Research Journal of Recent Sciences ISSN 2277-2502
Vol. **1(9),** 59-66, September **(2012)** *Res.J.Recent Sci.*

Delineation of Groundwater Potential Zones using Satellite Remote Sensing and Geographic Information System Techniques: A Case study from Ganjam district, Orissa, India

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Available online at: www.isca.in
Received 5th July 2012, revised 18th July 2012, accepted 19th July 2012

Abstract

Water plays a vital role in the development of activities in an area. The surface water resources are inadequate to fulfill the water demand. Productivity through groundwater is quite high as compared to surface water, but groundwater resources have not yet been properly exploited. Keeping this view, the present study attempts to select and delineate various groundwater potential zones for the assessment of groundwater availability in the coastal part of Ganjam district, Orissa using remote sensing and GIS technique. Satellite IRS-IC LISS III, Landsat TM digital and SRTM data have been used in the present study to prepare various thematic maps, viz., geomorphological, geological, slope, drainage density, lineament density map. On the basis of relative contribution of each of these maps towards groundwater potential, the weight of each thematic map has been selected. Further, within each thematic map ranking has been made for each of the features. All the thematic maps have been registered with one another through ground control points and integrated step by step using the normalized aggregation method in GIS for computing groundwater potential index. On the basis of this final weight and ranking, the ground water potential zones have been delineated. Thus from the present study it is observed that an integrated approach involving remote sensing and GIS technique can be successfully used in identifying potential groundwater zones in the study area. Five categories of groundwater potential zones, viz., excellent, very good, good, moderate and poor have been demarcated. Major portions of the study area has "good" as well as "Moderate" prospect while a few scattered areas have poor prospect. The excellent potential areas are mainly concentrated along the shore line.

Key words: Groundwater, satellite remote sensing, geographic information system.

Introduction

Water is one of the most essential commodities for mankind and the largest available source of fresh water lays underground[1]. It is one of the most significant natural resources which support both human needs and economic development. Tremendous increase in the agricultural, industrial and domestic activities in recent years has increased the demand for good quality water to meet the growing needs. Groundwater is mostly preferred to meet this growing demand because of its lower level of contamination and wider distribution.

The occurrence of groundwater at any place on the earth is not a matter of chance but a consequence of the interaction of the climatic, geological, hydrological, physiographical and ecological factors. Groundwater exploration operation is essentially a hydrogeological and geophysical inference operation and is dependent on the correct interpretation of the hydrological indicators and evidences[2].

The movement of groundwater is controlled mainly by porosity and permeability of the surface and underlying lithology. 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. The surface hydrological features like topography, geomorphology, drainage, surface water bodies, etc. play important role in groundwater replenishment. High relief and steep slopes impart higher runoff, while the topographical depressions help in an increased infiltration. An area of high drainage density also increases surface runoff compared to a low drainage density area. Surface water bodies like rivers, ponds, etc. can act as a recharge zones enhancing the groundwater potential in the vicinity. Hence, identification and quantization of these features are important in generating groundwater potential model of a particular area[3].

Remote sensing is an excellent tool for hydrologists and geologists in understanding the "perplexing" problems of groundwater exploration. In recent years, Satellite remote sensing data has been widely used in locating groundwater potential zones[4, 5]. Satellite remote sensing data is not only cost-effective, reliable and timely but also meets the essential requirements of data in the geographical Information System (GIS) domain, which are "current, sufficiently accurate, comprehensive and available to a uniform standard"[6]. Integration of the information on the controlling parameters is best achieved through GIS which is an effective tool for storage, management and retrieval of spatial and non-spatial data as well as for integration and analysis of this information for meaningful solutions. The technique of integration of remote sensing and GIS has proved to be extremely useful for groundwater studies[7-9].

