

Application of GIS and Remote Sensing for Identification of Groundwater Potential Zone in the Hilly Terrain of Bangladesh

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Abstract

Groundwater is the most significant assets on the planet and is declining continuously. The integration of GIS system and remote sensing turned into substantial tools in the field of subsurface water study, which assists in surveying, observing and monitoring the groundwater capitals. With this backdrop, using GIS and remote sensing application, a study was conducted to identify the potential groundwater zones in the hilly district Khagrachhari. The ground water potential zones were identified based on different thematic maps such as drainage, density, lineament density, slope, land use or land cover, soil and geology by using weighted overlay analysis. The groundwater potential zones were investigated orderly into four classes known as poor, moderate, good and very good. This groundwater potential information will work as a guideline to the concerned local authority to identify effectively the suitable locations for the extraction of groundwater.

Keywords

Groundwater, Potential zone, GIS, Remote sensing, Hilly terrain, Khagrachhari



Introduction

There is nothing more fundamental to life on earth than the water. About 785 million people on the planet or 1 of every 9 individuals need access to water. The water emergency is on the number four worldwide hazard regarding the effect on society (WHO and UNICEF, 2017). Of the world's absolute water supply of about 332.5 million cubic miles, more than 96% is saline water. What's more, of the absolute freshwater, more than 68% is locked up in ice and glaciers. Another 30% of freshwater is in the ground (Igor, 1993). The groundwater is very essential for human civilization. Groundwater is actually the surface water that saturates the ground through a procedure called infiltration. New populations in new territories of a district need to discover new groundwater to fulfill their water requirements (Gupta and Srivastava, 2010). High relief and steep slopes cause higher runoff, while topographical depressions increase infiltration. Likewise, a zone of high seepage thickness expands surface overflow. Surface water bodies, like streams, lakes, and rivers, have recharge zones (Murugesan *et al.*, 2012).

The water crisis in Chattogram hill tract is a typical problem during the dry season. In recent five years, the problem has intensified because of deforestation in local area and evaporation from water springs and streams. Moreover, stone extraction has further affected the water streams, apart from the damaged caused by landslides (TDS, 2018). Like other districts in the hill tract, people living in remote territories of Khagrachhari are confronting an intense scarcity of water. Their only sources of water are little streams that evaporate in summer. Local people need to travel a significant distance to fetch drinking water from streams (TFE, 2019). According to BBS (2011), about 67% households get the facilities of drinking water from tube-well, 0.5% from tap and the remaining 32.5% households get water from other sources like river, lake, pond, wetland, shower, etc. But the people of this district face water crisis mainly in the time of dry seasons. Besides, the development of urbanization is occurring faster. In such circumstances, the local authority is compelled to find out the potential groundwater zone. For this reason, groundwater-discharge zones need to be identified with a focus on appropriate water management.

The research was conducted by using remote sensing data with the geographical information system (GIS) for identifying the groundwater potential zone. The groundwater potential was set up by incorporating the geology, slope, land use/land cover and soil maps alongside seepage designs (Balakrishnan, 2019). This information will be helpful for effective identification of suitable areas for extraction of groundwater. The aim of the study was to identify the groundwater potential zones in Khagrachhari district, which will act as a guideline for the local authority as well as the local community to construct the artificial dam that can help minimize the water crisis in this area.

Materials and Methods

The study area

The Khagrachhari local government legislative council was created in 1989 following the Chattogram hill tracts peace accord. It was transformed into Khagrachhari hill district council in 1997 (Banglapedia, 2015). Khagrachhari district is situated in the middle of 22°38' and 23°44' north latitudes and in the middle of 91°44' and 92°11' east longitudes. It borders Tripura territory of India on the north, Rangamati and Chattogram districts on the south, Rangamati area on the east, Chattogram region and Tripura province of India on the west (Figure 1). The total area of

this district is about 2699.56 km² and the total population is 525664. The Golamoon, Chotto Panchari, Karmi Mura, Lutiban, Kuradia, Bhanga Mura and Jopisil hill ranges are located in this district combined with hills, small rivers, streams and flat land.

