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ORIGINAL ARTICLE

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An application of Analytical Hierarchy Process (AHP) technique for identifying groundwater potential zones in West Tripura district, Tripura, India: A case study

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ABSTRACT

Groundwater is the most prominent supplier of fresh water to mitigate the water demands in day-to-day life. It fulfils the urge for water requirements for domestic, agricultural, industrial, and other developmental purposes. The present study mainly focused on identifying groundwater potential zones in West Tripura since it has the most populous and urbanised district. The Analytic Hierarchy Process (AHP) technique was adopted as a part of the Multi-Criteria Decision Analysis (MCDA) approach for gauging the potential groundwater areas by determining the quantitative weights of controlling factors are geomorphology, slope, lithology, soil type, rainfall, LULC, drainage, topographic wetness, curvature, topographic position, and lineaments. All the factors related to thematic layers are assigned to weight and overlayed in the geospatial environment to identify the groundwater potential zones (GWPZ). The outcome of the investigation is that the total area of excellent and good groundwater potential is 260.32 km^2 (27.60%), followed by 520.13 km^2 (55.17%) under the moderate potential zone. Consequently, 82.77% of the area falls within the groundwater potential zone, while 17.23% is under the poor potential zone. The ROC (Receiver Operating Characteristics) curve has been prepared to validate the groundwater potential map of the West Tripura district.

HIGHLIGHTS

- Identification of the groundwater potential zones has been done using the Analytic Hierarchy Process for assigning weightage to the 11 parameters.
- Highest groundwater potentiality exists in flood plains and lunga areas.
- Poor groundwater potentiality exists in tilla and hilly areas.

1 | INTRODUCTION

Water is an inevitable natural resource for the existence of life in any form, and civilization from ancient times depends on its availability. Among all different sources, groundwater is the most reliable source of fresh water. In the global context, 34% of the clean water supply is groundwater (Magesh *et al*., 2012). It supports the lives and livelihood of two billion people worldwide (Misi *et al*., 2018). In India, 85% of people drink and use groundwater for domestic purposes, and 60% of groundwater is extracted for irrigation activities (Mukherjee and Singh, 2020). With the growth of developmental activities, the overexploitation of groundwater has already raised issues on its sustainability. Excessive groundwater extraction for domestic, agricultural, and plantation areas negatively impacts Tripura's groundwater level (Paul *et al*., 2019). Managing the groundwater potential areas is considered the highest priority in this context. The term groundwater potential is used to identify the possible areas for groundwater availability on the regional scale. Earlier, the conventional study was driven by geology, lithology, hydrogeology, and geophysics to delineate the potential zones of groundwater, which were more laborious and time-consuming. However, the high-resolution images in the geospatial environment have made the delineation easier (Manap *et al.,* 2013). Through GIS analysis, the geometric and non-geometric relations between different relevant parameters have exposed and enhanced the accuracy of output of spatial distribution with the application of Frequency Ratio, Weights of Evidence, Artificial Neural Networks, and Fuzzy logic to identify groundwater potential zones. Most of these statistical techniques assume results before investigation and fail to integrate subjective preferences or to manage the complex multiple criteria (Thapa, 2017). In this case, the Analytic Hierarchy Process (AHP) follows a structured approach that is transparent, simple, and reliable in decision-making. It develops a hierarchy among the criteria, makes a pairwise comparison matrix, calculates relative weights, and prepares a consistency check of the priority weights (Singh *et al*., 2019). Thus, AHP is a significant approach for delineating groundwater potential zones. It analysed the relative importance of each relevant parameter with assigned weights according to their involvement. This paper attempts to delineate the groundwater potential zones in the West Tripura district with the integration of GIS and the Analytic Hierarchy Process. It will help planners and government officials identify vulnerable groundwater areas and plan for its sustainable use.

2 | MATERIALS AND METHODS

2.1 | Study Area

West Tripura district is situated in the western part of the hilly state of Tripura. It extends from 23˚40'N to 24˚07'N and 91˚12'E to 91˚32'E (Fig.1). The district is covered with four geologic formations, namely Bokabil, Tipam Sand Stone, Dupitila, and Present-Day Deposit. Bokabil formation of hard sedimentary rocks is found in the Baramura hill range. Dupitila and Tipam sandstone covers highly dissected tillas and a few parts of valley-fill areas, whereas present-day deposit is found in flood plains. Morphologically, the district is structured with hills, tillas, lungas (paleo-channels), and flood plains. All those physical features impact the subsurface water storage of the study area. Haora is the main river originating from the Baramura range, flows towards the western direction of the study area, and enters Bangladesh. The river is significant as most settlements are growing up in its floodplains. Though West Tripura is one of the prosperous districts in Tripura, agriculture is the primary source of income in rural households. The flood plains and lungas are fertile for agriculture, so farmers practise *kharif* and *rabi* crops yearly. *Kharif* crop cultivation depends on monsoon rainfall, but the *rabi* crops are cultivated under open bore wells, and few pockets depend on pumping river water. The monsoon rainfall is irregular, the farmers have to rely on groundwater for irrigation in the *kharif* season. Thus, the pressure on groundwater is gradually increasing daily in the West Tripura district.

2.2 | Methods

LULC has been extracted from Landsat 8 OLI satellite images by classifying with Maximum Likelihood Classification in GIS. Lineaments, slope, curvature, and drainage density have been extracted through raster calculation of SRTM DEM, and rainfall data has been collected for the past decade from the India Meteorological Department (IMD) at a 0.25-degree gridded scale. Geomorphology, lithology, and soil data have been extracted as shapefiles from GSI and NBSS-LUP (National Bureau of Soil Survey and Land Use Planning) (Table 1).

