Analyzing Groundwater Potential Recharge Zones Using AHP, RS and GIS Techniques in Bishwamvarpur Upazila, Bangladesh

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Abstract

This study shows the demarcation of capacity zones where groundwater can get recharged in Bishwambharpur Upazila in Sunamganj, Bangladesh by using analytic hierarchy process, remote sensing, and geographic information system techniques. To create thematic maps of several geospatial factors having an immediate or indirect effect on the availability of groundwater, geology, slope, geomorphology, soil, LULC (land-use land-cover), drainage density, lineaments density, and rainfall distribution, remotely sensed and conventional statistics have been obtained from several reasserts and analyzed in GIS software. Integration of AHP with RS and GIS can be embodied as a method that transforms and balances geospatial data, as well as weightage ranking, in order to utilize the information for sensible judgment. Weighted overlay assessment has been used to mix all geospatial elements to assemble a map of the examiner vicinity in which the capacity recharge zones for groundwater may be found. The result reveals the 3 potential zones for groundwater recharge, that is 'good', 'moderate' and 'poor' occupies 26.42 km² (10.7%), 195.92 km² (79.6%) and, 23.66 km² (9.6%) respectively. A significant shift in the trend of groundwater use, especially rising population, the extension of irrigation land, economic growth, and climate change all contribute to an ever-increasing demand for groundwater.

Keywords: Groundwater; Delineation; Potential recharge zone; GIS and AHP

1. Introduction

Throughout the Solar System, the planet earth is a unique one where the environment is suitable for life, and the water resource is the key component that makes it possible. Around 71% of the earth's lithosphere is blanketed with water [1]. Yet, there may be an excessive freshwater shortage for drinking, irrigation, and enterprise considering that saltwater withinside the shape of seas and oceans make 97% of the water on the earth whereas simply around 2% is frozen up icebergs and glaciers withinside the polar regions, and the other 1% as the shape of river structures and underground water [1]. Freshwater is mostly found in groundwater and moving channels [1]. Global water use has elevated by almost six-fold during the last one hundred years and persists to develop regularly around 1 % each year due to population growth, industrialization and patterns shifting in consumption [2]. The global water resource is also affected by climate change in several ways, with complex spatio-temporal patterns, feedback effects, and anthropogenic footprints [3]. Variations in precipitation and temperature will directly affect the surface water budget [4] especially in those regions where rainfall volumes will drop off; this indicates decreasing streamflow volumes and a decrease in freshwater availability in different seasons [5]. As a result, surface water in many locations is not the precise preference for human use and consumption in economic sectors [6-9]. For a minimum of one month every year, almost 4 billion people experience excessive physical water shortage [10]. About 1.6 billion human beings, or nearly one-fourth of the population of the world, face extreme water scarcity, and that means they lack the needful framework to get access to fresh water and as an alternative, they have to rely on river water which is not good for consumption [11]. Groundwater is an invaluable resource that contributes to the survival of terrestrial and aquatic ecosystems and also human societies [12-13]. In nature, freshwater is allocated all over the place and plays an essential part in preserving ecosystem functions, the well-being of people, and economic advancement [14]. Worldwide, within all freshwater withdrawals, groundwater makes up one-third accounting for an approximate 42%, 36%, and 27% of freshwater being used for residential, farming, and industrial uses, respectively [15]. The ever-growing need for groundwater as a result of increasing world-wide population, extending irrigated farming areas, and industrial growth with less regard for the environment has put the strain on groundwater supplies. As a result, depletion of groundwater occurs on an extensive scale, as does the degradation of water quality [16-17]. Groundwater storage fluctuates in different places, and there is a need to detect recharge zones through geospatial technology as a crucial approach for the water management system [18]. Withdrawing unplanned groundwater may result in difficulties to locate water by drilling bore wells [19]. Groundwater exploitation has been unplanned and unmanaged in the Ganga plain region, resulting in the aquifer-stress condition as dropping groundwater depth [20].