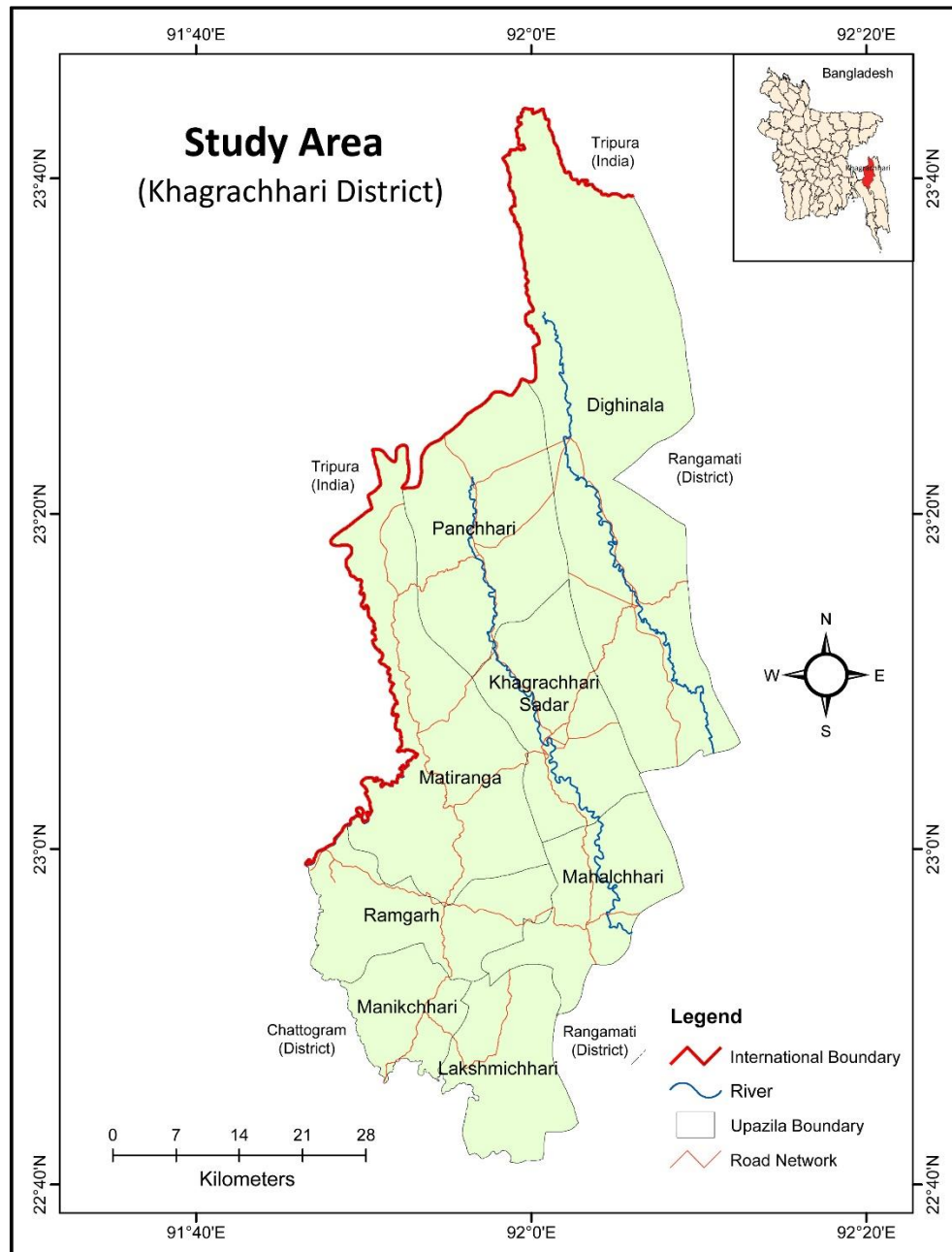


Figure 1: Geographical location of Khagrachhari district in Bangladesh

Data collection

In order to delineate groundwater potential zones, different thematic maps were set up from remotely sensed data. The six thematic map layers were prepared and included in the assessment of drainage density, lineament density land use or land cover, slope, geology and soil. For

preparing land use or land cover, slope and lineament density, the study used Landsat-8 (OLI) (30-meter spatial resolution) operational image; whereas for soil, Brammer soil classification 1996 and the geological division map were prepared based on GSB (1996) and USGS (2000). For different thematic maps, different tools are used which are shown below:

Drainage density

SRTM (Shuttle Radar Topography Mission) digital elevation data was used to generate drainage map by using the hydrological tool in ArcMap and then run the Kernel density estimation to produce the drainage density of the study area.

