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ORIGINAL ARTICLE

Geographic information system and analytical hierarchical process approach for groundwater potential zone of lower Kulsi basin, India

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Abstract

Groundwater is a natural resource that performs human needs for drinking and other domestic purposes, agricultural productivity, and manufacturing activities. The potentiality of groundwater is the foremost aspect of sustainable land and water resource development in a region where surface water is insufficient to fulfil demand. This study aims to demarcate potential groundwater zones using the Analytical Hierarchical Process and Geographic Information System techniques based on geomorphology, soil, geology, lineament density, slope, drainage density, land use/land cover, rainfall, and surface water. Data were collected from authentic governmental organizations, mainly daily gauge rainfall from 2009 to 2018, high spatial resolution satellite images for land use land cover, the Survey of India topographical map with 20 m contour interval for elevation and slope, and the National Bureau of Soil Survey and Land-use Planning, India soil map was utilized in the case of the lower Kulsi basin, India. The input thematic layers were integrated using ArcGIS 10.6 software. Assigned weight to each category of input layers according to Saaty's rating scale based on their character and influence on the potentiality using AHP. The resultant groundwater potential map derives five different grades of potentiality, very high, high, moderate, low, and very low. A high and very high probability of groundwater occurs within the alluvial plain. About 57.77% of the total area is under the category of moderate to very low-graded groundwater potentiality. After being validated successfully, the resultant map will contribute to determining potential groundwater reserves and land–water resource management plans.

Keywords Analytical Hierarchical Process (AHP) · Weighted overlay · Remote sensing · Geographic Information System (GIS) · Groundwater potential

Introduction

Groundwater is part of precipitation landed on the ground and is stored after infiltration into the subsurface soil and moves slowly to become the source of water supply to streams, lakes, wetlands, and marshy land. Dependence on groundwater resources for irrigation, drinking and other domestic purposes is increasing daily in areas with insufficient surface water. Hydrogeological ground survey for identifying and delineating potential groundwater zone is expensive and time-consuming (Israil et al. 2006; Arulbalaji et al. 2019; Alikhanov et al. 2021). The potential groundwater mapping using geospatial tools can help field hydro-geologists conduct groundwater mapping faster and more efficiently (Lee et al. 2012; Talukder et al. 2013; Fashae et al. 2014; Adeyeye et al. 2019). Remote sensing data cannot detect groundwater directly. Still, the surface features derived from the satellite image, such as landform, geology, soil, land use/land cover, and available surface water bodies, can indicate groundwater existence (Todd and Mays 2005; Jha and Peiffer 2006). Applying Geo-informatics due to its advantages of spatial, temporal, and spectral availability of data covering large and inaccessible areas has emerged as a valuable tool for evaluating, monitoring, and managing groundwater resources within a short period (Jha et al. 2007). Much research has been done on delineating potential groundwater zone using geospatial techniques in different environmental conditions. Some of them are the Tirnavos area, Greece (Oikonomidis et al. 2015); the Wadi Aurnah basin, Western Arabian Peninsula (Al-Saud 2010); Comoro watershed, Timor Leste (Pinto et al. 2017); Kurdistan region of Iran (Rahmati et al. 2014); Southwest Nigeria (Fashae

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et al. 2014); mid-latitude semi-arid areas of Korea (Lee et al. 2012); Sultan mountains, Turkey (Ozdemir 2011); Guna tana landscape of upper Blue Nile basin, Ethiopia (Andulem and Demeke 2019); Beheshtabad watershed and Chaharmahal-and-Bakhtiari, Iran (Naghibi and Pourghasemi 2015); semi-arid region of India (Machiwal et al. 2011); Narava basin, Vishakhapatnam, India (Narendra et al. 2013); Southern Western Ghats, India (Arulbalaji et al. 2019); Rajura Taluka of Maharashtra (Rokade et al. 2007); and Musi basin of India (Ganapuram et al. 2009).

Different methods and tools have been applied to identify the probability zone of groundwater effectively in the past literature, such as integration of remote sensing and GIS with resistivity data (Selvarani et al. 2016), influence factor (Selvam et al. 2015), statistical methods (Falah et al. 2017), groundwater modelling (Sashikumar et al. 2017), machine learning decision trees (Prasad et al. 2020;), machine learning ensemble techniques (Arabameri et al. 2021), artificial neural network (Lee et al. 2018), neuro-fuzzy (Termeh et al. 2019), decision trees (Duan et al. 2016), multi-criterion decision analysis (Alikhanov et al. 2021), multi-criterion analysis using a hierarchical analytical process (AHP) (Machiwal et al. 2011; Arulbalaji et al. 2019; Saranya and Saravanan 2020). The AHP method has flexibility in nature, which allows the revision of the weights and rating of the factors to be suitable for other regions according to their specific characteristics (Oikonomidis et al. 2015). AHP is a decision-making process comparing the importance of two criteria through pairwise comparison, which Thomas L. Saaty introduced in 1980. It is a suitable technique for evaluating the consistency of the result and reducing discrimination in the decision-making process (Saaty 1990). The present study uses AHP integrated with GIS techniques to delineate a potential groundwater zone in the lower Kulsi basin.

People of the lower Kulsi basin primarily depend on groundwater resources for domestic and agricultural purposes. A study on groundwater prospects is significant for the region's land and water resource management. Therefore, the study aims to focus on the combination of AHP and GIS techniques for the identification and delineation of groundwater potential zone in the lower Kulsi basin by the integration of nine influencing input parameters such as geomorphology, soil, geology & lineament density, slope, drainage density, land use/land cover, available surface water bodies and distribution of rainfall pattern. The findings of this research can help scientists, decision-makers, local government, and localities tackle the problem that arises in low potential areas for increasing groundwater recharge structure, utilizing alternate water resources by harvesting rainwater, irrigation facilities, and crop productivity of the basin.