Satellite remote sensing provides an opportunity for better observation and more systematic analysis of various geomorphic units/landforms/lineaments due to the synoptic and multi-spectral coverage of a terrain. Investigation of remotely sensed data for drainage map, geological, geomorphological and lineament characteristics of terrain in an integrated way facilities effective evaluation of ground water potential zones. Similar attempts have been made in the generation of different thematic maps for the delineation of groundwater potential zones in different parts of the country[10]. Analysis of remotely sensed data along with Survey of India Topographical and collateral information with necessary ground check helps in generating the base line information for ground water targeting. In the present study a part of the coastal tract of the eastern margin of the Ganjam district, Orissa has been selected for qualitative evaluation of ground water potential zones using remotely sensed data.

Study Area: The study area is a part of a coastal tract situated on the eastern margin of Ganjam district, Orissa (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 width of the coastal tract varies from 8 to 12 km and extends for a length of about 70 km. The area is bounded by three natural water bodies, the Chilka Lake, the largest brackish water lagoon in Asia, on the north, Bahuda river estuary on the south and the Bay of Bengal on the east.

Geology: Major parts of Ganjam district 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, Pegmatites and Quartz vein[11].

Geomorphology: Ganjam district presents a unique physiographic setting with highly rugged mountainous region in the West, North, Central, 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[12] 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.

Hydrogeology: The contrasting water bearing properties of different geological formations usually play an important role in the occurrence and movement of groundwater. The crystalline rocks of Archaean age occupy 93% of the total geographical areas. The narrow discontinuous patches of recent to sub recent alluvium along the major river courses occupy about 376 sq.km area in the district. Hydrogeologically the weathered and fractured zones of the crystalline and the porous alluvium and coastal deposits constitute the main repository of ground water in the district. Depending upon the water yielding properties of various formations, the district can be broadly grouped into three distinct hydrogeological units viz. Consolidated Formations, Semi consolidated Formations and Unconsolidated Formations[13].

Structure: Ganjam district forms a part of the Eastern Ghats. These rocks have undergone polyphase deformation revealed by structural features like foliation, joints, folds, faults etc. Gneissosity and Foliation are well developed in khondalites and granitic rocks, crude foliations are also common in Charnockite[14] recognized 2 major periods of folding: (a) The earlier folds (both normal and isoclinal) about ENE-WSW and NE-SW axial hands and (b) later cross folds about N-W, NNW-SSE axes. The dominant NE-SW foliation observed is the result of regional NE-SW folding. The structural analysis utilizing Landsat imageries revealed at least 5 major tectonic events represented by NE-SW, ENE-WSW, N-W, NW-SE and NNE-SSW tectonic patterns in chronological order[15]. The major NE-SW, NE-SE, N-S and E-W lineaments are closely related to the fold movements.

Material and Methods

Data Collection: The landsat TM data (Path-140/ Row-047), IRS-IC LISS-III Digital data images (Path-106/ Row-058) and SRTM (DEM) have been used in the present study. Survey of India (SOI) Toposheet (No. 74E/3, 74A/15, 74A/16) at 1:50,000 scales have also been used. Secondary data on hydrology and ground water well data have been collected from Central Ground Water Board, Bhubaneswar and from the field to support mapping. Geographic Information System and Image Processing (ARC VIEW, ARC GIS and ERDAS IMAGINE software) have been used for analysis and mapping of the individual layers as described in the flow chart (figure 2).

Satellite Data Analysis: The main task in this stage was to carry out analysis and interpretation of satellite data, in order to produce thematic maps, such as lithology, structural and land use maps. 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.

Spatial Database Building: The main task was to bring all the appropriate data and other collateral data together into a GIS database. All the available spatial data was assembled in the digital form and properly registered to make sure the spatial component overlaps correctly. 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. This stage produced derived layers such as Geomorphology, Drainage, Drainage density, Lithology, Lineament density, Surface water body, Slope etc.

