

Research Article

Groundwater Prospect Evaluation in the Interfluves of the Rivers Brahmaputra and Kolong, Assam Using Remote Sensing and GIS Techniques

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Abstract Groundwater prospect evaluation in the interfluves of the Rivers Brahmaputra and Kolong, Assam has been studied by considering the geomorphology, lithology, drainage pattern and drainage density, slope and land use/land cover (LU/LC) of the area. The major geomorphic, lithologic and land use/land cover units of the area have been identified and delineated from satellite imageries. Slope map and drainage map of the study area were generated from the SOI toposheets as well as from the satellite imageries. The drainage density map was generated from drainage network of the interfluves using GIS. To demarcate the different groundwater-prospect zones of the study area, all the thematic layers are integrated by raster index overlay technique in GIS. Weights are assigned to different thematic layers and ranks are assigned to different categories/classes of the thematic layers for the overlay analysis in GIS. The resultant map was classified into groundwater prospect zones as very good, good, moderate and poor. The groundwater prospect zone map indicates that the most part of the area is having well to very good groundwater prospect zones.

Keywords *Drainage density; Hydrogeomorphology; Index overlay; Prospect zone*

1. Introduction

Groundwater is an essential component of the environment and economy. It sustains the flow in our rivers and plays an important role in maintaining the fragile ecosystems (Sedhuraman et al., 2014). Occurrence and movement of groundwater in an area is governed by several factors such as geomorphology, lithology, drainage pattern and drainage density, slope, land use/land cover (LU/LC) and the interrelationship among these factors. Geomorphic settings of an area plays an increasingly important role in hydrogeological studies as it can provide valuable supplementary information regarding groundwater recharge and their occurrence and distribution, thus initiating a recent trend in hydrogeomorphological studies (Goswami et al., 2002). The advent of remote sensing has opened up new vistas in groundwater prospect evaluation, exploration and management (Mondal, 2008). Remotely sensed data and GIS techniques are vital tools for delineation and evaluation of groundwater potential zones of an area (Krishnamurthy and Srinivas, 1995; Khan and Moharan, 2002; Sankar, 2002). Different geomorphic units that characterize the landform of the drainage basin contribute significantly to the recharge capability and groundwater prospect of specific areas of drainage basins. Groundwater prospect zone maps form a good database and help the hydrogeologists as well as the concerned departments in identifying potential around the problem

areas. These groundwater prospect zone maps may serve as helpful tools to the field geologists to quickly identify the prospective groundwater zones for conducting site specific investigations as well as to select the sites for planning recharge structures to improve sustainability of drinking water sources, wherever required. As a result, groundwater development and management in the study area becomes more efficient and easier.

In this study an attempt has been made to demarcate the groundwater prospect zones in the study area by considering the important geomorphic as well as hydrogeologic features of the area.

1.1. Study Area

The study area represents a part of Nagaon and Morigaon districts of Assam falling between longitudes 91°57'6"E and 93°4'46"E and latitudes 26°9'21"N and 26°37'17"N. It lies in the Survey of India Toposheets No. 78N/15, 78N/16, 83B/3, 83B/4, 83B/6, 83B/7, 83B/8, 83B/10, 83B/11, 83B/12, 83B/14, 83B/15, 83F/2 on scale 1:50,000 covering an area of around 2,100 sq. km. The study area, bounded by the Rivers Brahmaputra and Kolong, is situated on the southern bank of the River Brahmaputra and is endowed with fertile land and abundant rainfall during monsoon. Precipitation is the main source of groundwater recharge in the area. Physiographically the area represents almost a flat terrain but to some extent it is undulatory at western, south-western and eastern part of the area. The area is drained by a number of tributaries of the river Brahmaputra flowing from east to west. River Kolong, which is an anabranch of the River Brahmaputra, is the main distributary channel of Brahmaputra. Total length of the Kolong River is approximately 250 km. Other major rivers in the area are the Sonai, Kopili, Diju, Misa, Haria and Jamuna.

