analyses such as table analysis and classification, polygon classification and weight calculation. Polygons in each of the thematic layers were categorized depending on the recharge characteristics, and suitable weightage have been assigned to them (table 2). The values of the weightage are based on[18,19]. The final stage involved combining all thematic layers and has been classified into four groups such as Very Good, Good, Poor and Very Poor using the Jenks (Natural Break) classification method.

Results and Discussion

Generation of Thematic Maps: Primarily IRS IC is used for producing the thematic maps. Landsat TM is useful in delineating numerous lineaments from which lineament density map has been prepared. SRTM (DEM) is also used in preparing the slope map along with the SOI Toposheet. These three data are useful in delineating the groundwater potential zones validated with restricted field check.

Landuse Map: The diverse types of land-use in the study area classified into 11 classes (figure 3). Major part of the study area is covered by alluvium deposits. Most of the study area is covered by hard rock of Archaean age.

Lithology Map: Lithology is a very vital aspect in forecasting groundwater potential zones. Extraction of geological information from satellite data depends on the identification of different patterns on an image resulting from the spectral arrangement of different tones and textures. Depending on the rock reflectance properties, satellite images are used and they play important role in rock identifications. A lithology map is prepared using the IRS IC and Landsat TM Digital Data and simultaneously ground check verification is done in field (figure 4).

Table-2
Classification of Thematic Map Weighted factor influencing Groundwater potential zones and Feature Ranking

Sl. No.	Theme	Features	Weight
1	Landuse	Crop Land	25
		Mixed Forest, Water Bodies,	16
		Sea, Dense Forest, River, Sand, Wet Land,	10
		Laterite, Barren Land, Settlement	5
2	Geomorphology	Younger Coastal Plain, Young Flood Plain, Valley Fill,	25
		Water Logger area, Water Bodies, Lake	16
		Shallow Buried Pediplain, Sand dune, Beach, Spit	10
		Settlement, Residual Hill, Denudation Hill, Insitu Laterite, Transported Lateritic mound	5
3	Lithology	Beach Alluvium	15
		Lake, Water Bodies	12
		Khondalite	9
		Transported Laterite, Insitu Laterite, Pyroxene Granulite, Granitic Rocks, Unclassified crystalline Archaean, Settlement	5
4	Drainage density (Km/Km^2)	1.68-3.61	10
		0.92-1.68	7
		0.31-0.92	5
		0-0.31	2
5	Lineament density (Km/Km^2)	111.43-268	13
		56.76-111.43	9
		18.92-56.76	5
		0-18.92	1
6	Slope (degree)	14.79-39	15
		5.94-14.79	12
		1.22-5.94	8
		0-1.22	4