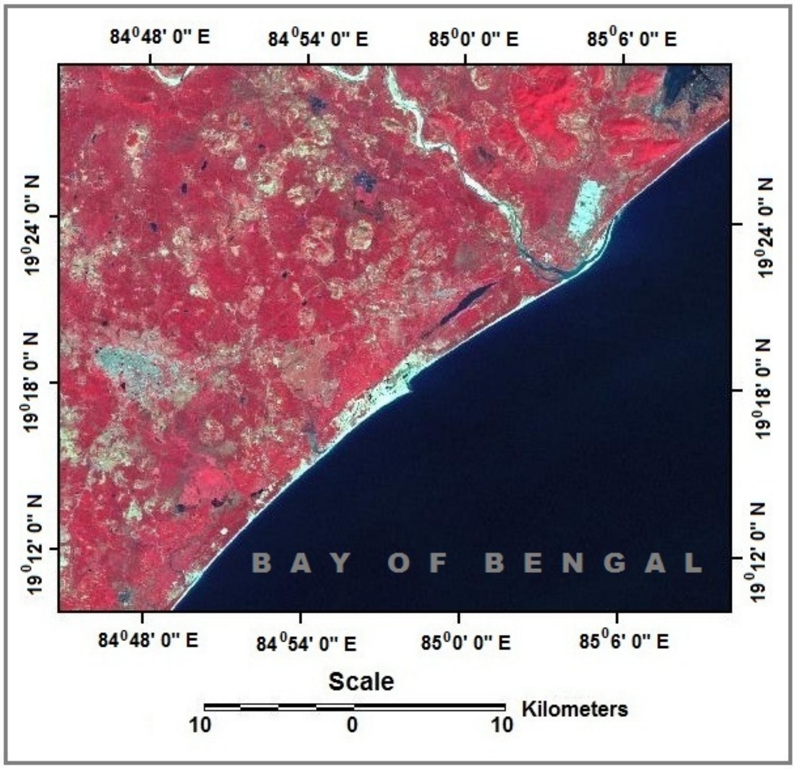


Figure-1
Satellite Map of Study Area

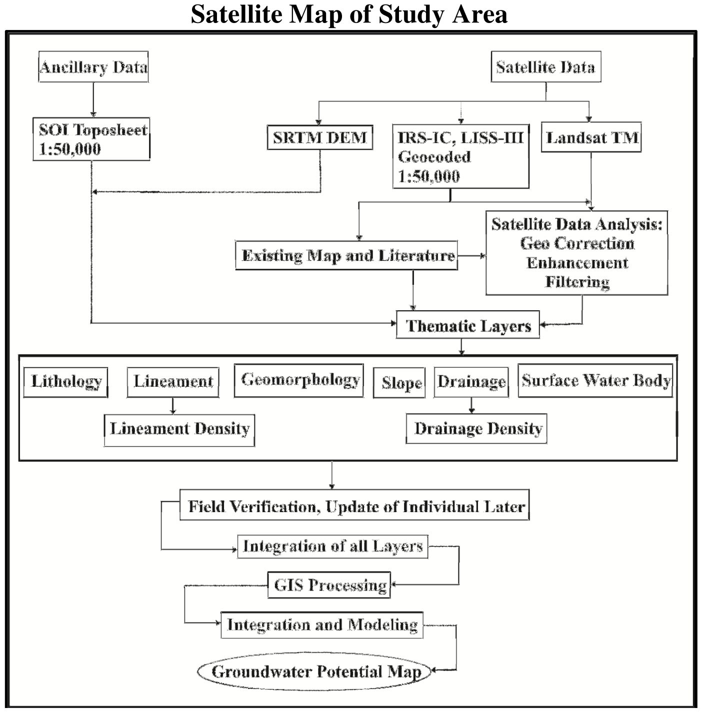


Figure-2
Flow Chart

Spatial Data Analysis: In this stage, the entire input layers derived from stage 2 and 3 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 1). The values of the weightage are based on[17, 18].