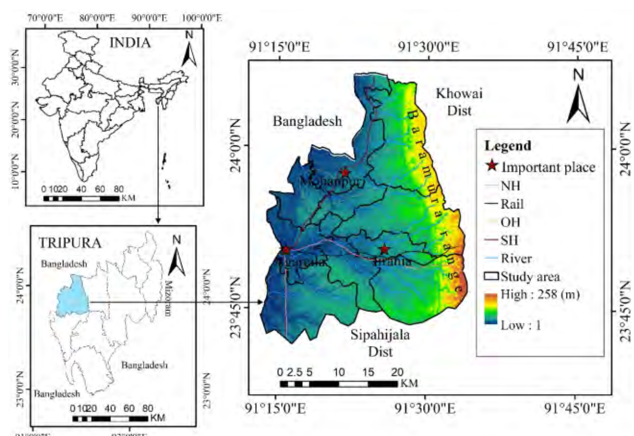

FIGURE 1 Location map of the study area

TABLE 1 Data for groundwater potential zone

Criteria	Source
Geomorphology	Collected from the Geological Survey of India
Slope, Curvature	Analysed from DEM through a raster calculator
Rainfall	IMD Grided data https://www.imdpune.gov.in
Lithology	Collected from the Geological Survey of India
Soil type	National Bureau of Soil Survey and Land Use Planning https://esdac.jrc.ec.europa.eu/content/tripura-soils-sheet-1
Lineament & Drainage density, TWI, TPI	Calculated through raster calculator in ArcGIS 10.7
Land use Land cover	MLC used on Landsat 8 OLI

2.2.1 | Topographic wetness index (TWI)

The Topographic Wetness Index is named as Compound Topographic Index or Topographic Moisture Index and can be calculated by following the formula:

$TWI = ln\,(A/\tan\beta)$

Where A is the Catchment area and $\tan\beta$ is the slope in degree. The high value represents wet topography, and the low value represents drier area.

2.2.2 | Topographic position index (TPI)

The Topographic Position Index (TPI) represents the difference in height between the central cell and its surrounding neighbouring cells. TPI has been calculated following the ESRI script (Jenness, 2006). The high positive TPI value represents the cell height higher than the neighbouring cell, whereas the high negative TPI value represents the cell height lower than the neighbouring cells. The positive high value represents the hilltop and mountain, whereas the low value represents the valley bottom, and near zero represents the plain land. The following formula has been accepted for the calculation of TPI.

$$TPI = To - \frac{(\sum_{n-1} Tn)}{n}$$

Where To = Heights in the central cell, Tn = elevation of the grid, and n = total number of surrounding point elevation.

Next, rasterisation, re-projection, and resampling were formulated to bring homogeneity among the collected data layers into a 30 m cell size and the WGS 1984 coordinate system. Finally, all the raster layers were weighted and overlayed to calculate the groundwater potential zones (Fig. 2).

2.2.3 | Analytic hierarchy process (AHP)

The Analytic Hierarchy Process (AHP) has been applied to assign the relative weights of the interrelated parameters to identify the potential groundwater zones. It is the crucial tool in Multi-Criteria Decision Analysis (MCDA) to simplify the relation between various critical parameters by creating a pairwise comparison matrix. A scale from 1 to 9 has been employed to give quantitative importance to the parameter (Saaty, 1980). The importance of parameters has been assessed through discussion with professional experts in the study area. The formulation of a pairwise comparison matrix is a significant part of AHP. The column value of each variable is divided by the sum of column values and creates normalisation. After that, the average of the row value has been divided by the number of criteria to assign

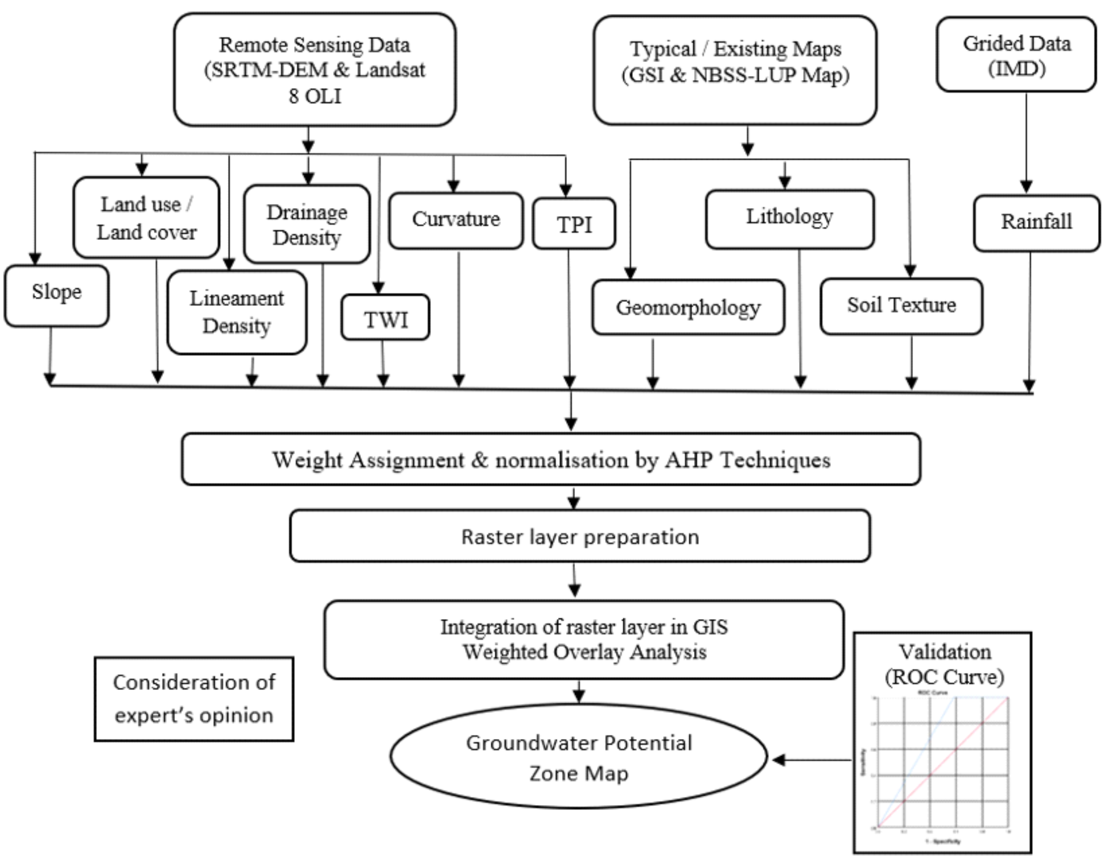

FIGURE 2 **Flow-chart to identify the groundwater potential zones**

the relative weights. The consistency ratio has been worked out to check the validity of the weights prepared through the comparison matrix. If the CR value is less than 0.1 or equal, the variable's relative importance has been considered accurate. To calculate the priority vector, the weighted sum value of the component matrix has been divided by the number of criteria.

$$\lambda_{max} = \frac{C1 + C2 \ldots. Cn}{n}$$

Where (λ_{max}) is the priority vector. C1…Cn expresses the weighted sum value of PCM, and '*n*' represents the number of criteria.

The following formula has calculated the consistency index.