Lineament density

For extracting lineament of the study area, the Landsat-8 OLI was used by using the Lineament extraction tool from pci Geometica software. The density was estimated by using line density tool from ArcMap software.

Slope

The slope map was prepared by using the surface tool in ArcMap from Landsat-8 OLI.

Land use or land cover

Supervised classification technique in ERDAS Imagine was used for preparing land use or land cover map.

Groundwater potential zone

It was undertaken by assigning suitable weights to each thematic feature after considering their relative contribution characteristics such as drainage density, lineament density, land use or land cover, etc. towards the occurrence of groundwater. Finally, weighted overlay analysis was used for identifying groundwater potential zone (Ghodratadi and Feizi, 2015; Gupta and Srivastava, 2010; Lakshmi and Reddy, 2018; Ibrahim-Bathis and Ahmed, 2016; Murugesan *et al.*, 2012).

Results and Discussion

Drainage density

The physical appearance of both surface and sub-surface enhancements largely depends on the drainage pattern (Evans, Wayne Skaggs and Wendell Gilliam, 1995). Drainage pattern implies arrangement of surface and sub-surface characteristics (Melton, 1957). The more the drainage density, more will be the runoff over the surface. As a consequence, the infiltration rate is less in this area. With the decrease of drainage density, the runoff is less and the infiltration rate is more (Lakshmi and Reddy, 2018).

Coarse drainage texture depends on low drainage density, whereas the fine drainage texture depends on high drainage density. Hence the lower the drainage density, the higher the probability of recharge or potential groundwater zone (Waikar and Nilawar, 2014). The drainage network of Khagrachhari district was prepared with the help of the ArcMap hydrology tool and the density was estimated by running the kernel density estimation. In this study, drainage density was divided into five categories, e.g. 0 to 0.16 km⁻¹ is very low, 0.16 to 0.32 km⁻¹ is low, 0.32 to 0.48 km⁻¹ is moderate, 0.48 to 0.64 km⁻¹ is high and 0.64 to 0.80 is very high, respectively. The

average drainage density of study area was 0.48 km^{-1} . Within a part of the study area the drainage density was higher in the middle part (0.80 km^{-1}) (Figure 2.a). In the lower part of the district, low drainage density (0.16 km^{-1}) was recorded.