Table-1
Thematic Map Weight and Feature Ranking

Theme	Weight	Features	Rank
Geomorphology	6	Younger Coastal Plain	10
		Young Flood Plain	9
		Valley Fill	8
		Shallow Buried Pediplain	7
		Insitu Laterite	5
		Transported Laterite	4
		Residual Hill	2
		Denudation Hill	2
Lithology	5	Beach Alluvium	9
		Older Alluvium	8
		Insitu Laterite	5
		Transported Laterite	4
		Unclassified Crystalline Rocks	2
Drainage density (per km)	4	<0.75	10
		0.75-1.50	9
		1.50-2.25	7
		2.25-3.0	6
		3.00-3.5	4
		>3.5	2
Lineament density	3	>110	8
		50-110	6
		20-50	4
		<20	3
Slope (%)	2	1.714-3.076	10
		3.076-4.438	9
		4.438-5.8	7
		5.8-7.62	5
		7.62-8.524	3
Surface water body (area in radii in m)	1	<90	6
		90-900	3
		>900	0

Satellite Data Interpretation: The final stage involved combining all thematic layers using the method that are modified from DRASTIC model. This model is used to assess ground water pollution vulnerability by Environmental Protection Agency of the United State of America[19]. The output has been classified into five groups such as very high, high, moderate, low and very low using the quantile classification method[16]. Groundwater potential index (GWPI) in the present study has been determined by the formula[20] as shown below:

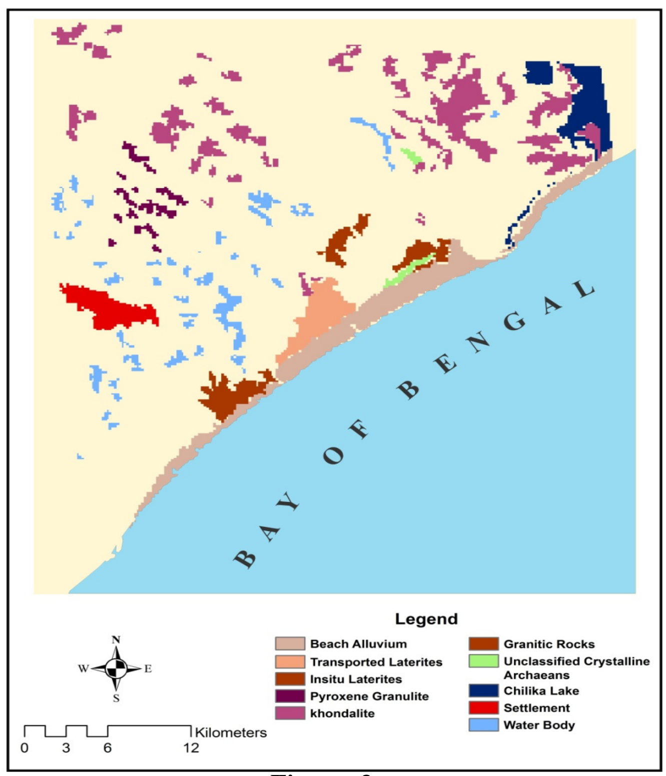
GWPI = $(G_g{}^wG_g{}^r + D_g{}^wD_g{}^r + D_d{}^wD_d{}^r + L_h{}^wL_h{}^r + L_t{}^wL_t{}^r + L_d{}^wL_d{}^r + W_w{}^wW_w{}^r + S_s{}^wS_s{}^r)$/ Total Weight.

Where: G_g: geomorphology, D_g: drainage, D_d: drainage density, L_h: lithology, L_t: lineament, L_d: lineament density, W_w: surface water body, S_s: slope. With "w" representing weight of a theme and "r" the rank of a feature in the theme. GWPI is a dimensionless quantity that helps in indexing the probable groundwater potential zones in an area. It is classified as Excellent GP (>7.1), Very good GP (5.8-7.1), Good GP (4.4-5.8), Moderate GP (3.0-4.4) and Poor GP (<3.0).

Results and Discussions

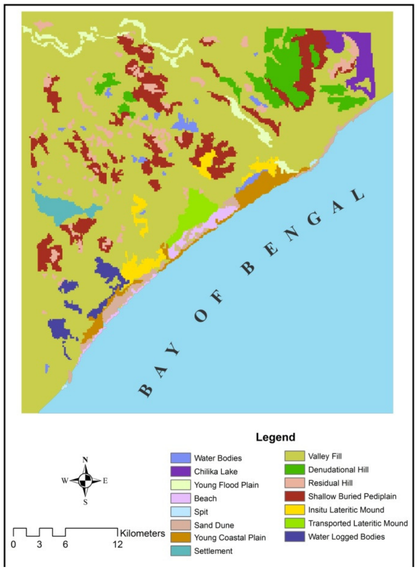
Generation of Thematic Maps: Primarily IRS IC is used for generating the thematic maps. Landsat TM is useful in demarcating the water bodies and also in identifying numerous lineaments. SRTM (DEM) is also used in preparing the slope map along with the SOI toposheet. These three data are useful in delineating the groundwater potential zones corroborated with limited field check.