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

Random Index (R.I) has been randomly generated depending on the number of elements. The table for R.I is :-

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49	1.51	1.54	1.56	1.57	1.58

Finally, the Consistency Ratio (CR) has been calculated by adopting the formula.

$$CR = \frac{CI}{RI}$$

Where CR represents the consistency ratio, CI is the consistency index, and RI is the random index.

2.2.4 | Weighted overlay analysis

To explore the groundwater potential zones, Weighted Overlay Analysis has been performed with the raster data set (Fig. 2). The formula is:

GWP = [(Gmw) (Gmwi) + (Slw) (Slwi) + (Rfw) (Rfwi) + (Liw) (Liwi) + (Stw) (Stwi) + (Ldw) (Ldwi) + (Ddw) (Ddwi) + (TWIw) (TWIwi) + (TPIw) (TPIwi) + (Cuw) (Cuwi) + (LULCw) (LULCwi)]

Where, GWP = Groundwater potential, Where Gm = Geomorphology, Sl = Slope, Rf = Rainfall, Li = Lithology, St = Soil texture, Ld = Lineament Density, Dd = Drainage density, TWI = Topographic Wetness Index, TPI = Topographic Position Index, Cu = Curvature, LULC = Land Use and Land Cover, 'w' is the normalised weight of the criteria matrix, and 'wi' represents the weight of individual subclasses.

3 | RESULTS AND DISCUSSION

3.1 | Geomorphology

Geomorphology is important in forming groundwater zones (Paramaguru *et al*., 2020). It influences surface water movements and sub-surface water flow according to the topography, affecting local and regional scales. According to the Geological Survey of India (North-Eastern division), West Tripura district's geomorphologic setup is composed of four major types of morphological units, like moderately dissected hills, highly dissected tillas, pediment pediplain complex, and younger alluvial plains. The moderately dissected hills are found in the eastern part, occupying an area of 154.29 km² (16.37%), interrupting the surface water from infiltrating because of the high topography gradient and allowing faster surface runoff. In contrast, the younger alluvial plain covers an area of 221.67 km² (23.52%) with minimal gradient, and gentle topography provides more time for water stagnation and increases the chance of percolation. It can be observed that alluvial aquifers are one of the most significant sources of groundwater. The highly dissected land occupied an area of 460.66 km² (48.86%) spread out and channelled surface water towards the lunga. The lunga land comprises the pediment pedi-plain complex covering an area of 99.44 km², 10.55% of the total study area (Table 4). Therefore, the tilla (upland) and hills have poor water storage, but lunga (low land) and flood plains have the potential for groundwater recharge; they accumulate all the surface flow from the uplands (Fig. 3a).

3.2 | Lithology

Lithology has substantial influences on the percolation of water. It determines surface water infiltration (Sapkota *et al*., 2021). According to the lithologic distribution map, the maximum land areas of the West Tripura district are under ferruginous sandstone, which makes a poor contribution to groundwater recharge due to its petrographic characteristics. This type of lithology is observed in the southern part of the districts and found parallelly along the Baramura hill ranges. It covers an area of 546.63 km², which is 57.98% of the total study area. The north and north-western parts of Agartala plains have porous sandy and silty clay lithology that allows water to percolate and recharge the local aquifer. It occupies an area of 190.81 km², which is 20.25% of the total land area. The unstabilised sand, silt, and clay cover an area of 47.49 km² along the Haora river basin. It is the most convenient lithology for groundwater recharge. Conversely, the shale, siltstone, and sandstone occupy a hilly area of 157.74 km² and are devoid of groundwater recharge (Fig. 3b).

3.3 | Land Use and Land Cover

Land use land cover is one of the determining factors of the groundwater recharge process (Raju *et al.,* 2022). The land cover and land utilisation of an area represent the interception layer, which firstly intercepts with precipitation. The precipitated water flows further as the surface runoff or penetrates through the interception layer, contributing to the aquifer's recharge. Each land use class has allowed a particular rate of percolation. The study area has been divided into eight land use land cover classes, namely natural vegetation, rubber plantation, settlement, agricultural land, water body, barren land, shrubland, and tea plantation, influencing the water recharge capacity. The most suitable land for water percolation is agricultural land and water bodies, occupying 16.42% and 3.38%, respectively. Moderate infiltration has been found in natural vegetation, rubber plantations, tea plantations, and shrubland, occupying 26.35%, 22.41%, 5.39%, and 3.25% area, respectively (Table 4). Settlement and bare land occupy 21.34% and 1.41% of the area, causing hindrances to groundwater recharge in West Tripura (Fig. 3c).

3.4 | Soil Texture

Soil texture plays a crucial role in the percolation of water. The coarse texture allows water to penetrate easily rather than the fine texture. In the study area, soil texture varies from clay to coarse loam. According to the estimated global hydrologic soil classification, the predominant hydrologic soil groups within West Tripura are C (<50% sand and 20-40% clay) and D (<50% sand and >40% clay) categories. These are mainly characterised by moderate high and high potential for surface runoff (Ross *et al*., 2018). In this case, terrain plays a controlling role as the eastern hilly land has a coarse texture than the western plain land. However, the eastern region is not competent for groundwater storage because of the steeper slope characteristics. Conversely, the flood plains located in the western part with clay to fine loam soil texture can store groundwater and allow percolation of the surface runoff. The maximum part of the study area covered with fine loam having undulating topography is moderately suitable for groundwater recharge. It covers an area of 414.75 km² which is 44.01% of the total study area (Table 4). The terrain characteristics allow water to move through the minute particles quickly. However, the wet soils have high runoff potential (regardless of texture) due to a groundwater table within 60 cm of the surface (Fig. 3d).