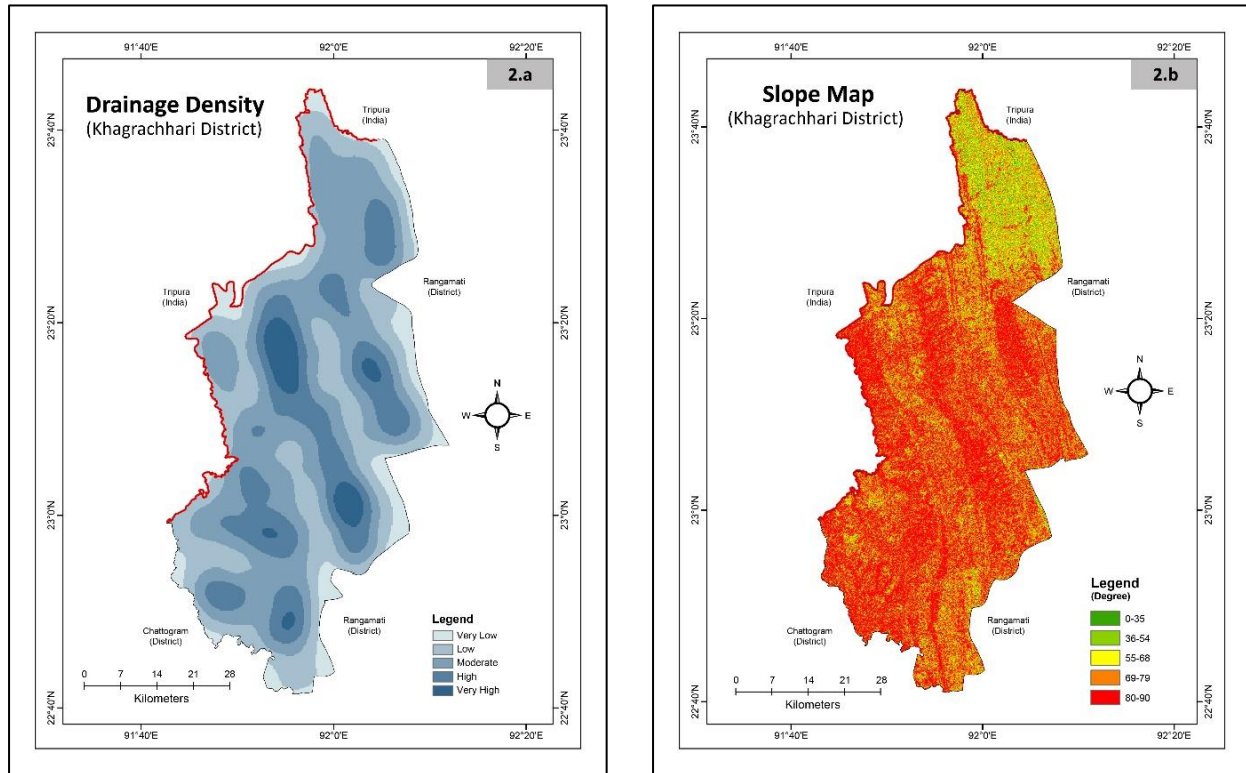


Figure 2: a) Drainage density and b) slope map of Khagrachhari district in Bangladesh

Slope map

The slope is one of the determining elements of groundwater, and it is understood from the horizontal spacing of the contours. It gives a clear idea of the amount of infiltration of water. Precipitation infiltration is a powerful hydrological parameter in acquiring groundwater potential (Batelaan and De Smedt, 2001). This hydrological parameter is controlled by the slope. The lower slope indicates the fatter surface; on the other hand, higher slope represents the steeper surface (Rust, 1972). In low slope areas, infiltration into the ground is progressively more as surface flow is less due to fast surface runoff. With the increase of slope ration, surface flow also increases, and infiltration into the ground gets lesser (Gabet and Sternberg, 2008). The slope of the study area ranges from 0 to 90 degree. Most the border area in this district has high slope. The lowest slope (0 to 35 degree) area is situated in the Northern part of Khagrachhari district (Figure 2.b).

Geology

Geologically, the examination zone of underground consists of four major classes: alluvial deposits, bed rocks, Surma group and Tipam group. The soil which is deposited in the riverbeds is known as alluvial deposits. Deposited particles depend on the speed of flow. Strong flow deposits large size cobble, whereas weak flow deposits small size cobble particles (Macdonald,

2007). The total area of the alluvial deposits in Khagrachhari is about 104 km². Bedrock is a store of strong stone that is regularly covered underneath soil and other broken or unconsolidated material (Encyclopedia Britannica, 2020). Some middle portion and the north to south western part of Khagrachhari district are abundant with bedrocks. It covers total 880 km². The Surma group of the miocene-pliocene age overlies the barail bunch with an unconformity. The Surma group features a thickness of about 3.5 to 4.5 km and consists of monotonous alternating sandstone, shale, siltstone and a few conglomerates (Rashid, 1991). The total area of Surma group in the study area is 997 km² (Figure 3.a) The Tipam sandstone formation commonly comprises of grey-brown to pale-grey, coarse-grained, cross bedded, gigantic sandstone. Intercalations of grey shale, conglomerate horizons, pebbles, wood fragments and petrified trunks also occur (Banglapedia, 2015).