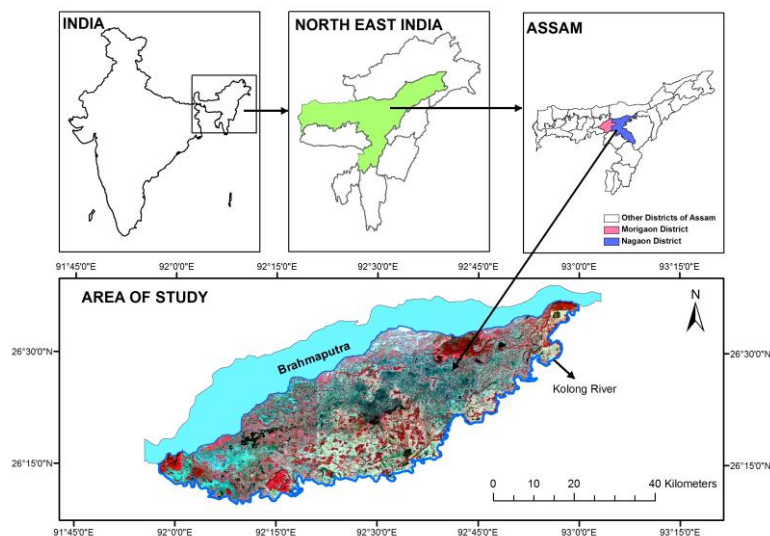


Figure 1: Location map of the study area

2. Database and Methodology

Since satellite data provides an opportunity for better observation and more systematic analysis of various resource parameters and other related features due to the synoptic and multi-spectral coverage of a terrain, IRS-IC, LISS III (December, 2005) and PAN image (13th March, 2007) data have been used to map the spatial distribution of various resource parameters which are relevant for finding groundwater prospect zones in the interfluves.

The methodology is divided into two parts. The first part deals with the delineation of hydrogeomorphic units considering parameters influencing the hydrogeological properties. It consists of generation of individual thematic layers (Figure 2) and integration of various thematic layers in GIS by raster index overlay technique to generate the groundwater prospect zones map. The second part deals with the evaluation of hydrogeomorphic and geologic units based on hydrogeological characteristics of the controlling parameters.