Materials and methods

Geographical background

The Kulsi River is a south-bank tributary of the Brahmaputra River. It is located in the northern front of the Shillong Plateau, a northward-flowing river that drains over Assam's plain region and joins into the Brahmaputra River. In Meghalaya, the river is known as the Khri River, where the tributaries Um Krisina River, Um Siri, and Um Ngi confluence with the Khri River at Ukiam; after reaching the alluvial plain of Assam, the river is known as Kulsi River. The Kulsi river basin has a total area of around 1956 km^2. Geographically, its latitude and longitudinal extension are 25°31′ 58.8″ N to 26°75′ 3.33″ N and 91°E to 91°48′ 30″ E, as shown in the Fig. 1. The upper catchment of the study area is composed of moderate to highly dissected structural hills and valleys, which depict the surface runoff of the rugged hilltop, and the debris slopes are moderate to steep. The catchment has elevations ranging from 80 to 1220 m. The topographic subunits of the low-lying plains are the young alluvial plain, the old alluvial plain, the active flood plain, and the older flood plain. The pediment complex is another crucial landform unit with a moderate slope sustaining natural vegetation and grassland. The upper catchment is mainly composed of fine soil texture soil, the parent material is Gneiss, and the downstream section of the river is covered mainly by alluvium. The upper catchment area belongs to the age of the Proterozoic structure, and the downstream belongs to the age of Meghalaya, formed during the Barpeta-I, Sorbhog, and Hauli formations.

The lower Kulsi Basin is located in the sub-tropical monsoon type of climatic zone with highly seasonal

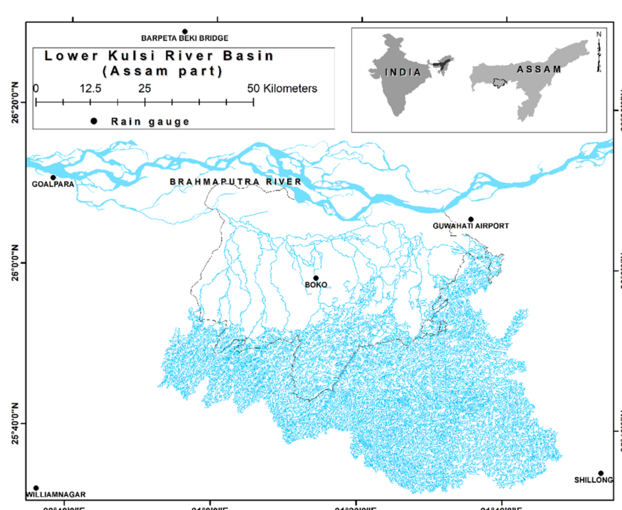

Fig. 1 Location of the lower Kulsi basin, Assam, India

Photograph 1 water collected from a pond near the farmland during the dry season of the Kulsi basin

rainfall in summer and dry winter. Average annual rainfall was recorded at 1956.67 mm at the Boko rain gauge station located in the central part of the basin (Fig. 1). More than 78% of the rain occurs only in summer (May to September), causing surface runoff causing, flood inundation in the lowland, vulnerability for soil erosion, and landslides on the rugged topography in the catchment. About 4.43 mm of average monthly rainfall occurs in winter. Below 1% of the total rainfall occurs only in the winter (December to February), causing water shortage issues in the basin (Photograph. 1). A basin area of 37.37 km^2 was covered by agricultural land with traditional crop practices on hill slopes demanding more water.

Materials

The details of the most authenticated governmental data are listed in Table 1.

Methods

The study uses GIS-based multicriteria decision analysis with AHP to delineate potential groundwater zone. The study of the potential groundwater zone of the lower Kulsi River basin is based on the integrated criteria layer such as geomorphology, soil texture, geology, lineament density, slope, drainage density, land use/land cover, rainfall, and available surface water (Table 1). Figure 2 illustrates the flow chart of the model for preparing potential groundwater zones. The weight of the criteria layers is assigned according to the importance of the probability of groundwater. The consequences of each criteria layer are given as per Saaty's rating scale (1–9) value for intensity of relative importance. Satay's rating scale of importance tells a value of 9 for extreme importance; a value of 8 indicates very strong plus, seven means very strong, six indicates strong plus, five indicates a strong preference, four means moderate plus, 3 implies moderate importance, two standards weak or slight and 1 for two activities contribute equally (Saaty 2008). All the influencing criteria layers have been compared in a pairwise comparison matrix according to the scale (Table 3) and normalized weight (Table 4) using the AHP extension module in Arc GIS. Consistency ratio (CR) is the ratio of the consistency index for the matrix to random consistency indices of the number of criteria used in the model (Eq. 1).

$$\text{ConsistencyRatio}, \boldsymbol{CR} = \frac{\boldsymbol{CI}}{\boldsymbol{RCI}} \tag{1}$$

where $\boldsymbol{CI} = \frac{(\lambda_{max} - \boldsymbol{n})}{(\boldsymbol{n} - 1)}$ where $\boldsymbol{n}$ is the number of the factors used in the analysis

RCI is random consistency indices.

According to Saaty, the revision of the preference matrix is recommended if CR is greater than 0.1. If CR is 0.10 or

Table 1 Detailed of the database

Data type	Description	Time	Spatial coverage	Sources
Toposheet	Base map, streams, elevation	1967	1:50,000	Survey of India (SOI), North East Zone Assam Nagaland, Guwahati
Satellite Image-IRS LISS IV	Land use, drainage, roads	26/01/2018	5.8×5.8	National Remote Sensing Center, Hyderabad
Thematic maps	Soil -Soil texture	1999	1:250,000	National Bureau of Soil Survey and Land-use Planning, India (NBSS&LUP) www.nbsslup.in
	Geomorphology, Geology, lineament	–	1:50,000	Geological Survey of India (GSI) www.gsi.gov.in
Meteorological data	Rainfall	2009–2018	Guwahati airport, Boko, Goalpara, Shillong, Williamnagar, Tikirikila, and Beki bridge	Regional Meteorological Centre, Guwahati, India; Regional Sericulture Research Institute, Boko (RSRI)
Hydrological data	Hydrogeological condition, groundwater depth	2001–2021	–	Central Groundwater Board, North-East Region, Guwahati. (CGWB NER)

Table 2 Random consistency indices of different numbers of factors used

N	1	2	3	4	5	6	7	8	9	10	11	12
RCI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48

less, it is acceptable for the analysis. The CR is 0, which means a perfect level of consistency in the pairwise comparison. The consistency ratio for the groundwater potential map is calculated using Eq. 1 $CR = 0.086$ (as $CI = 0.1250$, and $RCI = 1.45$ for nine numbers of criteria in Table 2). The threshold value of assigned weight for the study on potential groundwater zone is 0.086 means a perfect level of consistency in the pairwise comparison of criteria layers; therefore, the judgment matrix is reasonably consistent and acceptable.

Each criteria layer is classified using the Reclassify arc tools of Arc GIS 10.6 software. Table 5 illustrates the assigned weight and rank of subcategories of each influencing criteria layer. The criteria layers were integrated with the weighted overlay analysis method in the GIS environment using Eq. 2.

$$\text{GWPZ} = \sum_{i}^{n} \left(X_A \times Y_B \right) \quad (2)$$

where GWPZ is ground Water Potential Zones.