Soil map

Soil is another factor that determines the infiltration capacity of a region. The rate and measure of infiltration differ contingent upon grain structure. In coarse-grained permeable structures, groundwater infiltration is higher (Fagbohun, 2018). In fine-grained soils, for example, clay, infiltration is increasingly slow (Çelik, 2019). In the study area, there are mainly three types of soils. They are non-calcareous grey floodplain soils, brown hilly soils and reserved forest soil. The brown hilly soil covers most of the area of Khagrachhari district. The total area of this is about 2309 km² that is 80% of total area. Due to the low steepness the rate of infiltration is better in non-calcareous grey floodplain soils than brown hilly soil. It covers nearly 2% of total area (Figure 3.b).

Land use or land cover

Land use or land cover mapping is one of the significant remote sensing applications. Land use or land cover map is an important indicator for groundwater detection that provides knowledge about human action and many others uses. Land use or land cover plays a noteworthy role in the advancement of groundwater assets (Yu and Schwartz, 1998). It provides the information about soil moisture, infiltration, groundwater and surface water. It controls many hydrogeological processes such as infiltration, evapotranspiration, surface runoff, etc. The surface cover gives roughness to the surface, and lessen the release in this way expands the infiltration. From the perspective of land use, thick vegetation is an appropriate site for groundwater investigation (Todd and Mays, 2005).

Table 1: Land use or land cover of Khagrachhari district in Bangladesh

Name	Area (km ²)	Percentage
Hilly forest	1957	16.80
Cultivated land	458	14.38
Human settlement	415	1.01
Water body	29	67.81

For preparing land use or land cover map of 2019 of the study area (Figure 4.a), Landsat-8 OLI and thermal infrared sensor (TIRS) Level 1 imagery was used and the classification was done through unsupervised classification in ERDAS imagine. The classification with area and

percentage of land coverage of Khagrachhari district is presented in Table 1.