Lithology Map: Lithology is a very important aspect in predicting 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 3).



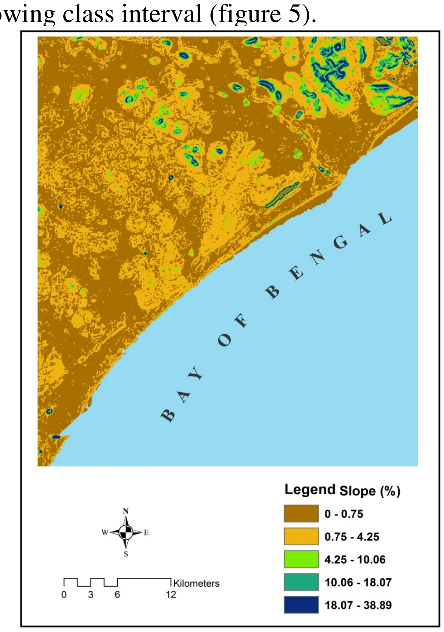
Figure–3
Geology Map of the Study Area

Geomorphology Map: Geomorphological map is prepared based on visual interpretation of Landsat TM and IRS LISS-III data on 50:000 scales and the geohydrology characters of the study area. Using the photogeologic elements[21], viz., tone, texture, shape, size, association etc. the various geomorphological units have been demarcated (figure 4).



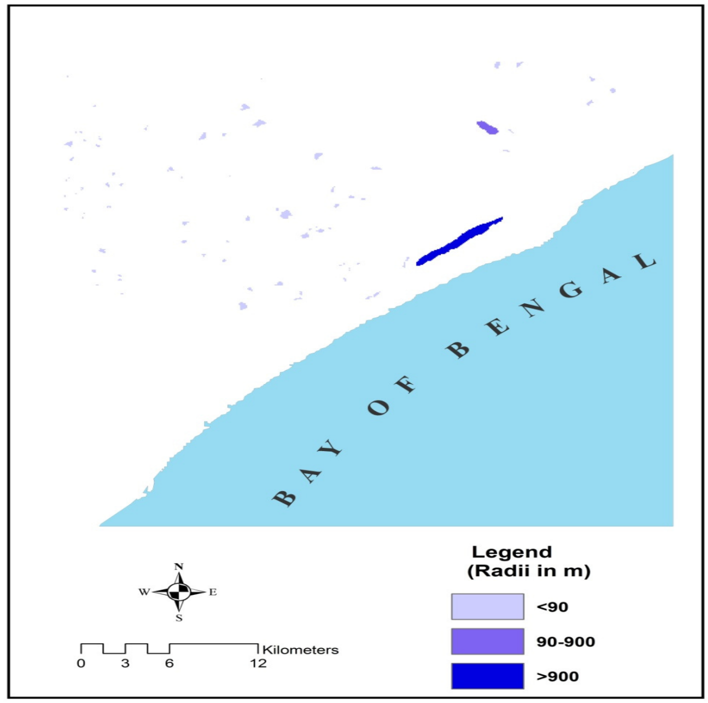
Figure–4
Geomorphology Map of the Study Area

Slope Map: Slope always plays a crucial role in groundwater potential mapping. Using the SOI Toposheet and SRTM data of the area, a slope map of the area is prepared. 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 5).