3.5 | Slope

The slope has a direct and indirect impact on the groundwater level. It influences the infiltration of subsurface water, which ultimately determines the groundwater recharge. The higher degree of slope increases surface runoff but hinders water percolation. On the contrary, a lower slope increases the chances of water infiltration because the water percolation rate exceeds the runoff. The slope varies from 0° to 2° have been categorised as the level slope due to flat topography and high water concentration. It covers an area of 160.09 km² which is 16.98% of the total study area. The slope ranges between 2° to 5° and is considered a gentle slope due to its nearly flat topography, which has the potential for groundwater recharge. It covers an area of 490.25 km² which is 52.02% of the total study area. Undulating topography has been observed between 5° to 10° slope, which is considered moderate. It covers an area of 234.46 km² which is 24.87% of the total study area. A

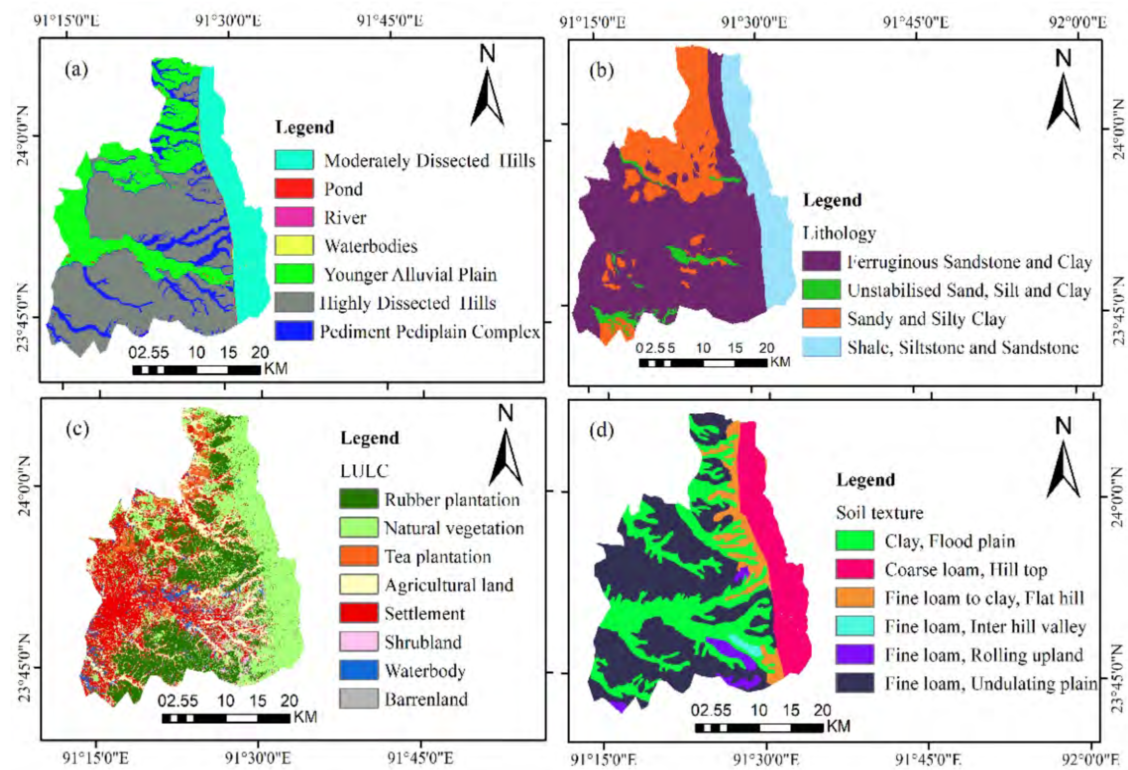

FIGURE 3 a) Geo-morphology b) Lithology c) LULC d) Soil texture of the study

moderately steep slope is unsuitable for groundwater recharge as it falls under hilly topography. It covers an area of 45.16 km² which is 4.79% of the total study area (Table 4). In steep slopes, runoff exceeds the infiltration; thus, it is unsuitable for groundwater recharge. This land covers an area of 12.71 km², which is 1.34% of the total study area (Fig. 4a).

3.6 | Rainfall

The amount of rainfall intensity and duration of the rainy season have predominant control in the development of the aquifer and fluctuation of the groundwater table (Bora and Krishnaiah, 2020; Krishnaiah, 2014). The rate of precipitation and duration are positively correlated with the possibility of groundwater recharge. According to IMD climatic classification, the district falls under tropical monsoon, which receives maximum rainfall between May to Sept. The average rainfall data for the last ten years has been taken from IMD gridded data, clipped, and resampled accordingly. The rainfall map has been divided into five classes: (i) 2459 to 2540, (ii) 2385 to 2459, (iii) 2305 to 2385, (iv) 2206 to 2305 and (v) 2099 to 2206 mm. The maximum rainfall of 2459 to 2540 mm exists in the northern part of the district, which covers an area of 131.99 km². It is 14% of the total study area. The rainfall gradually decreases toward the southern part, and minimum rainfall between 2099 to 2206 mm is observed in the 112.87 km² area. It is 11.97% of the total study area (Fig. 4b).

3.7 | Lineament Density

Lineaments are the linear structures in the earth's topography representing the fracture zones. The cracks, joints, rupturing, and structural alignments of topography provide pathways for sub-surface flow. More infiltration is generally feasible when there is a higher degree of lineaments. This study extracts lineaments by analysing the high-resolution satellite images in GIS. Very high lineament density has been observed at the pediments of Baramura hill range and the conjunction of tilla and lunga topography. It covers an area of 43.84 km² which is 4.62% of the total area. Very low lineaments have been observed in the 485.04 km² area, which is 51.46% of the total study area (Table 4). It is mainly found in the district's western part and upland areas (Fig. 4c).

3.8 | Drainage Density

Drainage density plays a significant role in groundwater formation. On the other hand, high drainage density promotes channelised surface run-off, while low density facilitates the inland flow of surface water. The drainage density in the study area is prepared by constructing line density using spatial analysis tools of ArcGIS 10.7. It is found that high drainage density in the study area is associated with the major rivers. The different drainage density classes are very high density (45.38 km²), high density (146.82 km²), moderate density (218.99 km²), low density (262.49 km²) and very low density (268.99 km²). All lunga, charas, and