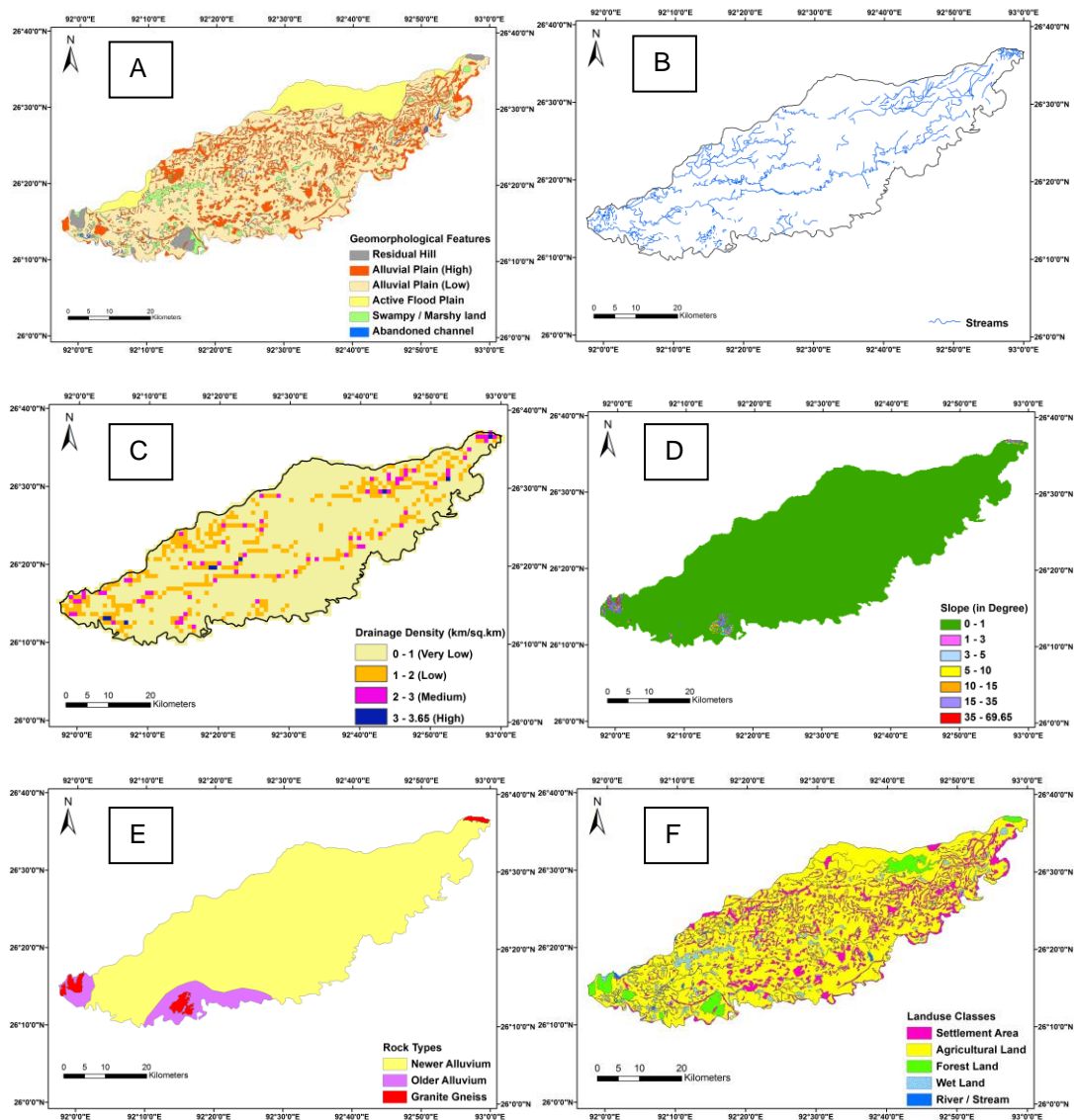


Figure 2: (A) Geomorphological Map; (B) Drainage Map; (C) Drainage Density Map; (D) Slope Map; (E) Lithology Map; (F) Land use/Land cover Map

The digitized vector maps pertaining to chosen parameters, viz. geomorphology, lithology, slope, drainage density and land use/land cover were converted to raster data of 10 x 10 m grid cell size. A simple mathematical model called Weighted Index overlay analysis is used for a combined analysis of multiparameter in raster format to generate the groundwater prospect map. Each raster map of these parameters was assigned respective theme weight and their class ranks.

Each thematic map was assigned a weight depending on its influence on the movement and storage of groundwater (Kumar et al. 2007; Avatar et al. 2010; Preeja et al. 2011; Narendra et al. 2013). Relative ranking of each thematic unit in a theme were assigned as knowledge based hierarchy using Spatial Analyst tool of ArcGIS. The Weights and Ranks were assigned to thematic maps and thematic units on a 10 point scale based on their influence on the groundwater recharge process (Table 1).

Table 1: Assigned rank and weight for different features of various thematic layers

Theme Unit	Feature/category	Rank	Weight
Geomorphology	Residual Hill	1	10
	Alluvial Plain (High)	3	
	Alluvial Plain (Low)	4	
	Active Flood Plain	4	
	Swampy/Marshy Land	1	
	Abandoned Channel	4	
Lithology	Younger Alluvium	3	8
	Older Alluvium	2	
	Granite	1	
Drainage Density	Very Low	5	7
	Low	4	
	Moderate	3	
	High	2	
	Very High	1	
Slope	Nearly Level (0 – 1)	7	10
	Very Gentle (1 – 3)	6	
	Gentle (3 – 5)	5	
	Moderate (5 – 10)	4	
	Strong (10 – 15)	3	
	Steep (15 – 35)	2	
	Very Steep (>35)	1	
Land use/ Land Cover	Settlement area	1	5
	Agricultural Land area	3	
	Forest Land	2	
	Wet Lands	3	
	Streams/ Rivers	3	

These five thematic raster layers were integrated by Raster Index Overlay technique in GIS to create a groundwater prospect zone map for drinking purpose. In the index overlay technique, the values were calculated using the following formula:

$$S = \sum S_{ij} W_i / \sum W_i \dots (1)$$

Where, S = Weighted score of a pixel

W_i = Weight for the ith output map

S_{ij} = Rank of the jth class of the ith map

Values of j depend on the class occurring at the current location.