X is the weight of the thematic layers.

Y is the rank of the subcategories of the thematic layer.

$_A$ is 1, 2, 3… X of the thematic layer.

$_B$ is 1, 2, 3… X of the thematic layer subclass.

Finally, the groundwater potential map was generated. Further, the map is validated with the help of observed data from the Central Ground Water Board, NER, Guwahati, and

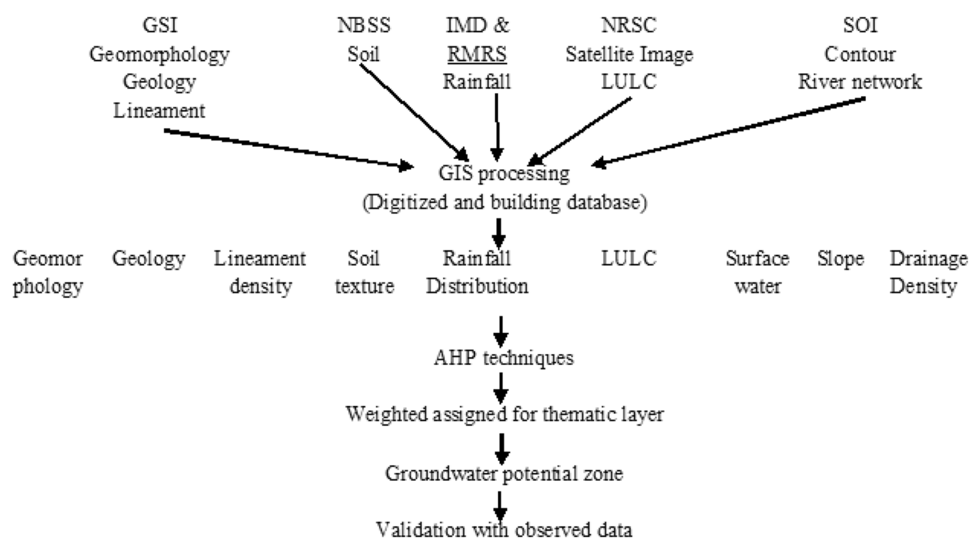

Fig. 2 Flow chart for the preparation of potential groundwater zone

Table 3 Pairwise comparison matrix of criteria layers

Sl. No	Contributing factors	Assign weight	Geomorphology	Soil	Geology	Lineament density	Slope	Drainage density	LULC	Rainfall	Surface water
1	Geomorphology	8	8/8	8/6	8/6	8/6	8/5	8/5	8/7	8/4	8/7
2	Soil	6	6/8	6/6	6/6	6/6	6/5	6/5	6/7	6/4	6/7
3	Geology	6	6/8	6/6	6/6	6/6	6/5	6/5	6/7	6/4	6/7
4	Lineament density	6	6/8	6/6	6/6	6/6	6/5	6/5	6/7	6/4	6/7
5	Slope	5	5/8	5/6	5/6	5/6	5/5	5/5	5/7	5/4	5/7
6	Drainage density	5	5/8	5/6	5/6	5/6	5/5	5/5	5/7	5/4	5/7
7	LU/LC	7	7/8	7/6	7/6	7/6	7/5	7/5	7/7	7/4	7/7
8	Rainfall	4	4/8	4/6	4/6	4/6	4/5	4/5	4/7	4/4	4/7
9	Surface water	7	7/8	7/6	7/6	7/6	7/5	7/5	7/7	7/4	7/7

Table 4 Results of consistency ratio for normalized weight

Sl. No	Contributing factors	Eigenvector	Geomorphology	Soil	Geology	Lineament density	Slope	Drainage density	LULC	Rainfall	Surface water	Weighted sum	Row average	λ
1	Geomorphology	0.435	0.435	0.434	0.434	0.434	0.428	0.428	0.442	0.435	0.442	4.351	0.435	10.000
2	Soil	0.326	0.327	0.326	0.326	0.326	0.321	0.321	0.331	0.326	0.331	3.268	0.326	10.000
3	Geology	0.326	0.327	0.326	0.326	0.326	0.321	0.321	0.331	0.326	0.331	3.268	0.326	10.000
4	Lineament density	0.326	0.327	0.326	0.326	0.326	0.321	0.321	0.331	0.326	0.331	3.268	0.326	10.000
5	Slope	0.268	0.271	0.272	0.272	0.272	0.268	0.268	0.258	0.272	0.258	2.680	0.268	10.001
6	Drainage density	0.268	0.2719	0.272	0.272	0.272	0.268	0.268	0.258	0.27	0.258	2.680	0.268	10.001
7	LULC	0.386	0.380	0.381	0.381	0.381	0.402	0.402	0.386	0.381	0.386	3.869	0.386	10.000
8	Rainfall	0.217	0.217	0.217	0.217	0.217	0.214	0.214	0.220	0.217	0.220	2.176	0.2171	10.000
9	Surface water	0.386	0.380	0.381	0.381	0.381	0.402	0.402	0.386	0.381	0.386	3.869	0.386	10.000

published groundwater report on www.cgwb.gov.in. A comparative analysis of water yield and the groundwater depth with probability zone is carried out to validate the resultant map. The location map of tube wells was superimposed on the delineated potential groundwater map to verify the competence of the combined GIS and AHP methods in detecting GWPZ in the study area. Photograph 2 and 3 illustrates the field verifications of tube wells in the lower Kulsi basin.

Results and Discussion

Description of the input criteria

Geomorphology: As per the data of the Geological Survey of India, the main geomorphic units in the lower Kulsi River Basin are structural & denudation hills, younger & older alluvial plains, and pediments (Fig. 3). The geomorphic features control the surface and sub-surface movement of water. The geomorphic feature helps to evaluate the groundwater potential and prospects (Kumar et al. 2008). The higher weight is assigned for water bodies, floodplains, and alluvial plains, and the lower weight is assigned for denudation and structural hills for delineation of the potential groundwater zone of the lower Kulsi basin.

Drainage: The Kulsi River is a left-bank tributary of the Brahmaputra. These streams flow from the southern Meghalaya Plateau as the Khri River, flow towards the west, then north direction, and form a narrow valley descending to the Kulsi River. It develops a dendritic pattern of the drainage system in the upper catchment area. The debris slopes are moderate to severe erode with finer alluvial soil high acceleration. Um Krisinya, Um Siri, Um Ngi, Boko, Singra, Singua, and Deosila are left-bank tributaries of the Kulsi River. Batha and Umshru are the only two tributaries on the right bank. The drainage networks of a basin depend on the lithology, and it provides an essential index of infiltration rate (Arulbalaji et al. 2019). The drainage density is another crucial parameter for potential groundwater mapping. The drainage density is obtained by dividing the total length of the channel in the basin by the basin's total area. The study's drainage density range is 0 to 4 km/sq. Km. Figure 4 illustrates the drainage density map of the study area, which was prepared using line density arc tools of GIS software. The high drainage densities imply low infiltration and hence the low potential of groundwater.