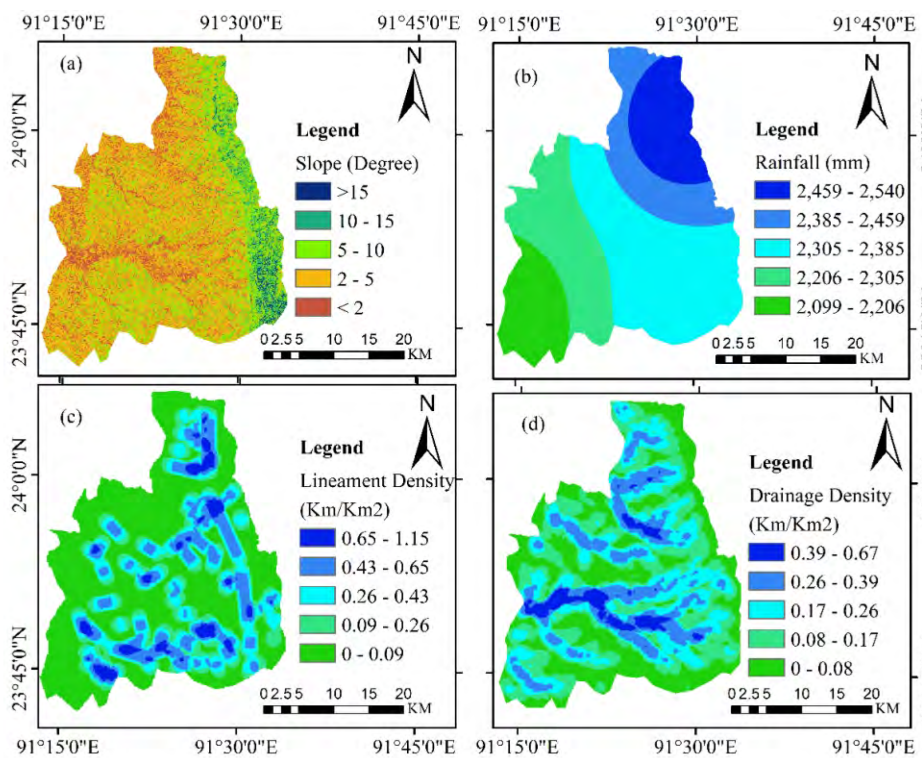

FIGURE 4 a) Slope b) Rainfall c) Lineament density d) Drainage density of the study area

nalas increase the drainage density and groundwater possibility in the West Tripura district. Rainwater during monsoon season is retained by forming a bundh between lunga and charas, which is later used for cultivation. So, the nearby land of lunga, nala, chara, and rivers is the most potential area for groundwater zones (Fig. 4d).

3.9 | Topographic Wetness Index (TWI)

The value of Wetness ranges from 3.54 to 23.38. The study area has been classified into five classes, namely very high (14.43 to 23.38), high (10.93 to 14.43), moderate (8.52 to 10.93), low (6.65 to 8.52), and very low (3.54 to 6.65). In West Tripura, high topographic wetness has been found along the river basin, flood plains, and Lunga areas, while low to very low wetness has been observed in the hills and tilla areas. Hence, river basins, flood plains, and lunga areas have more potential for groundwater recharge (Fig. 5a).

3.10 | Curvature

Curvature determines the water accumulation and deceleration rates. In the study area, curvature values range from -6.73 to 8.98. The extreme value of curvature is observed in the eastern hilly part, while low to flat curvatures are found in plain land, flood plains, and lunga areas. The water percolation rate is high among the concave surface of flood plains and lunga areas. So, these landforms have the potential to recharge groundwater. The study area has been classified into five curvature classes: very low (-6.73 to -0.81), low (-0.81 to -0.26), flat (-0.26 to 0.16), high (0.16 to 0.66), and very high (0.66 to 8.98) (Fig. 5b).

3.11 | Topographic Position Index (TPI)

TPI value in the study area has varied from -71.24 to 78.45. Five distinct landform classes have been identified from TPI value in West Tripura, i.e., very high (13.87 to 78.45), high (3.31 to 13.87), moderate (-3.37 to 3.31), low (-13.71 to -3.73), and very low (-71.24 to -13.71). The high TPI value represents the hills and tilla areas, whereas the low TPI value represents the district's plain lands, flood plains, and lunga areas. So, low TPI areas have much more potential for groundwater recharge than high TPI areas (Fig. 6).

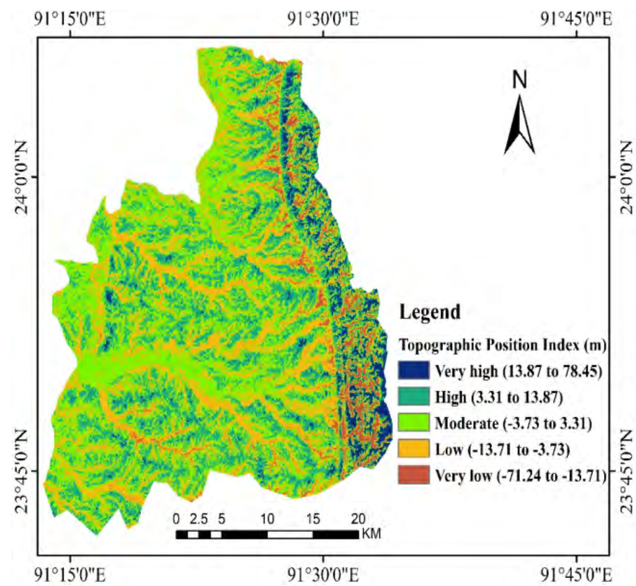

FIGURE 6 Topographic Position Index (TPI) of the study area

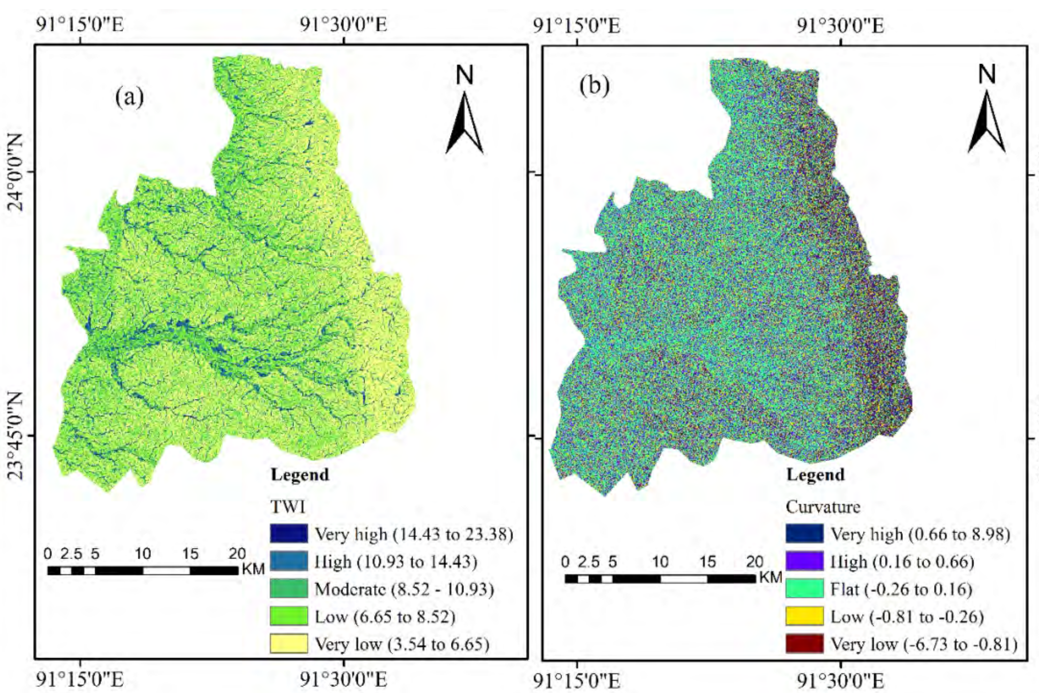

FIGURE 5 a) Topographic Wetness Index, b) Curvature of the study area

3.12 | Groundwater Potential Zones

The potential zones have been mapped using the Analytic Hierarchy Process (AHP) technique. A pair-wise comparison matrix has been calculated using Satty's scale of relative importance (Tables 2 and 3).