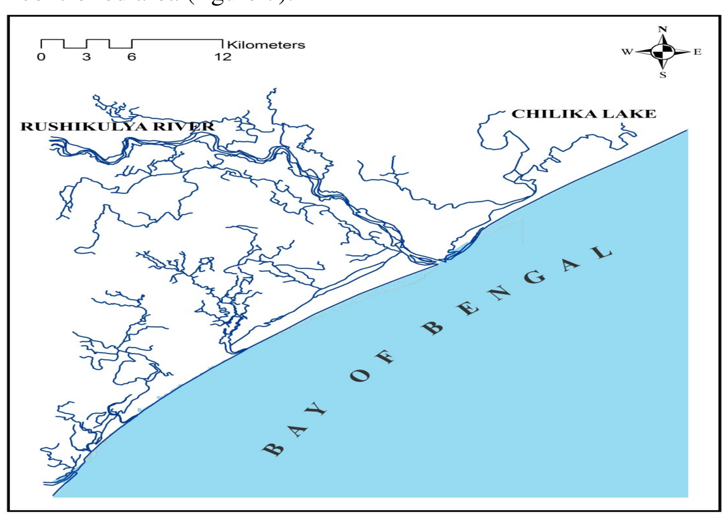
Figure–5
Slope Map of the Study Area

Surface Water Body Map: Surface water body map is prepared from Landsat TM Satellite data. The supervised maximum likelihood classification[22] is used to delineate the surface water body present in different parts of the area. The study area is covered by many water logged bodies, ponds, lakes and rivers (figure 6).



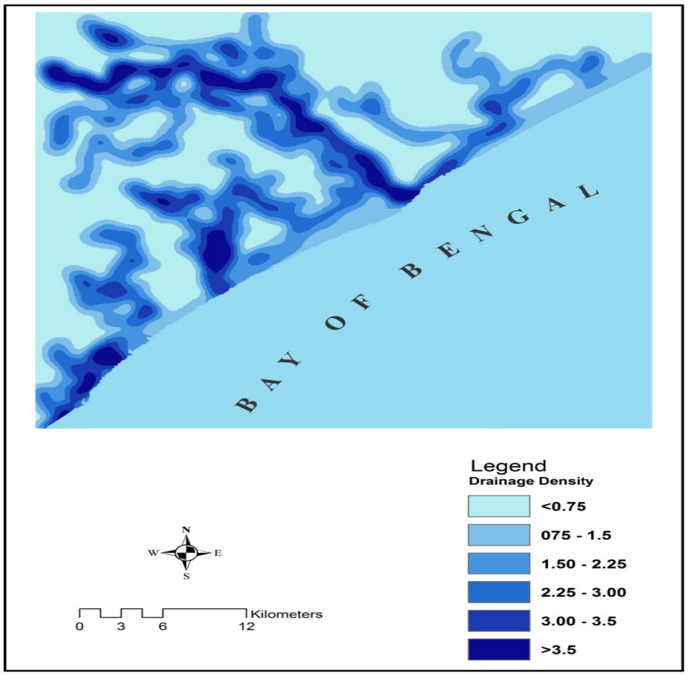
Figure–6
Surface Water Body Map of the Study Area

Drainage Map: A surface drainage map is prepared from SOI Toposheet at 1:50,000 scale and satellite data. The study area is covered by Rushikulya and Bahuda River. Mostly the drainage pattern is dendritic in nature but locally it exhibits structurally controlled area (figure 7).



Figure–7
Drainage Map of the Study Area

Drainage Density Map: From the above Drainage map, a density map is generated. In this density map, the values have been assigned depending on the density of the drainage pattern (figure 8).