Slope: The slope measures the steepness or degree of inclination relative to the horizontal plane. It gives necessary information on the nature of the structure and geodynamic processes at the regional level (Riley et al. 1999). DEM for the study area is prepared from the contours of the Survey of India topo sheet with 20-m intervals to generate a slope map of the basin (Fig. 5a). The DEM is the primary input for

Table 5 Factors influencing groundwater and assigned weight used for delineating potential groundwater zone in lower Kulsi basin

Sl No	Contributing factors	Classes	Rank	Assigned Weight
1	Geomorphology	Alluvial Plain	7	15
		Flood Plain	8	
		Dissected Structural Hills and Valleys	2	
		Dissected Denudational Hills and Valleys	2	
		Pediment Peneplain Complex	5	
		Water bodies	9	
2	Soil	Coarse-silty	7	11
		Fine-loamy	5	
		Coarse-loamy	5	
		Fine	4	
		Clayey	7	
		River	9	
3	Geology	White to Greyish Sand, Silt, Pebbles, and Clay	7	11
		Oxidized to Feebly Oxidized Sand Silt and Clay	7	
		Feebly Oxidized Sand, Silt, and Clay	7	
		Dolerite	2	
		Amphibolite	3	
		Grey and pink Porphyritic Granite	2	
		Highly Oxidized dark brown to red-brown Loamy Sand	5	
4	Lineament density(km/km^2)	0–7.26	3	11
		7.26–19.75	5	
		19.75–33.11	7	
		33.11- 49.37	8	
		49.37–74.06	9	
5	Slope (in %)	0–5	8	9
		5–15	5	
		15–30	4	
		30–45	2	
		> 45	2	
6	Drainage density (km/km^2)	0–0.55	8	9
		0.55–1.16	7	
		1.16–1.90	4	
		1.90–2.74	4	
		2.74–4-04	2	
7	Land use/Landcover	Barren Land	4	13
		Crop Land	5	
		Tea Plantation	6	
		Forest	7	
		Grass Land	5	
		Marshy Land	8	
		Railway	2	
		River	9	
		Road	2	
		Sand Bar	7	
		Settlement	2	
		Scrub forestland	5	
		Stone mining	2	
		Water Body	9	

Table 5 (continued)

Sl No	Contributing factors	Classes	Rank	Assigned Weight
8	Rainfall (in cm)	160.4–176.3	5	8
		176.3–190.4	6	
		190.4–201.2	6	
		201.2- 211.3	7	
		211.3–228.1	7	
9	Distance from surface water (in m)	< 1	9	13
		1–50	7	
		50–100	5	
		> 100	3	

Photograph 2 Tube well in a rural area of the Kulsi basin

Photograph 3 Tube well in an urban area of the Kulsi basin

the generation of topographic information. The elevation of the lower Kulsi river basin varies from 40 m near Nagarbera (where Kulsi joins into the Brahmaputra River) to 1120 m above mean sea level at Um Tynrai hilltop. A slope map is prepared with the help of DEM using spatial analysis tools of Arc GIS 10.6 software (Fig. 5b). The slope of the basin has been categorized into five classes: level (0–5), gentle (5–15), moderate (15–30), high (30–45), and very high (> 45). The gentle and level-sloping area has prioritized a suitable groundwater potential zone.

Soil: As per the soil map of the National Bureau of Soil Survey and Land-use Planning, the lower Kulsi River Basin is composed of five different categories of soil texture they are coarse-silty, clay, fine-loamy, coarse-loam, and fine soil with above 1 m deep (Fig. 6). The soil type plays a vital role in the amount of water infiltrated into the sub-surface and contributes to groundwater recharge (Ibrahim-Bathis and Ahmed 2016; O'Leary et al. 1976). Soil with a low infiltration rate and highly permeable soil is most suitable for high groundwater potential. Therefore, fine soil gives high priority, and clayey, coarse loam and fine loam soil provide a low priority to delineate the potential groundwater zone.

Geology: The spatial geological data available on the Geological Survey of India website, www.gsi.gov.in, are used to delineate potential groundwater zone. Figure 7 explains that the upper catchment area belongs to the age of the Proterozoic with dolomite, amphibolite, and Grey-pink porphyritic Granite structure. Highly fractured & weathered rock in the upper catchment structure is considered ideal for highly potential groundwater, and high weight is assigned to such rocks.

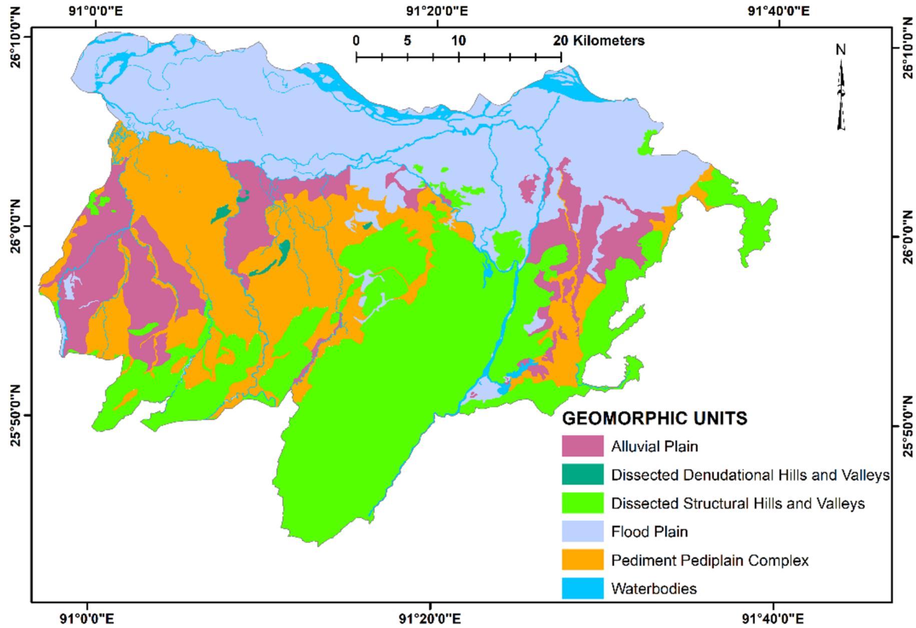

Fig. 3 Major geomorphic unit of the study area extracted from the Geological Survey of India (GSI)