The groundwater potential map suggests that the study area has four different kinds of potential zones, namely excellent, good, moderate, and poor. The excellent groundwater classes occupy 1.62% (15.33 km^2), the groundwater level is found good at 25.98% (244.99 km^2), moderate is observed at 55.17% (520.13 km^2), and poor groundwater potential is found at 17.23% (162.22 km^2) area (Fig. 7). These categories are extracted based on the combinations of the GWPZ delineations parameters. Where rainfall, drainage density, geomorphology, lithology, topography (TWI &TPI), slope, and soil texture influence more than lineaments, curvature, and LULC (Table 3). Rainfall and drainage have been given the maximum priority weights of 16.8% and 16.2%; these are the primary sources of groundwater recharge. Drainage accumulates runoff, which increases the possibility of surface water percolation. The available literature and research on this topic published by National and State government authorities and other agencies have identified various suitable groundwater table heights according to the preceding combinations of controlling factors. Finally, the delineated area having 2 meters and less groundwater table height is considered very high or excellent potential. In this case, the area under the excellent category is located alongside the Haora River, Dhonai Gang, Kala Chara, Ghoramara Chara, and Lohar Nala basin scattered over the Agartala plain. The poor potential areas are mainly characterised by tillas, dissected hills, and hill ridges where the groundwater is found at a lower level, the severity of water scarcity prevails and is accordingly observed in the southeastern part of the district. These areas are significant where the water level

TABLE 2 Pair-wise comparison matrix of study parameters

Parameters	Gm	Sl	Rf	St	Li	Dd	TWI	TPI	Ld	Cu	LULC
Gm	1.000	1.000	0.500	3.000	3.000	0.333	0.500	1.000	3.000	5.000	6.000
Sl	1.000	1.000	0.500	1.000	1.000	0.333	0.500	3.000	2.000	5.000	7.000
Rf	2.000	2.000	1.000	2.000	2.000	1.000	2.000	3.000	5.000	5.000	7.000
St	0.333	1.000	0.500	1.000	0.500	0.500	1.000	0.500	5.000	5.000	5.000
Li	0.333	1.000	0.500	2.000	1.000	0.500	1.000	1.000	5.000	7.000	5.000
Dd	3.000	3.000	1.000	2.000	2.000	1.000	2.000	1.000	3.000	5.000	6.000
TWI	2.000	2.000	0.500	1.000	1.000	0.500	1.000	2.000	2.000	3.000	5.000
TPI	1.000	0.333	0.333	2.000	1.000	1.000	0.500	1.000	1.000	3.000	7.000
Ld	0.333	0.500	0.200	0.200	0.200	0.333	0.500	1.000	1.000	3.000	5.000
Cu	0.200	0.200	0.200	0.200	0.142	0.200	0.333	0.333	0.333	1.000	3.000
LULC	0.166	0.142	0.142	0.200	0.200	0.166	0.200	0.142	0.200	0.333	1.000

Where Gm= Geomorphology, Sl= Slope, Rf= Rainfall, St= Soil texture, Li= Lithology, Dd= Drainage density, TWI= Topographic Wetness Index, TPI= Topographic Position Index, Ld= Lineament density, Cu= Curvature LULC= Land use & Land Cover

TABLE 3 Normalized Pair-wise comparison matrix of study parameters

Parameters	Gm	Sl	Rf	St	Li	Dd	TWI	TPI	Ld	Cu	LULC	Weight
Gm	0.087	0.082	0.093	0.205	0.249	0.056	0.052	0.071	0.108	0.118	0.105	0.112
Sl	0.087	0.082	0.093	0.068	0.083	0.056	0.052	0.214	0.072	0.118	0.122	0.096
Rf	0.175	0.164	0.186	0.136	0.166	0.170	0.209	0.214	0.181	0.118	0.122	0.168
St	0.029	0.082	0.093	0.068	0.041	0.085	0.104	0.035	0.181	0.118	0.087	0.084
Li	0.029	0.082	0.093	0.136	0.083	0.085	0.104	0.071	0.181	0.165	0.087	0.102
Dd	0.263	0.246	0.186	0.136	0.166	0.170	0.209	0.071	0.108	0.118	0.105	0.162
TWI	0.175	0.164	0.093	0.068	0.083	0.085	0.104	0.143	0.072	0.070	0.087	0.104
TPI	0.087	0.027	0.062	0.136	0.083	0.170	0.052	0.071	0.036	0.070	0.122	0.084
Ld	0.029	0.041	0.037	0.013	0.016	0.056	0.052	0.071	0.036	0.070	0.087	0.047
Cu	0.017	0.016	0.037	0.013	0.011	0.034	0.034	0.023	0.012	0.023	0.052	0.025
LULC	0.014	0.011	0.026	0.013	0.016	0.028	0.020	0.010	0.007	0.007	0.017	0.016

λ = 12.1813, CI =0.1181, CR = 0.0777, RI = 1.52

Where Gm= Geomorphology, Sl= Slope, Rf= Rainfall, St= Soil texture, Li= Lithology, Dd= Drainage density, TWI= Topographic Wetness Index, TPI= Topographic Position Index, Ld= Lineament density, Cu= Curvature LULC= Land use & Land Cover