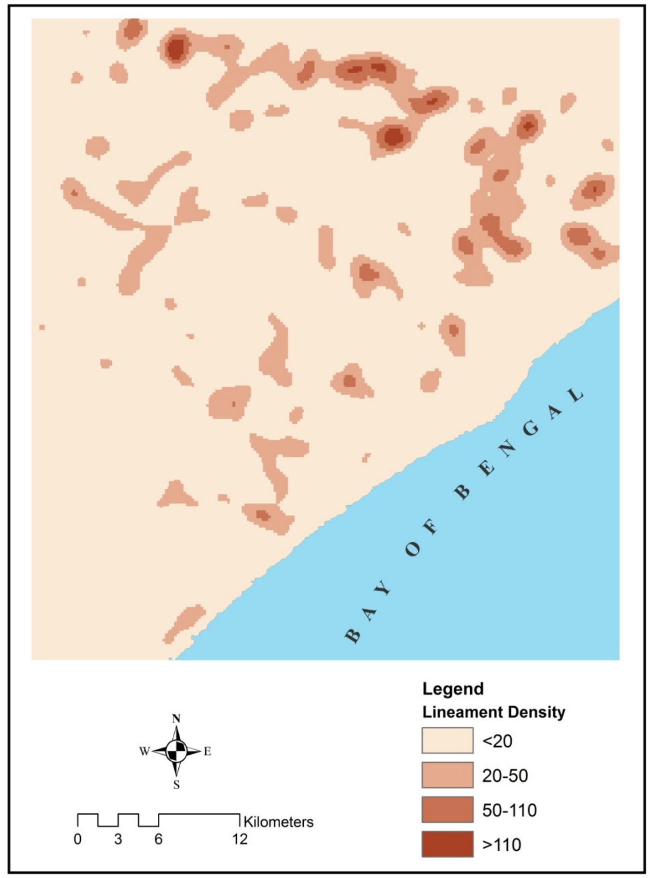


Figure–8
Drainage Density Map of the Study Area

Lineament Map: A surface lineament map is prepared from the SRTM DEM data. The study area exhibits a structurally controlled region. The areas have much high altitude hilly structures which are linearly aligned (figure 9).

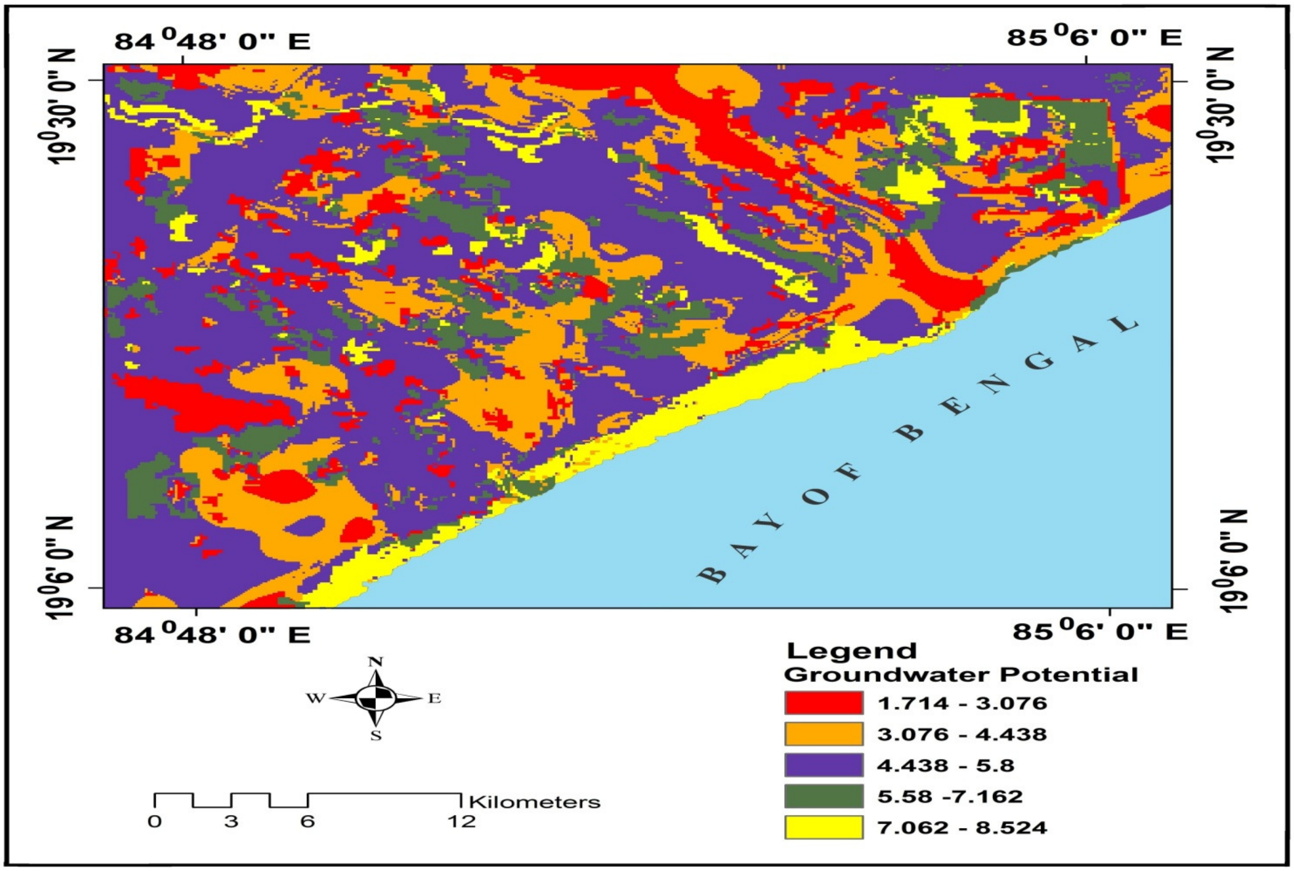
Figure–9
Lineament Map of the Study Area