In the groundwater prospect zone map (Figure 4), four zones viz. poor, moderate, good and very good, within the study area were delineated.

3. Results and Discussion

The various terrain parameters considered in the present study, i.e., geomorphology, lithology, slope, drainage density, land use/land cover etc. are believed to be the controlling factor of the precipitation, flow and storage of water in the area and, hence, influence the groundwater storage potential of the area. A drainage map of the area gives an idea about the permeability of rocks and also gives an indication of the yield of the basin (Wisler and Brater, 1959). Therefore, a drainage map of the study area was generated from the digitized base map as well as satellite imagery (Figure 2b). In the study area it has been observed that no systematic drainage pattern has been developed on sand surface. Most of rivers/streams present in the area are meandering in nature that develops in flood plains due to sluggish river flow. A network of streams up to the 4th order has been identified; the 2nd to 3rd order being the dominant. The hydrogeological significance of these influencing parameters is discussed on the basis of their response to the groundwater occurrence and contribution to the recharge phenomena.

3.1. Geomorphology vs. Groundwater Prospects

The study area, comprised of the interfluvies between the Rivers Brahmaputra and Kolong, can broadly be represented by a number of distinct geomorphic units' viz., residual hills, alluvial plains, active flood plains, swamps/marshy lands and abandoned channels etc (Figure 2a). Each of these units, being characterised by distinctive hydrogeologic features, also forms distinct hydrogeological unit.

Residual Hills: The residual hills of the area are highly fractured and jointed and their elevations vary from 100 to 435m above the plains. This unit is of minor hydrogeologic significance due to its unfavourable topography, lithology and structure. However, owing to the favourable factors like high amount of rainfall, low overall permeability of the formation and rugged topography, this unit represents a high runoff zone that contributes significantly to groundwater recharge in the plains.

Alluvial plains: Alluvial plain deposits occupy a major part of the study area with a huge thickness of unconsolidated alluvial sediment deposited mainly by the Brahmaputra and its tributaries and sub tributaries flowing through the area. Lithologically this zone consists mainly of gravel, sands, silts and clays mixed in varying proportions. Fluvial geomorphic features like palaeochannels, old meanders, channel-fill deposits etc. are common and as such, this unit form recharge as well as discharge areas with water table resting within 1 m to 5 m from ground surface. Because of their high porosity and permeability attributed by favourable lithologic composition, groundwater prospect in the alluvial plains is considered as very good.

Active Flood Plains: As this unit consists of unconsolidated materials, the groundwater potential in this area is considered to be very good. Natural levees are formed in these areas during flood recession which are good sites for shallow depth groundwater within around 30m from ground surface. **Swampy/Marshy land:** Because of low lying submerged conditions, groundwater prospect in this zone is considered as poor.

Abandoned channel: These are old abandoned courses of streams which were subsequently filled up with alluvial sediments and thus could act as highly productive shallow aquifer zones. Due to the high permeability of the deposited material such as gravel and coarse to medium sand, this geomorphologic unit is considered as very good prospect zone for groundwater.

3.2. Drainage Density vs. Groundwater Prospects

Drainage density is considered as one of the important parameters in the evaluation of groundwater potential, as it has direct impact on recharge volume. According to Strahler (1957) drainage density is an expression of the closeness of spacing of channels, thus providing quantitative measure of length of stream within a square grid of the area in terms of km/km^2 . Areas having high drainage density are not suitable for groundwater development because of the greater surface run off. Thus, in the preparation of groundwater prospect zone map using GIS, the highest ranking was assigned for very low drainage density as it indicates good groundwater prospect zone and the lowest ranking was assigned for high drainage density as it implies low groundwater potential (Table 1).