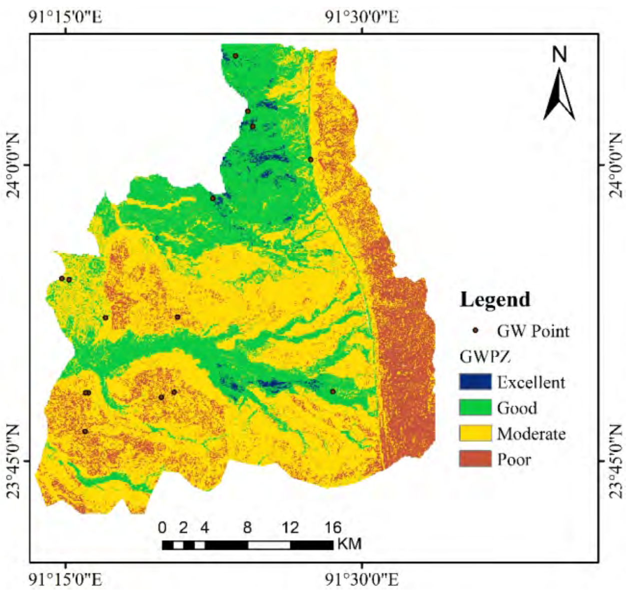

FIGURE 7 Groundwater potential zone of West Tripura District

depth is more than 10 meters. This implies that one has to dig deeper to reach the water table in these regions. When the groundwater level crosses 10 meters, sophisticated equipment is required to extract it. For this adverse situation, the area should be considered and equipped with deep borewells and pipelines to continue the water supply.

Physiography and climate play an important role in the groundwater recharge of the West Tripura district. The district exhibits a typical geomorphic feature like valley ridge topography where valley, hills, tilla and lunga are the main physiographic features (Ramesh, 1983). The district is under tropical monsoon climate, so the uncertainty of rainfall and heterogenous topography creates surface water availability imbalance in this region (Phukan and Saha, 2022). Thus, man has to depend on groundwater during dry seasons and even in the monsoon gap period. In this aspect based on the analysis, it can be sum-up that, the valley and lunga area of the district accumulate surface water and become mostly potential areas for groundwater recharge due to their concave slope and geological structure. In

TABLE 4 Normalised weight for groundwater variables of study area

Variables	Classes	Area (km²)	Area (%)	Sub-score	Normalised weight	Weight (%)
Geomorphology	Highly dissected structural tilla	460.66	48.86	2	0.112	11.2
	Pediment Pediplain complex	99.44	10.55	4		
	Younger alluvium	221.67	23.52	5		
	Pond	3.36	0.36	4		
	River	1.42	0.15	5		
	Waterbody	1.83	0.19	4		
	Moderately dissected hill	154.29	16.37	1		
Lithology	Ferruginous Sandstone and Clay	546.63	57.98	2	0.102	10.2
	Un-Stabilized Sand, Silt & Clay	47.49	5.04	5		
	Sandy & Silty clay	190.81	20.25	4		
	Shale, Siltstone & Sandstone	157.74	16.73	1		
Lineament Density	0.65-1.15 km/km²	43.84	4.62	5	0.047	4.7
	0.43-0.65 km/km²	128.68	13.67	4		
	0.26-0.43 km/km²	155.54	16.50	3		
	0.09-0.26 km/km²	129.57	13.75	2		
	0-0.09 km/km²	485.04	51.46	1		
Soil Texture	Clay, Floodplain	285.70	30.28	5	0.084	8.4
	Coarse loam, Hilltop	146.84	15.58	3		
	Fine loam to clay, flat hill	62.97	6.68	2		
	Fine loam, Inter hill valley	6.72	0.71	4		
	Fine loam, Rolling upland	25.69	2.72	1		
	Fine loam, Undulating plain	414.75	44.01	3		
Drainage	Very high (0.39 to 0.67)	45.38	4.81	5	0.162	16.2
	High (0.26 to 0.39)	146.82	15.57	4		
	Moderate (0.17 to 0.26)	218.99	23.23	3		
	Low (0.08 to 0.17)	262.49	27.85	2		
	Very low (0 to 0.08)	268.99	28.53	1		
Rainfall	2459-2540 mm	131.99	14.00	5	0.168	16.8
	2385-2459 mm	137.97	14.64	4		
	2305-2385 mm	354.86	37.65	3		
	2206-2305 mm	204.98	21.74	2		
	2099-2206 mm	112.87	11.97	1		

TABLE 4 Continued....

Variables	Classes	Area (km²)	Area (%)	Sub-score	Normalised weight	Weight (%)
LULC	Rubber plantation	211.29	22.42	3	0.016	1.6
	Natural vegetation	248.43	26.35	4		
	Tea plantation	50.89	5.40	2		
	Agricultural land	154.81	16.42	5		
	Settlement	201.33	21.35	1		
	Shrubland	30.71	3.26	4		
	Waterbody	31.90	3.38	5		
	Bare land	13.31	1.42	1		
Slope	Steep (>15)	12.71	1.34	1	0.096	9.6
	Moderately steep (10 to 15)	45.16	4.79	2		
	Moderate (5 to 10)	234.46	24.87	3		
	Gentle (2 to 5)	490.25	52.02	4		
	Level (0 to 2)	160.09	16.98	5		
TWI	Very high (14.43 to 23.38)	23.75	2.52	5	0.104	10.4
	High (10.93 to 14.43)	99.47	10.55	4		
	Moderate (8.52 to 10.93)	119.39	12.66	3		
	Low (6.65 to 8.52)	311.33	33.02	2		
	Very low (3.54 to 6.65)	388.73	41.25	1		
Curvature	Very high (0.66 to 8.98)	85.09	9.01	1	0.025	2.5
	High (0.16 to 0.66)	240.73	25.54	2		
	Flat (-0.26 to 0.16)	403.66	42.82	5		
	Low (-0.81 to -0.26)	181.72	19.29	4		
	Very low (-6.73 to -0.81)	31.47	3.34	3		
TPI	Very high (13.87 to 78.45)	41.80	4.43	1	0.084	8.4
	High (3.31 to 13.87)	248.64	26.37	2		
	Moderate (-3.73 to 3.31)	370.25	39.28	3		
	Low (-13.71 to -3.73)	244.23	25.91	4		
	Very low (-71.24 to -13.71)	37.75	4.00	5		