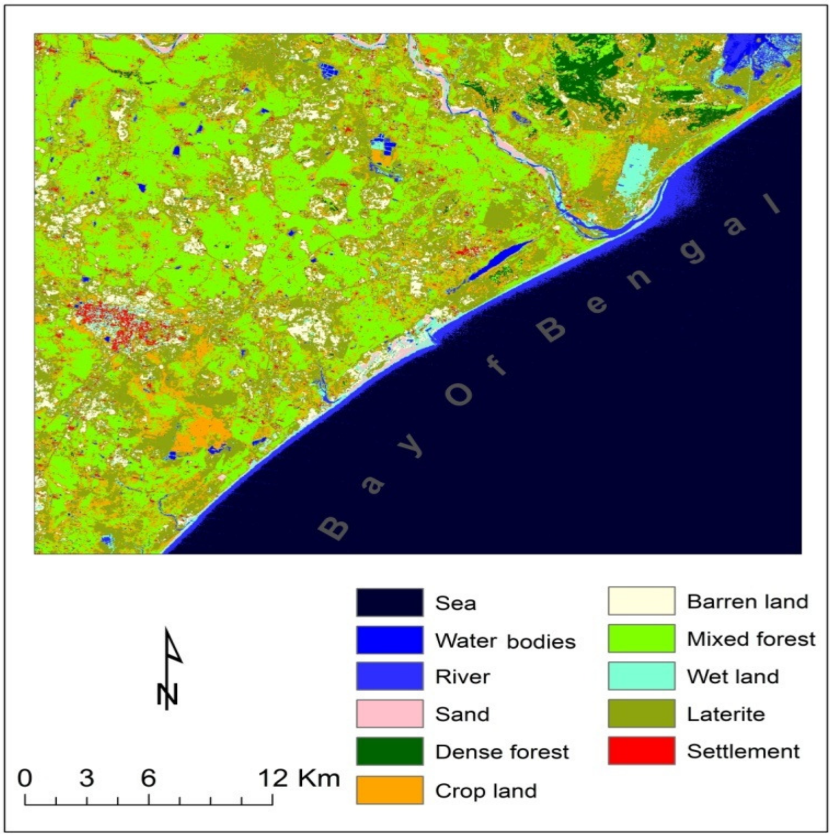

Figure-3
Landuse Map of the Study Area

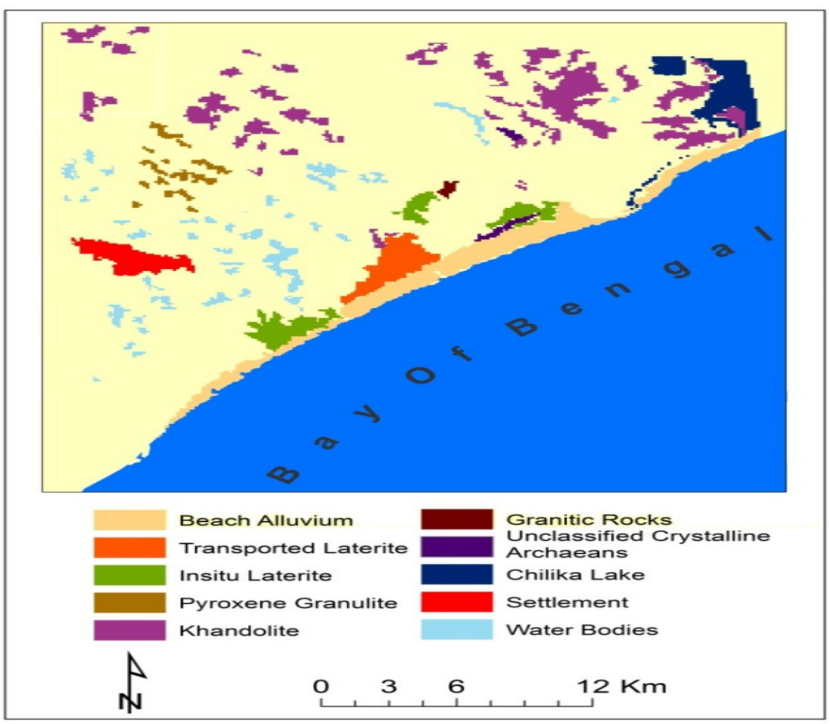

Figure-4
Lithology Map of the Study Area

Geomorphology Map: Geomorphological map is prepared based on visual understanding of Landsat TM and IRS LISS-III data on 50:000 scales and the geohydrology characters of the study area. Using the photogeologic elements [20], viz., tone, texture, shape, size, association etc. the various geomorphological units have been demarcated (figure5).

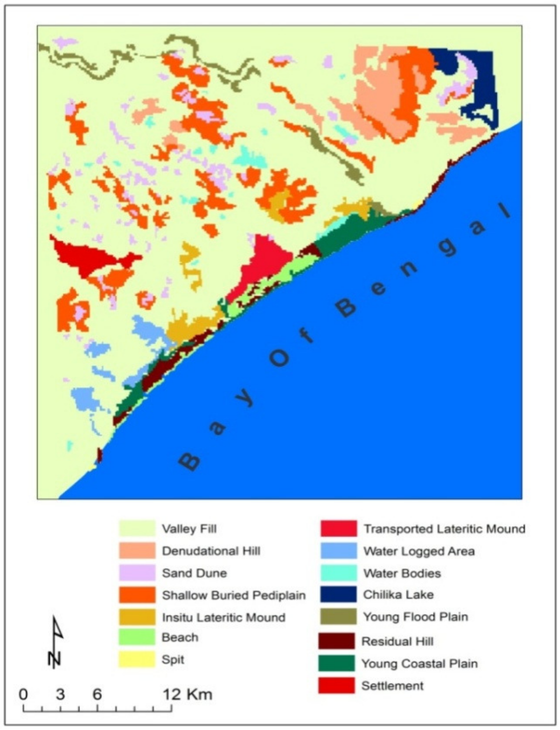

Figure-5
Geomorphology Map of the Study Area

Slope Map: Slope always plays a vitalcharacter in groundwater potential mapping. Using the SOI Toposheet and SRTM data of the area, a slope map of the area is arranged. The area, in general is very gentle slope. However, in the north-eastern part of the study area, there is an increase in slope. Despite of this very gentle slope, a slope map has been prepared according to the following class interval (figure 6).