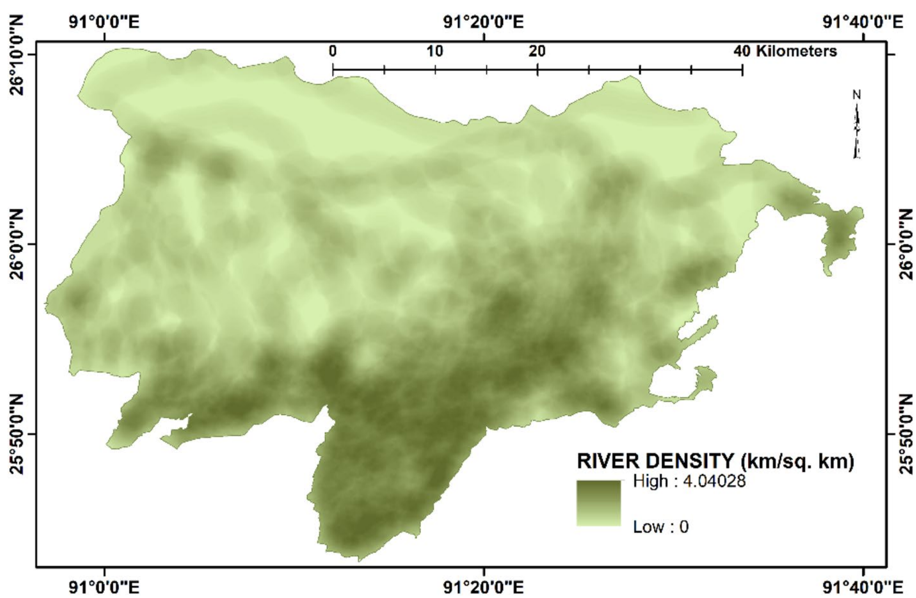

Fig. 4 River density map prepared from stream network

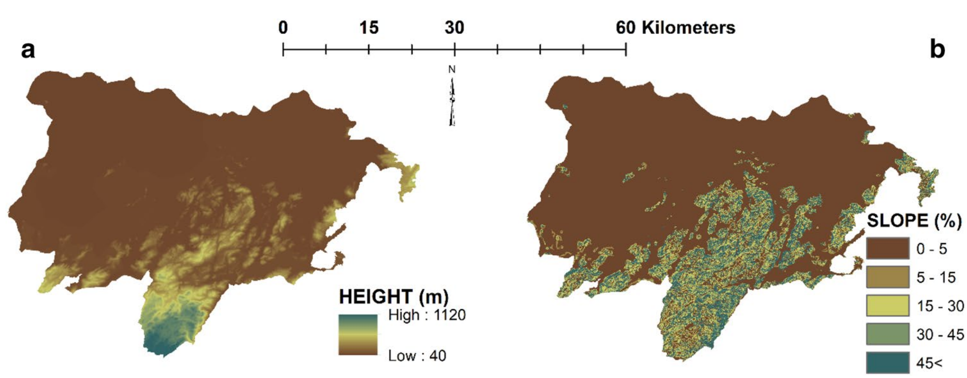

Fig. 5 a DEM prepared from of 20 m contour interval of the topographic map, **b** slope map of the lower Kulsi basin