To visualize the areas of sheet flow/channel flow four zones of different drainage density, viz. very low (0-1 km), low (1-2 km), moderate (2-3 km) and high (3-3.63 km) are derived based on spatial density analysis of drainage network in the study area (Figure 2c). As per the drainage density classification in the present study area more than 80% of the area falls under very low to low drainage density category which indicates good groundwater prospects.

3.3. Slope vs. Groundwater Prospects

Slope is one of the factors controlling infiltration of water, hence an indicator for groundwater prospect. Slope plays a key role in groundwater occurrence as infiltration is inversely related to slope. A break in the slope i.e., steep slope followed by gentler slope generally promotes an appreciable groundwater infiltration (Saraf and Choudhury, 1998). Topography relates to the local and regional relief and gives an idea about the general direction of groundwater flow and its influence on groundwater recharge (Gupta and Srivastava, 2010).

A slope map of the area generated from the digitized base map of the study area is shown in Figure 2d. The slope angle (in degree) in the area varies from 0° to $>35^\circ$. On the basis of the slope, the study area has been divided into seven slope classes. The areas having 0° to 1° slope fall into the 'very good' category because of the nearly flat level terrain and having relatively high infiltration rate. Most of the study area falls under this category. The areas with 1° to 3° slope and 3° to 5° slope categories are considered as 'good' for groundwater storage due to slightly undulating topography with some runoff. The areas having a slope of 5° to 10° may cause relatively high runoff and low infiltration, and hence are categorized as 'moderate.' Slopes above 10° categories are considered as 'poor' due to higher slope and runoff.

In the preparation of groundwater prospect map low ranking is given to steep dip whereas high ranking is attributed to gentle slope as slope plays a significant role in infiltration verses runoff. From the slope map of the study area (Figure 2d) it has been observed that northeastern, western and southwestern parts of the area have high slope gradient of more than 15 degrees indicating poor groundwater prospects as water runs rapidly off the surface. On the contrary the rest of the area which forms the $\frac{3}{4}$ th of the study area has good groundwater prospects due to nearly level to gentle slope of less than 5 degrees.

3.4. Lithology vs. Groundwater Prospects

Lithologically the area is occupied by consolidated formations belonging to Precambrian group of rocks, consisting of granites overlain by unconsolidated alluvial sediments of Quaternary age (Figure 2e). The Quaternary deposits, formed by the deposition of alluvial sediments viz., sands, silts, clays,

gravels and boulders comprising around 90 percent of the deposit, are highly favorable zone for groundwater. The other important lithological formation exposed in the area, mainly granite, has relatively no groundwater potential because of their massive nature and insignificant primary porosity.

3.5. Land Use/Land Cover vs. Groundwater Prospects

The land use/land cover (LU/LC) of an area plays a significant role in the development of groundwater resource. Infiltration and runoff are controlled by nature of surface material and the land use pattern. The rate of infiltration is directly proportional to the crown density of forest cover, i.e. if the surface is covered by dense forest, the infiltration will be more and the runoff will be less. With urbanization, the rate of infiltration decreases. From the point of view of land use, agricultural land with vegetation is an excellent site for groundwater exploration (Todd and Mays, 2005). The area with water bodies is good for groundwater recharge.

The major land use/land cover categories that were identified in the study area are Settlement area, Agricultural land, Forest land, River/Stream and Wet land (Figure 2f). The area under settlement category is 345.92 sq. km (16.47%), under agricultural land category is 1584.92 sq. km (75.47%) and Forest covers is 66.04 sq. km (3.14%) of the total geographical study area. There are several beels and wetlands in the area and the total area under this category is around 77.01 sq. km. The area under the river and stream category comprises only 26.11 sq. km. Thus the study area, covered by agricultural land, forest, wet land and water bodies has favourable groundwater potential. The weights and ranks are given to each category based on their groundwater prospects (Table 1).