Drainage Density Map: Adrainage density map is prepared on the basis of closeness of spacing of stream channels. It measures the total length of the stream segment of all orders per unit area. It is the inverse function of permeability. In this density map, the values have been assigned depending on the density of the drainage pattern and classified accordingly (figure7).

Lineament Density Map: These are the structurally controlled curvilinear or linear feature depending on their alignment. The express the surface as well as subsurface structural features. Depending on various structures like faults, lineaments etc., and different zones have been classified. Areas with high lineament density shows good groundwater potential The lineament density map shows a low density in most of the area comparatively to other parts of the study area (figure8).

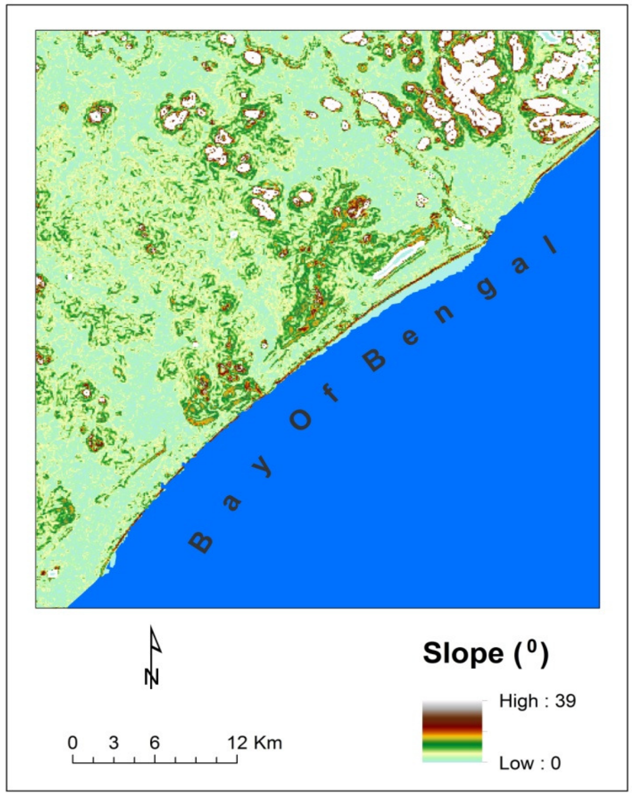

Figure-6
Slope Map of the Study Area

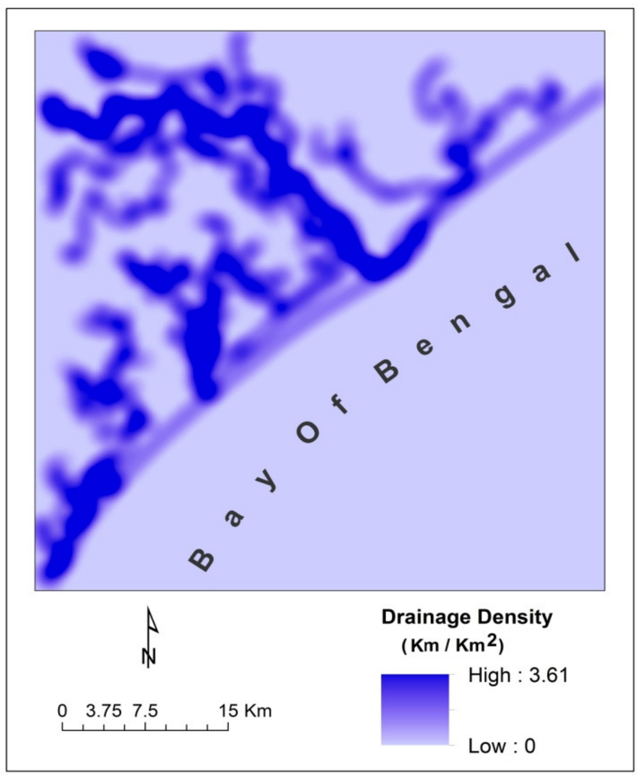

Figure-7
Drainage density Map of the Study Area

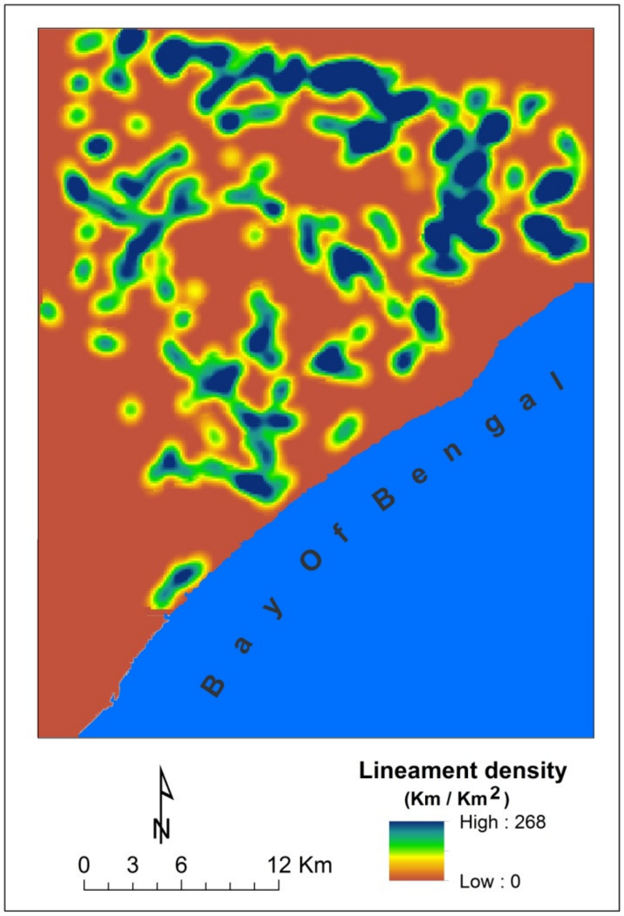

Figure-8
Lineament density Map of the Study Area

Depending on the groundwater potentiality, each class of the main six thematic layers (landuse, geomorphology, lithology, slope, drainage density, lineament density) are qualitatively placed into one of the following categories viz., i. Very Good (13.96-20), ii. Good (11.98-13.96), iii. Poor (9.95-1198), iv. Very Poor (6-9.95). All the thematic maps have been integrated in GIS. A final Groundwater Potential Map (figure 9) is prepared based on the above technique.