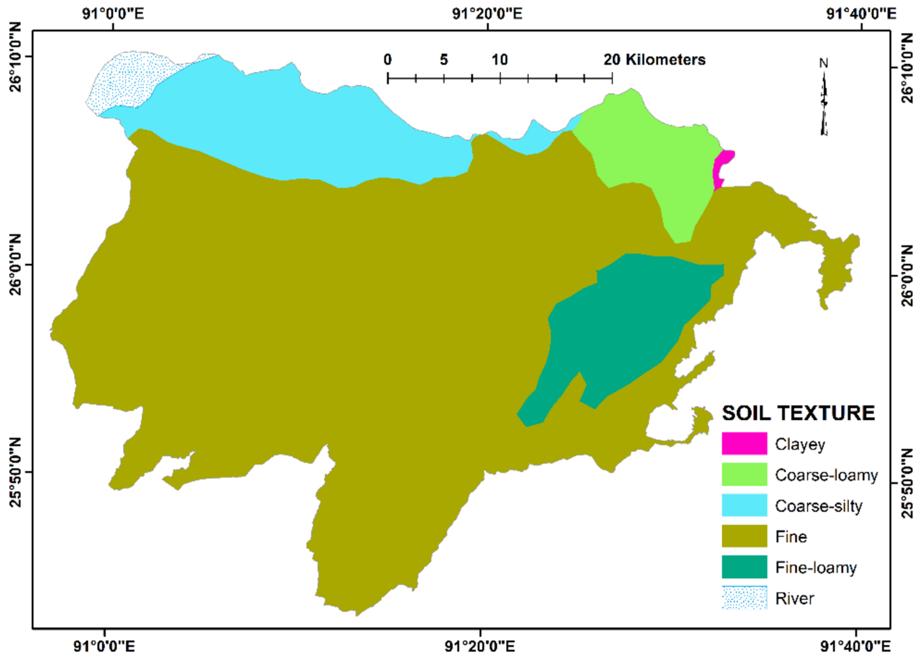

Fig. 6 Soil texture map of the lower Kulsi basin extracted from NBSS & LUP

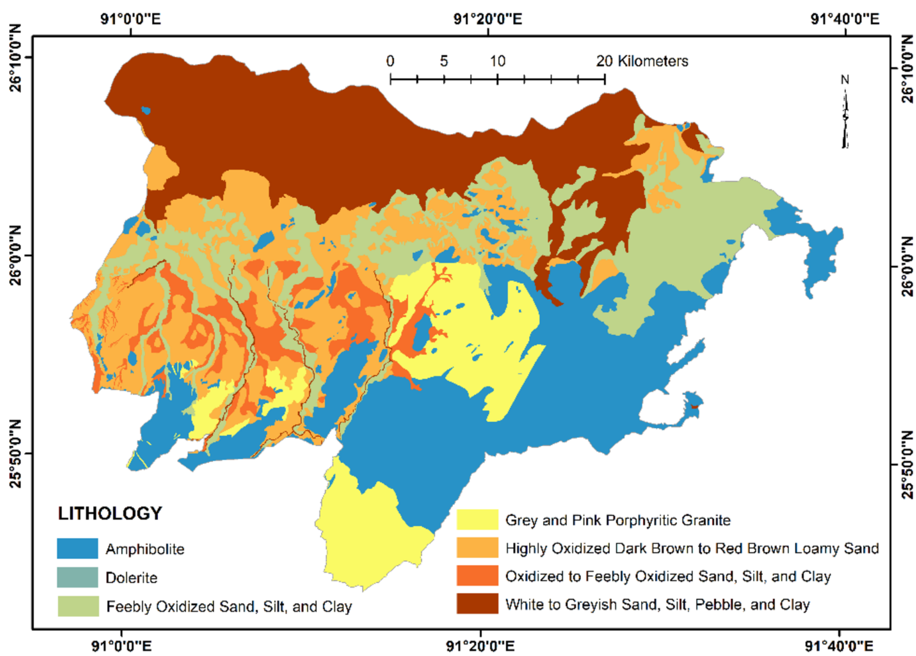

Fig. 7 Geological map of the lower Kulsi basin extracted from the Geological Survey of India (GSI)

Lineament density: O'Leary et al. (1976) define lineament as 'a mappable, a linear feature of the earth surfaces whose parts are aligned in a rectilinear or slightly curvilinear relationship and differ from the pattern of adjacent elements and presumably reflect some subsurface phenomenon' (Das 2017). The lineament represents the zone of faulting and fracturing, resulting in increased porosity and permeability (Yeh et al. 2016). It is the best geologic unit that helps to collect and store water at high capacity. Therefore, high-density lineament surface areas were given high weight to recharge groundwater. The geological lineament features data was collected from the website of the Geological Survey of India, www.gsi.gov.in, to prepare a lineament density map using the line density arc tools in GIS software. The lineament density of the Lower Kulsi river basin varies from 0 to 74 km/sq. Km (Fig. 8). The lineament density map was reclassified into five categories. High weight is assigned for high lineament density to delineate the potential groundwater zone.

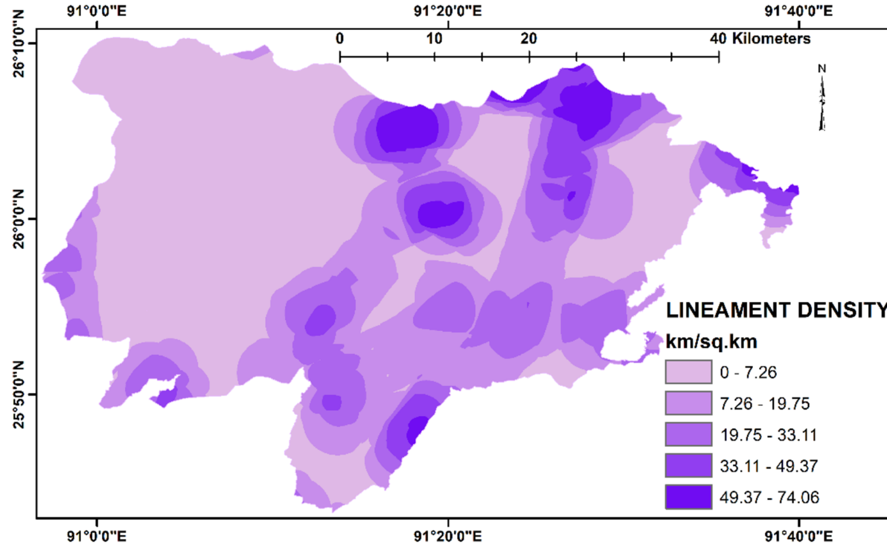

Fig. 8 Lineament density map of the study area prepared from the lineament feature extracted from the Geological Survey of India (GSI)

Rainfall: The Kulsi river basin experiences a southwest monsoon with high precipitation in the pre-monsoon period. Rainfall is the primary input of the hydrological cycle and the most dominant influencing factor for water resources management. The low infiltration and more surface runoff largely depend on the high intensity of rainfall in a short period (Thapa et al. 2017). The present study used ten years of average annual rainfall data from 2009 to 2018. The study area has only two rain gauge stations, Boko and Guwahati Airport. However, seven stations were used to estimate the rainfall distribution map more accurately. The rainfall distribution map was prepared using Interpolate Distance Weight (IDW) method in GIS software. IDW is the preferable method for measuring a river basin's smooth rainfall distribution in terms of mean error (Bakis et al. 2021). Figure 9 shows that the average annual rainfall of the study area varies from 1604.31 mm to 2280.83 mm. The high weights are assigned for high rainfall to delineate the potential groundwater zone.

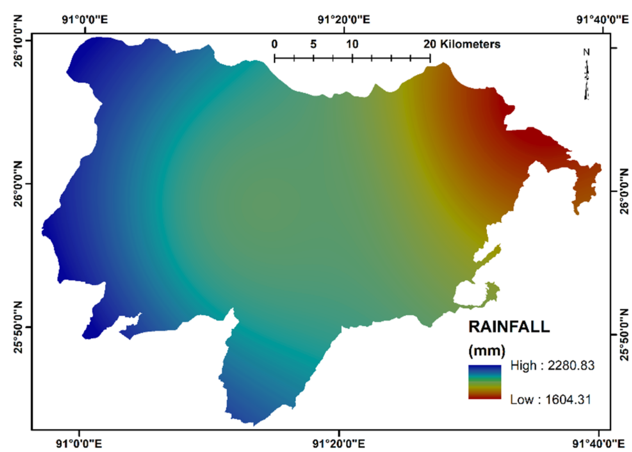

Fig. 9 Average annual rainfall distribution of the lower Kulsi River basin (2009 to 2018)

Land use/land cover (LULC): The variation of LULC of a watershed gives essential information on the interpretation of infiltration, surface runoff, soil moisture & groundwater. The LULC is the most influencing factor in the soil and water management plan. The LULC of the study area is delineated from the high spatial resolution satellite data (IRS LISS IV, DOP 26/01/2018) based on visual interpretation techniques in the GIS environment. The correctness of the LULC information derived from satellite images was assessed using the Kappa coefficient. There are 500 ground control points taken for the assessment. The Kappa coefficient was 0.828, indicating almost perfect strength of agreement between classified and ground truth data. The LULC of the study area is classified into 14 different types (Fig. 10). Forest and tea plantation areas are assigned high weight, and the land use of settlement, bare land, crop, road & railways give low weight for delineation of the groundwater potential zone. The watersheds' available surface water (ponds & wetlands), a large river, and associated marshy land influence more groundwater recharge and, thus, extreme weight for such land use.