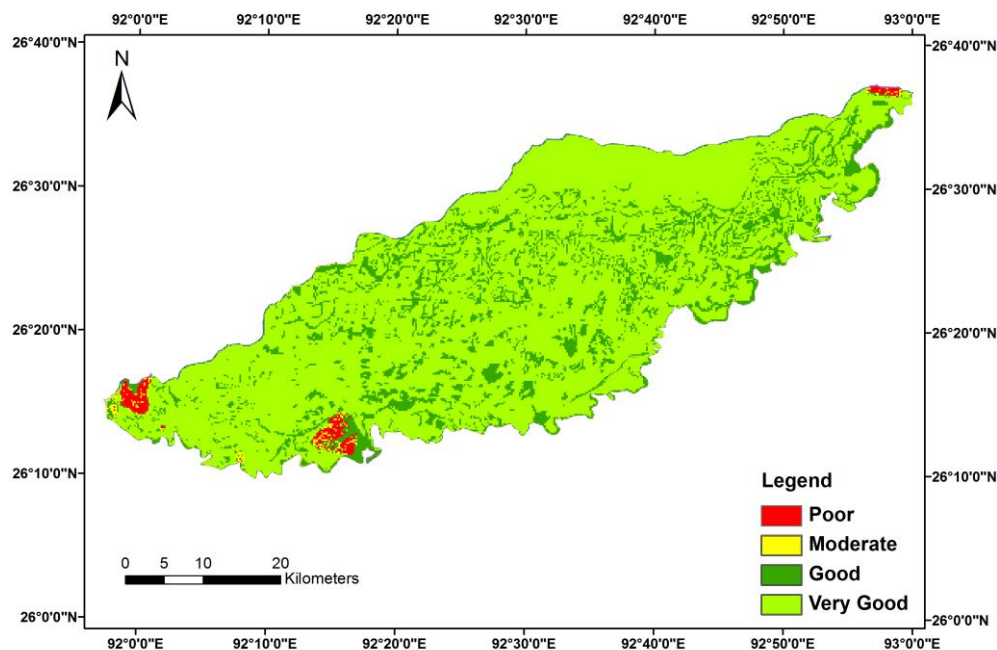


Figure 3: Groundwater prospect zones of the study area

3.6. Classification of Groundwater Prospect Zones

To demarcate the different groundwater-prospect zones of the study area, all the thematic layers such as geomorphology, lithology, drainage density, slope and land use/land cover are integrated applying the Eq.1 by raster overlay analysis technique through Spatial Analyst in ArcGIS. To get the groundwater prospect zones the values are classified into four classes by using the Equal Interval method of classification. Accordingly, the resultant groundwater prospect zone map of the study area was classified into very good, good, moderate and poor groundwater prospect zones (Figure 3).

It has been found that out of the total study area, 80.75% of the area belongs to very good groundwater prospect zones whereas 17.65% of the area belongs to good category, 0.48% of the area categorized as moderate and only 1.12% of the area belongs to poor category. Thus the groundwater prospect zone map indicates that the most part of the area is having well to very good groundwater prospect zones.

4. Conclusion

The study area is interfluvial between the Rivers Brahmaputra and Kolong. Precipitation is the main source of groundwater recharge in the area. Different hydrogeomorphic and geologic units have been delineated based on hydrogeological characteristics of controlling parameters. About 84% of the study area is covered by agricultural land, forest, wet land and water bodies which indicate very good groundwater potential in the study area. Lithologically the area is highly favorable for groundwater development. 3/4th of the total study area has good groundwater prospects due to nearly level to gentle slope of less than 5 degrees. Most part of the study area belongs to very low to low drainage density category indicating more infiltration and recharge to the aquifer. For demarcation of different groundwater prospect zones, the capabilities of using Remote Sensing and Geographical Information System have been used. Thus the groundwater prospects zonation of the study area based on geoinformatics approach clearly indicates that with the favorable combination of alluvial plains, flood plains, low drainage density, nearly flat terrain, good forest cover, favorable lithology and the land use/land cover pattern, the study area is having a very good groundwater potential. The resultant groundwater prospect zones map of the study area could be useful for sustainable development and management of groundwater resource in the area.

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