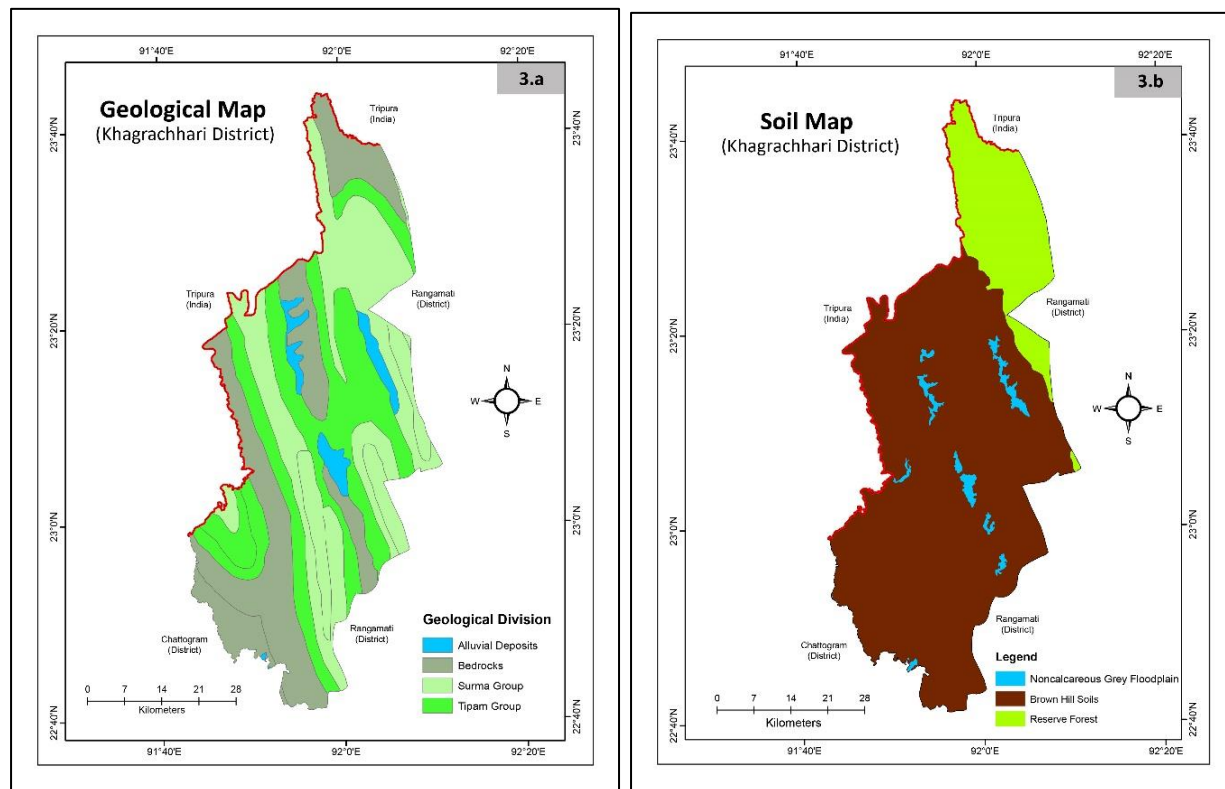


Figure 3: a) Geological and b) soil map of Khagrachhari district in Bangladesh

Lineament density

Lineaments (linear features) give information about underground faults and cracks, showing the event of groundwater (Todd and Mays, 2005). These are basically impressions of discontinuities on the Earth's surface brought about by the geographical or geomorphic forms (Clark and Wilson, 1994). Geological features which help give rise to lineaments include faults, shear zones, fractures, dikes, veins, bedding planes and stratigraphic contacts; and, therefore, the geomorphic features include streams, linear valleys and ridgelines (Ghodraty and Feizi, 2015). Lineament studies have immense applications in various disciplines of geosciences, for example, identification of tectonic features, recognition of folds and faults, exploration of mineral deposits, petroleum prospects, groundwater and so on (Waikar and Nilawar, 2014). These are distinguished using the advanced remote sensing information. Regions around the lineaments and crossing points of lineaments are viewed as ideal location for aggregation of groundwater because of the high infiltration capacity (Ibrahim-Bathis and Ahmed, 2016). It is accepted that with the increase of distance away from the lineaments, the intensity of fracturing decreases. This indicates that the best possibilities for groundwater occurrence are near lineaments (Solomon and Quiel, 2006). In this study, the lineaments of this area are extracted from satellite image. The magnitude of the lineaments is varying from 0.91 to 11.75 km. The lineament map is converted into major five (very low, low, moderate, high and very high with the corresponding value of 0 to 0.17, 0.18 to 0.34, 0.35 to 0.51, 0.52 to 0.68 and 0.69 to 0.85 km^{-1}) zones of different lineament density. This indicates that the very high value (0.69 to 0.85 km^{-1}) shows good potentiality of groundwater; on

the other hand, very low value (0 to 0.17 km⁻¹) reflects very poor potentiality of groundwater (Figure 4.b).