Groundwater potential zone

The result of the groundwater potential model is based on a total of nine influencing criteria, namely geomorphology, soil, geology, lineament density, slope, drainage density, rainfall, LULC, and surface water of the lower Kulsi River basin. Table 6 illustrates the extent of the potential groundwater zone of the lower Kulsi River basin. The resultant map (Fig. 11) is categorized into very low, low, moderate, high, and very high potential groundwater zone. The very high groundwater potential zone constitutes only 6.7% of

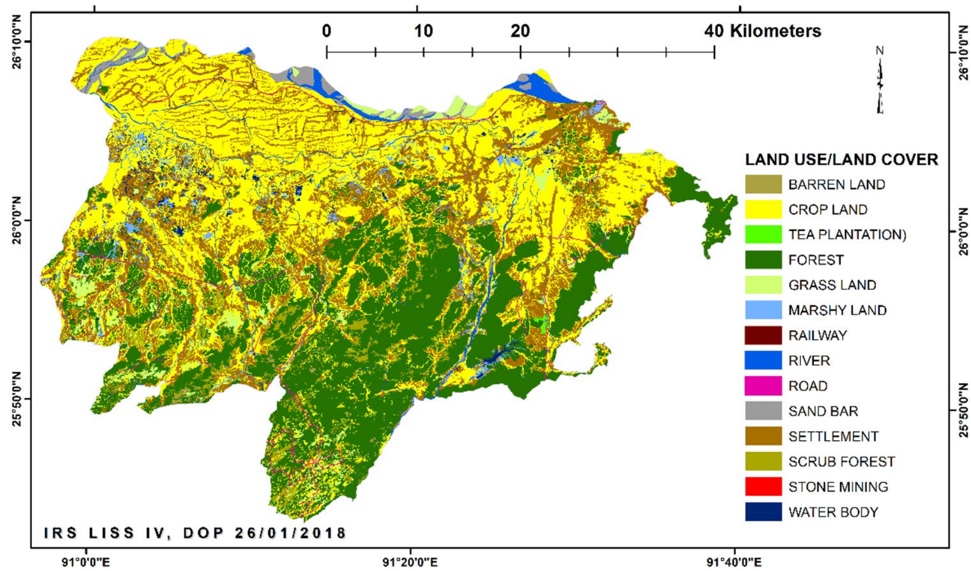

Fig. 10 Land use/land cover classification of the lower Kulsi basin using high spatial resolution satellite data

Table 6 Areal extent of the potential groundwater zone of the lower Kulsi basin

Sl. No	Groundwater potential zone	Area in km^2	Area in %
1	Very low	17.25	0.88
2	Low	486.74	24.87
3	Moderate	624.04	31.89
4	High	697.37	35.64
5	Very high	131.17	6.70
Total		1956.60	

the study area. It is mainly found on the bank side of the Brahmaputra River and is a remarkable wetland area of the basin. The high groundwater potential zone occupies the most significant space, about 31.89% of the total area. The moderate groundwater potential zone is seen in the central part of the study area, which constitutes 24.87%. The lower groundwater potential zone occupies about 25.81% of the total area, principally located in the basin's southern structural and hilly denudation area. Accordingly, 57.77% of the basin needs to improve its groundwater prospect through

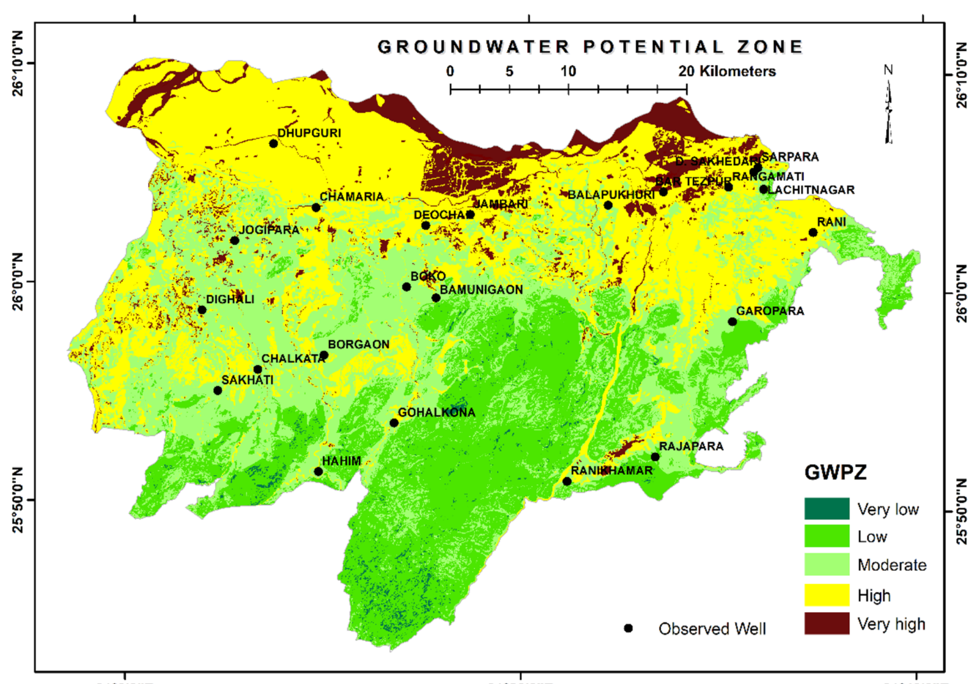

Fig. 11 Groundwater potential zone of the lower Kulsi basin based on the nine most influencing criteria layer using AHP and GIS techniques

proper land and water resource management and sustainable development.