TABLE 5 Groundwater level data of West Tripura district

Location	Block	Village	Latitude	Longitude	Water level (mbgl) Jan-2017	Observed	Estimated
1	Mohanpur	Mohanpur	23°58'18"	91°22'22"	3.56	Excellent	Excellent
2	Mohanpur	Ishanpur	24°02'43"	91°23'57"	4.71	Good	Good
3	Mohanpur	Simna	24°05'32"	91°23'36"	6.74	Good	Good
4	Hezamara	Subalsingh	24°00'17'	91°27'26"	8.54	Moderate	Moderate
5	Jirania	Champaknagar	23°48'31"	91°28'32"	2.43	Excellent	Good
6	Agartala	Narsinghgarh DTW	23°54'15"	91°14'49"	6.70	Moderate	Moderate
7	Agartala M.C.	Lichubagan STW	23°52'16"	91°17'20"	5.87	Good	Moderate
8	Agartala	Narsinghgarh DTW	23°54'11"	91°15'11"	9.12	Moderate	Moderate
9	Dukli	Suryamaninagar	23°46'30"	91°16'00"	4.71	Good	Poor
10	Agartala M.C	Badarghat	23°48'28"	91°16'10"	2.87	Excellent	Moderate
11	Dukli	Nagicherra OW	23°48'14"	91°19'51"	28.63	Poor	Poor
12	Dukli	Nagicherra EW	23°48'13"	91°19'50"	25.94	Poor	Poor
13	Agartala M.C	Bodhjungnagar STW	23°52'18"	91°20'40"	18.77	Poor	Poor
14	Mohanpur	Simna	24°01'58"	91°24'29"	4.68	Good	Good
15	Agartala M.C	Badarghat DTW	23°48'28"	91°16'01"	3.44	Good	Moderate

contrast, the ridge and tilla have convex slopes that bifurcate surface water outward and remain unsuitable for groundwater recharge (Das *et al*., 2024). Since the highest rainfall occurs in the hilly areas in the eastern part, the rainwater gradually descends down the mountain slopes and begins to accumulate in the low-lying area. The tilla has moderate capacity for water recharge as the slope is relatively less than the hills and the soil texture is from loam to clay. Therefore, the water follows gravity and is trapped in the valley and lungas which has clay to fine loam soil texture

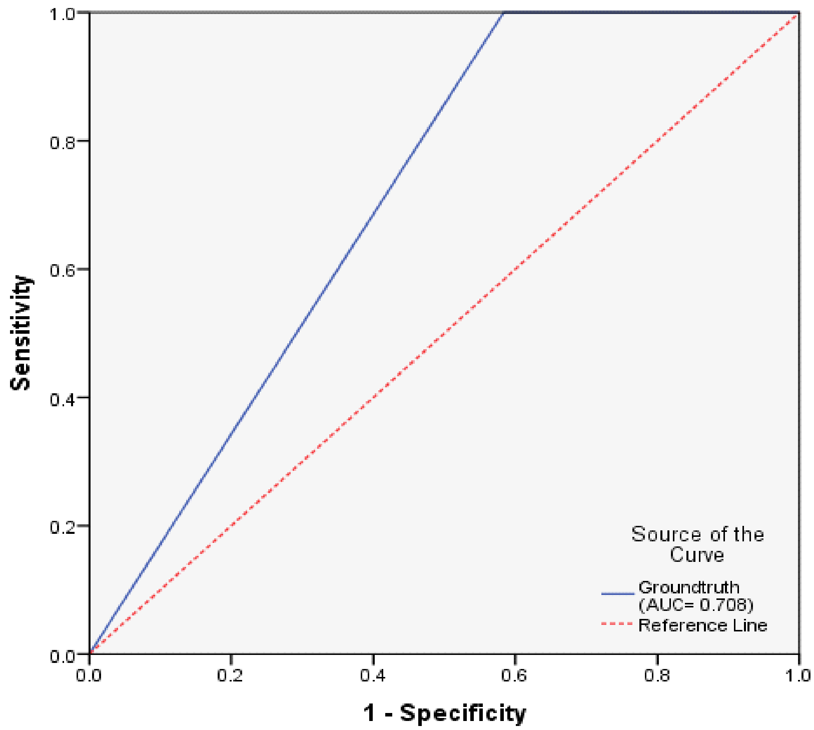

FIGURE 8 **Accuracy assessment through ROC curve (AUC = 0.708)**

with flat slopes. Thus, it slows down the water flow and allows surface water to enter the subsurface vadose zone as the areas are covered with unstable sand, silt and clay lithologic character that increases the possibility of groundwater recharge. The drainage density is high in those low-lying areas where the lunga merges with the main river. As the flow of water in the river is less, the water gets enough time to percolate. Thus, the valley and lunga become the district's most suitable area for groundwater recharge. Whereas the rocky surface made out of shale, siltstone and sandstone in the hilly area prohibits groundwater recharge and becomes poor in groundwater potential.

3.13 | Validation of Groundwater Potential in Different Blocks

Validation is the essential step of the research to establish the work as unique and genuine. In this study, the accuracy of groundwater potential has been assessed using AUC (Area Under the Curve) and ROC (Receiver Operating Characteristics) techniques (Fig. 8). For this purpose, water level data for 15 stations have been compared with the potential map (Table 5). It accesses the sensitivity and specificity of the map. The final output reflects that 70% of the area in this model falls under the curve.

4 | CONCLUSIONS

The present study focused on identifying the groundwater potential zones in the West Tripura district based on eleven parameters using AHP model. Among the selected parameters, rainfall, drainage density, geomorphology, lithology, and topographic wetness are crucial in increasing groundwater recharge. This study reveals that groundwater levels of <2 mbgl with excellent groundwater potential are found in the course of major rivers, nalas, and charas. The north-western part and the Haora river basin have good groundwater potential, where the groundwater level varies between 2 and 5 mbgl. Moderate groundwater potential zones ranging between 5 and 10 mbgl are located in the maximum part of uplands (tilla). A groundwater depth of more than ten mbgl is detected in the hilly area where runoff exceeds infiltration. The AHP model result shows that the district's 1.62% (15.33 km^2) area only has a high potential groundwater recharge. The major parts of the study area fall in moderate and good groundwater potential zones, which are 81.15% (765.12 km^2), and remain in poor potential. This research recommends the construction of check dams, wells, pits, ponds, canals, etc., for the enhancement of the groundwater level and its recharge with funding from the government and the involvement of the local people without harming biodiversity.

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DATA AVAILABILITY STATEMENT

The manuscript incorporates all datasets produced or examined throughout this research study.

CONFLICT OF INTEREST

The author(s) declares no conflict of interest.

AUTHOR'S CONTRIBUTION

Kausik Panja, Debasis Das and Manika Mallick wrote the fundamental frameworks, methods, datasets and interpretation of results. Moumita Hati, Deepa Rai and Atoshi Chakma contributed to the mapping and layout of all the figures and diagrams. Prof. Y.V. Krishnaiah provided valuable instruction on how to frame the work and field expertization in these works. All the authors contributed to the interpretation and reviewed the manuscript.

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