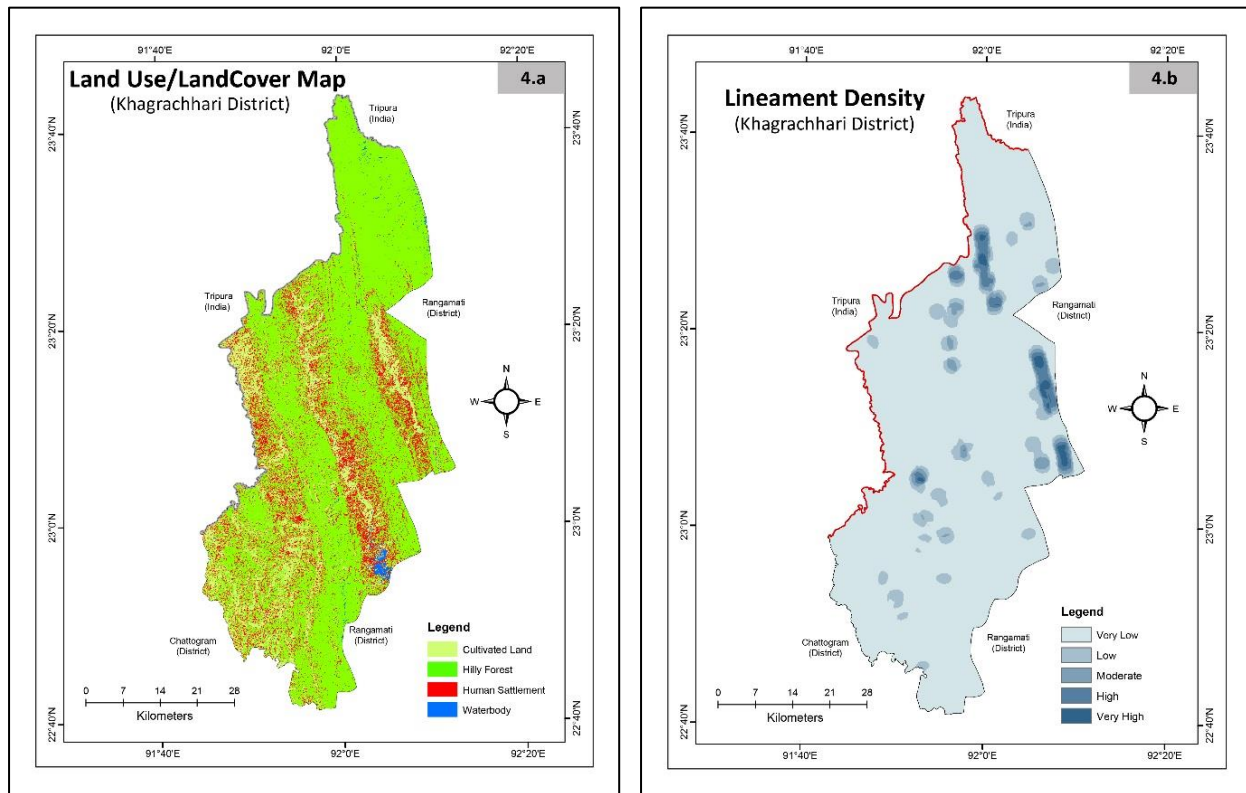


Figure 4: a) Land use or land cover and b) lineament density map of Khagrachhari district in Bangladesh

Groundwater potential zone

The groundwater potential zones are obtained by overlaying all the thematic maps using weighted overlay strategy along with spatial analysis tool in ArcMAP. While undertaking weighted overlay investigation, positions were given for each singular parameter of every thematic map. Subsequent to allotting weights to various parameters, individual ranks are given for sub-variables. For identifying the groundwater potential zone, thematic layers on GIS such as geomorphology, drainage density, soil, lineament density, slope and land use or land cover were analysed carefully and the ranks were assigned to the sub-variables (Yammani, 2007).

Table 2: Groundwater potential zones in Khagrachhari district in Bangladesh

Zone name	Area (km ²)	Percentage
Poor	91.41	3.30
Moderate	2329.90	84.34
Good	339.52	12.29
Very good	1.56	0.07

The groundwater potential map of the study area is prepared based on the examination of various themes, geology, land use or land cover, soil, drainage density, lineament density, and slope. The

groundwater potential map reveals the available quantum of groundwater (Teja and Singh, 2019). The groundwater potential map has been depicted into different zones appearing poor, moderate, good and very good (Figure 5). The very good and good zones informed about the sufficient groundwater assets whereas poor and moderate indicated the water exhaustion (Table 2). The maximum area of Khagrachhari district is covered by moderate groundwater zone, approximately 84% of the total area (Table 2). A very little portion of the district has appeared under very good zone and it is situated in the Sadar upazila. The good groundwater zone occurs in about 12% of this district (Table 2).