Results validation

The combined AHP and GIS-based model output of potential groundwater mapping were validated with the overlaying observed governmental records of tube wells and analyzing the published groundwater data of Central Ground Water Board, NER, Guwahati. Table 7 illustrates the locations, yielding capacities, and depths of 23 different tube wells over the last 20 years of observation of CGWB NER in the study area. Of the 23 wells, 14 are located in a high groundwater potential area, with a yielding capacity ranging from 17 to 46 m^3/hr. Eight wells are located in the moderate category of groundwater potential zone with 3 to 13 m^3/hr., yielding capacity. Only one well is located in the low-potential site. Still, the yielding capacity of the well is 11.16 m^3/hr., which is not matched fully due to the location of the well in the margin between moderate and low groundwater potential zone. No observed wells are found in very high and very low categories of potential groundwater zone. Table 8 illustrates the hydrogeological condition and groundwater prospect of the study area. About 639.39 km^2 (32%) basin area is occupied by structural and denudation hills with low to the deficient category of groundwater zone and water yielding capacity up to 5m^3/hr. Groundwater is restricted to 50 m, especially in weathered fracture joint structures. The hydrogeologic condition of surface water, river, and marshy land on young alluvial plains, including older flood plains and active flood plains occupying 113.87 km^2 (6%) area, are relatively thick, and extensive aquifers are drawdown up to the depth of 150 m. The yielding capacity of such a groundwater zone is very high, 150–200 m^3/hr. The moderate and low potential groundwater zone with moderately thick aquifer within 150 m depth hydrogeological conditions are characterized by geomorphic units like older alluvial plain, piedmont alluvial plain, and pediment complex. The yielding capacity of groundwater here is up to 150 m^3/hr., and the drawdown is within 12 m. Therefore, delineating potential groundwater zone using AHP and GIS techniques is based on nine contributing layers—geomorphology, soil, geology & lineament density, slope, drainage density, land use/land cover, and available

Table 7 Observed groundwater data of Tube Wells and their estimated potential zone

Sl no	Name	Longitude	Latitude	Yield (m^3/hr.)	Well depth (m)	Estimated Groundwater Potential Zone
1	Borgaon	91°09′58″	25°57′09″	29.52	120	High
2	Jogipara	91°05′15″	26°02′00″	44.94	189.0	High
3	Chalkata	91°06′30″	25°56′10″	20.94	101.9	High
4	Rani	91°34′30″	26°02′42″	38.00	200	High
5	Bamunigaon	91°15′28.8″	25°59′31.2″	29.52	87.85	High
6	Bar Tezpur	91°26′9.6″	26°5′2.4″	17.00	100	High
7	Boko DW	91°14′00″	26°00′00″	10.40	106.7	Moderate
8	Chamaria	91°5′31.2″	26°4′8.4″	37.92	200	High
9	Balapukhuri	91°24′08″	26°04′00″	13.50	201.3	Moderate
10	D. Sakhedari	91°31′30″	26o5′27.6″	26.00	92.45	High
11	Deochar	91°14′45.6″	26°7′44.4″	33.15	120	High
12	Dhupguri	91°7′8.4″	26°6′28.8″	23	92.7	High
13	Garopara	91°30′30.56″	25°58′35.8″	7.66	171.1	Moderate
14	Gohalkona	91°13′26.4″	25°53′45.6″	23.00	53.1	High
15	Hahim	91°9′21.6″	25°51′54″	46	90	High
16	Jambari	91°17′9.6″	26°3′21.6″	29.52	89.55	High
17	Lachitnagar	92°32′0.276″	26°4′40.58″	9.58	136.4	Moderate
18	Rajapara	91°26′41.20″	25°52′21.4″	11.16	180.6	Low
19	Rangamati	91°30′25.2″	26°6′7.2″	11.82	189.45	Moderate
20	Ranikhamar	91°22′ 14.19″	25°51′11.4″	10.80	119.74	Moderate
21	Sakhati	91°04′00″	25°57′15″	7.20	181.3	Moderate
22	Sarpara	91°31′4.8″	26°5′49.2″	3.00	251.3	Moderate
23	Dighali	91°3′38.16″	25°58′48″	28.50	153	High

Source: Groundwater information booklet of Kamrup & Kamrup Metro district, Assam, (CGWB, NER 2013)

Table 8 Hydro geomorphic unit of the lower Kulsi basin and groundwater prospect

Sl. no	Hydro geomorphic unit	Hydro geomorphic subunit	Hydrogeological condition	Groundwater prospect
1	2	3	4	5
1	Structural Hills and Valleys	Highly Dissected Structural Hills and Valleys Moderately Dissected Structural Hills and Valleys	Groundwater is restricted to 50 m depth in weathered residues, joints, and fractures having secondary porosity Thickness is 5–15 m in the weathered zone	Low yield prospect up to 5 m^3/hr Dug wells are feasible in weathered zones Boreholes at fractured zone at selected points
2	Denudation Hills and Valleys	Moderately Dissected Denudation Hills and Valleys Low Dissected Denudation Hills and Valleys		
3	Pediment	Pediment Pedi plain Complex	Moderately thick but discontinuous confine & unconfined aquifers, a thickness of 10–50 m within 50–100 m depth	Suitable for shallow tube well with a 10–20 m^3/hr yield Deep tube well with 100 m depth and yield capacity of about 30–50 m^3/hr Dug well feasible at foothills
4	Alluvial Plain	Piedmont Alluvial Plain Older Alluvial Plain		
		Younger Alluvial Plain	Relatively thick and regionally extensive confine & unconfined aquifers. Aquifer thickness, 30–70 m within 150–300 m depth	Large yield prospect Suitable for shallow tube wells with 30-50m^3/hr Deep tube wells of 150–200 m depth yield 50–150 m^3/hr
5	Flood Plain	Older Flood Plain Active Flood Plain		

Source: Central Ground Water Board, https://www.cgwb.gov.in

surface water bodies, and distribution of rainfall pattern is validated successfully.

Conclusion

The paper can conclude that the study has successfully demonstrated an integrated AHP and GIS-based method for evaluating the groundwater potentiality of the Kulsi River basin using nine input criteria that directly and indirectly influence groundwater. The lower Kulsi basin is categorized into the very low, low, moderate, high, and very high potential groundwater zones. Moderate, low, and very low potential zone are predominantly located in the southern hills and foothills and covers 57.77% of the basin area, which needs to improve its groundwater prospect through proper land and water resource management. The resultant output of the model has been validated successfully and can be applied to delineate potential groundwater zone. The model offers a valuable means for identifying the potential groundwater zones for planning and implementing soil and water conservation measures. As the basin's 755.64 km^2 (39%) area occupies the agricultural field, the groundwater potentiality map will help in sustainable water resource development, improve irrigation facilities crop productivity, and regulate groundwater recharge through proper land and water resource action plan. Therefore, the research will contribute to developing the water resource department of countries' local governments and communities if the groundwater potential map is used for the water resource development plan.

In this research, the potentiality of groundwater was delineated using high-resolution satellite data (5 m) for the first time with reasonable accuracy of the LULC map, DEM with 20 m contour interval to evaluate groundwater potential map more accurately. The results can be improved by improving the input of more rainfall stations within the basin and a large-scale soil map to more accurately delineate the potential groundwater zone.

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Data availability Data will be made available on reasonable request.

Declarations

Conflict of interest There is no conflict of interest.

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