Lineament Density Map: From the above Lineament map, a lineament density map is generated. The lineament density map shows a low density in most of the area comparatively to other parts of the study area (figure 10).



Figure–10
Lineament Density Map of the Study Area

Integration of Thematic Layers and Modeling through GIS: Weighted Index Overlay Model: Depending on the groundwater potentiality, each class of the main eight thematic layers (geomorphology, lithology, slope, drainage density, lineament density and surface water body) are qualitatively placed into one of the following categories viz., i. Excellent, ii. Very good, iii. Good, iv. Moderate, v. Poor. Suitable weightage on a scale of 'Six' has been given to each class of a particular thematic layer based on their contribution towards ground water potentiality. The rank of each thematic map is scaled by the weight of that theme. All the thematic maps are then registered with one another through ground control points and integrated step by step using normalized aggregation method in GIS for computing groundwater potential Index of each feature. The weight assigned to different classes of all the thematic layers and rank of each features are given in table 1. All the thematic maps have been integrated using GWPI formula in GIS. A final groundwater potential map (figure 11) is prepared based on the above technique.



Figure–11
Groundwater Potential Map of the Study Area

In the present study, the groundwater potential zones have been categorized into five types viz., excellent, very good, good, moderate and poor. Table 2 gives the upper and lower limits of the weights considered for demarcating these five types of groundwater prospective areas.

Table-2
Integrated Weight Range for Various Groundwater Potential Zones

Groundwater Category	Lower and Upper Weight Table
Excellent	>7.1
Very Good	5.8-7.1
Good	4.4-5.8
Moderate	3.0-4.4
Poor	<3.0

Conclusion

We established successfully in this study that remote sensing and GIS can provide the appropriate platform for convergent analysis of large volume of multi-disciplinary data and decision making for groundwater studies. These techniques have been successfully used and demonstrated for evaluation of groundwater potentiality of the area. The Weighted index overlay model has been found very useful in the mapping of groundwater prospective zones. Mainly IRS IC was used for preparing the thematic maps viz., lithology, geomorphology, drainage. Landsat TM was useful in demarcating the water bodies and also in identifying numerous lineaments. SRTM was also used in preparing DEM from which slope map is prepared. In this study area, five categories of groundwater potential zones have been delineated based on remote sensing and GIS technique. The five categories are: excellent, very good, good, moderate and poor. The groundwater potential map (figure 11) 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. The quantitative amount of groundwater potential zones can be carried out if geophysical resistivity data is available.

Acknowledgement

We would like to thank the Editor and Reviewers for comments and suggestions that helped us to improve the manuscript. The first author AB thanks Mr. Sudipta Sarkar, Research Fellow (NOCS, UK) and Mr. Anirvan Choudhury, Hydrogeologist, CGWB, Bhubaneswar, Orissa for their kind support and encouragement in this work.

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