Conclusion

Groundwater is one of the precious natural resource. Due to rapid growth in population and urbanization the demand of potential groundwater zone identification increases in the country as well as throughout the world. The collective use of the remote sensing and GIS based potential zone analysis has brought a new path in this field. Thus, the combination of remote sensing, GIS and MIF techniques has been employed in the present study and proved to be a powerful tool to understand the behavior of groundwater in anyarea. The weighted indexoverlay model has also been found to be very useful in the mapping of groundwater prospective zones. In this study area, four categories of groundwater potential zones have been elucidated based on remote sensing and GIS technique. The groundwater potential map near the coast line and in some parts of the north-eastern and north-western region shows excellent potential whereas greater part of the area shows good groundwater potential. Poor groundwater potentials are confined mostly in the hilly terrain and in settlement area. Thus, the study gives an overview of the groundwater potentiality of the area and a quantitative amount of groundwater potential zones can be carried out if geophysical resistivity data is available. Thus, the results will be useful in better organization and supervision of groundwater resources of the present area.

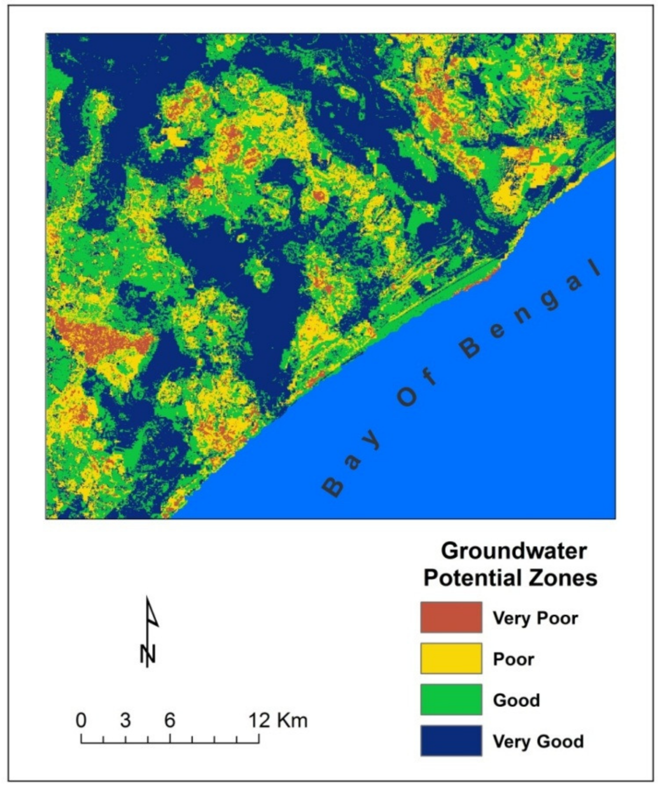

Figure-9
Groundwater Potential zone Map of the Study Area

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