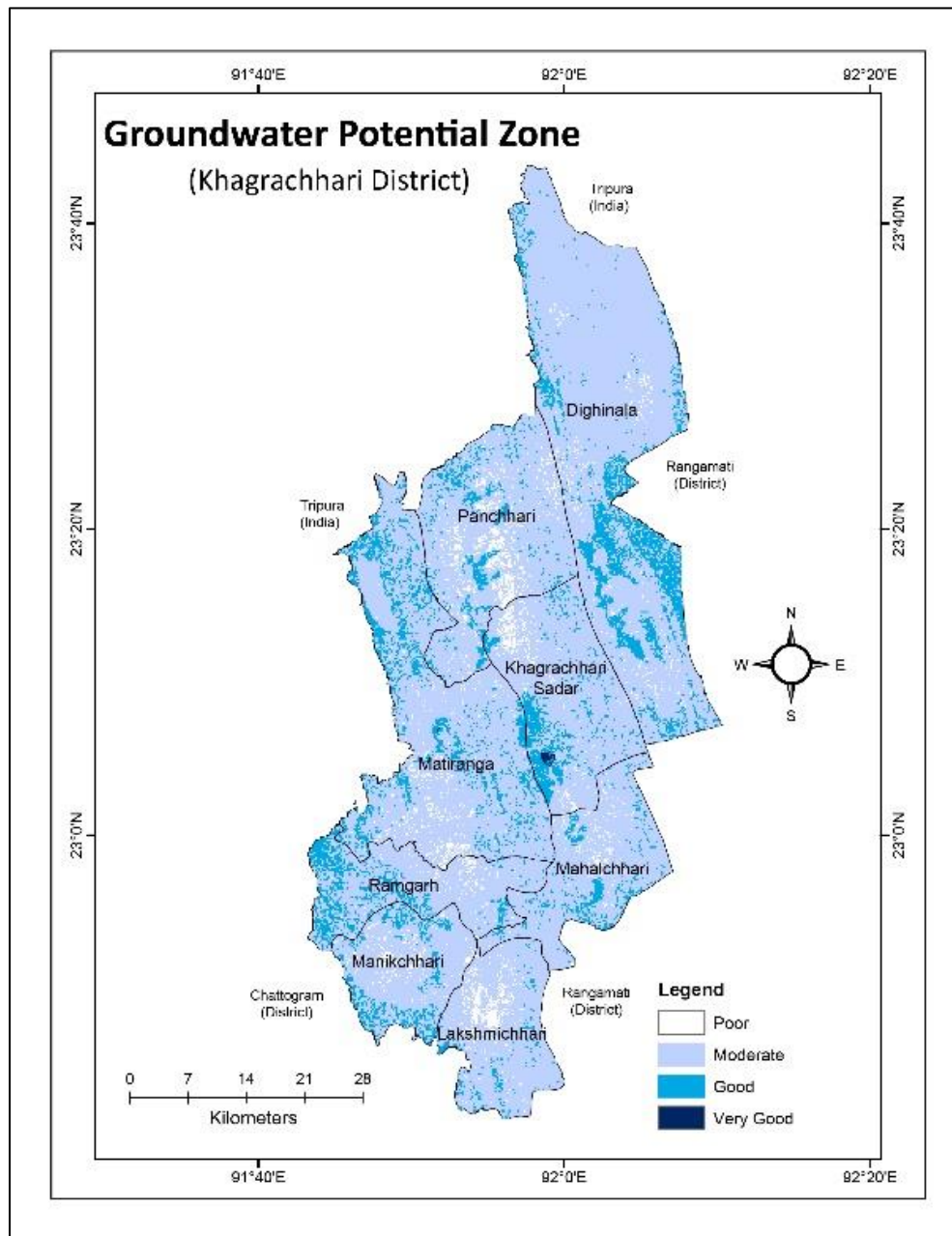


Figure 5: Groundwater potential zones map of Khagrachhari district in Bangladesh

Conclusions

The geographical information system (GIS) and remote sensing are remarkable and practical tools to discover groundwater potential zones. Through this study, incorporation of six thematic maps - drainage density, slope, soil, geology, lineament density and land use or land cover - give direct information to concerned specialists, local authorities and planners pursuing groundwater investigation. All the maps were weighted overlaid to make a groundwater potential zone map. The present study of Khagrachhari district showed that 1.56 km² out of the total area was identified as very good groundwater potential zone and 339 km² area as good groundwater potential zone. The study recommended that the groundwater potential zone of the Khagrachhari district will work to accommodate guidelines for coordinators, designers, and leaders. It helps them to take decision making in administration of groundwater resources, site determination for groundwater investigation, and exploitation. This study also would help to develop artificial recharge structures in perspective of groundwater use in the Khagrachhari region to full fill their water crisis during dry season.

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