Groundwater retention is a constituent of the hydrological cycle that is vital in acquiring water balance [21]. Groundwater aquifers in the subsurface are constrained and vary spatially [22]. This Upazila Bishwambhapur is situated in the Sunamganj district on the Himalayan foothills. Most of the area in this region is made up of marsh clay and peat. Bishwambharpur lies above the Bengal Aquifer System (BAS), which is truly the maximum crucial groundwater reservoir in Southern Asia, underpins the Ganges-Brahmaputra-Meghna (GBM) river system floodplains withinside the Bengal Basin [23]. In the Bengal Basin, over 10 million tube wells have been used to supply fresh water for over 100 million people from the BAS for household use as well as major crops irrigation [24]; Hand-pumped tube wells for residential use abstracts water from about 15m to 30m beneath ground level, and motor-driven water pumps extract groundwater from 50m to 75m below the surface level in the dry season. Municipal water supplies are typically extracted round the year from depths of 200m to 300m below the ground level [25]. Through recharge, it creates stability among groundwater and its exploration. Groundwater recharge is a water beneficial useful resource management approach that is important for regulating water usage and retention price for development, with a focus on semi-arid and arid regions [26-28]. Drilling checks and subsurface stratigraphy investigations are the maximum regularly hired strategies for delineating the placement of wellbores and the thickness of rock layer a good way to study groundwater deposits [29]. However, conventional strategies for identifying the presence of groundwater in an area are high priced to conduct and consume a great amount of time [30-31]. There are many approaches used to demarcate potential groundwater zones where they can be replenished, including geophysical, geological, hydro-geological, and remote sensing techniques [32]. In this 21st century, in order to assess the earth's natural resources, GIS and remote sensing methods play a crucial role [33]. The remote sensing method has the advantage of providing extensive coverage, as well as in inaccessible or remote locations. Remote sensing and GIS strategies require considerably a great lesser amount of time and cost to assess a region's potential zones for groundwater recharge (PZGWR) [34-35]. Remote sensing technology, together with traditional survey maps and the data is surprisingly useful to demarcate groundwater recharge areas [36-37]. For several in advance studies to demarcate zones with groundwater recharge potentiality, incorporating several geospatial factors yielded accurate sufficient results [38-39]. Groundwater availability is predicated upon numerous factors, for instance, geomorphology, drainage density, slope, geology, land use, soil texture, lineament density, and rainfall of an area [40-41]. According to various previous studies conducted around the world, the absence of technical knowledge of analytic geospatial systems makes recharge evaluations ineffective [42-43]. Thus, a sincere evaluation of the parameters can help to get a good and clear conception of the groundwater availability of a region. Also, a good understanding of the physical geography of the study area is necessary for getting the most out of this technique and an accurate result. For making the assessment more positive and accurate, researchers have accompanied numerous techniques or techniques collectively with GIS and RS, for instance, frequency ratio model [44-45], decision-tree model [46-47], multi-criteria decision [48], multi-criteria have an impact on difficulty assessment [49], weights of evidence [50-51], logistic regression model [52-53], fuzzy accurate judgment assessment [54] and random wooded place model [45], etc. In this regard, the analytic hierarchy process (AHP) is appeared as a precise, clear, efficient, and robust approach to delineate the capability zones for groundwater recharge, and it could be used due to the fact the approach or method in conjunction with GIS and RS [55]. The Analytic Hierarchy Process (AHP) is a system that combines math and psychology to organize and analyze complicated choices. It was created in the 1970s by Thomas L. Saaty and has since been improved upon. By defining its parameters and alternative possibilities, and tying those parts to the broader purpose, AHP gives a coherent foundation for a needed conclusion [56].

2. Study area

Bishwambharpur Upazila is situated at the Meghalaya foothills between 20° 01'to 20° 11'North latitude and 91° 12' to 91°24' East longitude in Sunamganj District. In its north is the Meghalaya state of India. In South Sunamganj Sadar and Jamalganj Upazila. In East Sunamganj Sadar Upazila and the Meghalaya state of India. In West Jamalganj and Tahirpur Upazila. Figure

1 represents the study area for this study and shows its relative location. The study area covers about 246 km² and supporting 513 people per km² with a total population of 1,26,259 people according to census 2011. Five rivers flow through this upazilla: Rupsha River, Jadukata river, Rokti river, Monai river and Gondamara river. Among these five rivers, Rupsha and Jadukata are the only perennial rivers. The rest are intermittent and mainly flow during the rainy season.

Bishwambharpur has variety in its geology with “Marsh clay and peat”, “Young gravelly sand” and “Dihing and Dupitila”. As like geology the geomorphology of the area varies with locations and can be identified four different types of geomorphologies. Among all the four types, Meghalaya foothills and Sylhet depression occupies almost the whole area and the middle portion is occupied by the haor basin. As the area is situated near the Meghalayan foothills, over the study area gentle to very strong slope can be found which has significant role in terms of recharge ability of groundwater. There are few fractures throughout the area and helps surface water to seep through them directly to groundwater which are denoted as lineament and has huge impact for finding the suitable recharge zones for groundwater. Two perennial rivers flow through the study area and therefore the drainage density of those locations is higher thus affects the recharge potential. There are four types of soil that can be found in Bishwambharpur which are sparsely located throughout the study area. Acid basin clays and grey piedmont soils occupies more than two-third of the entire area.

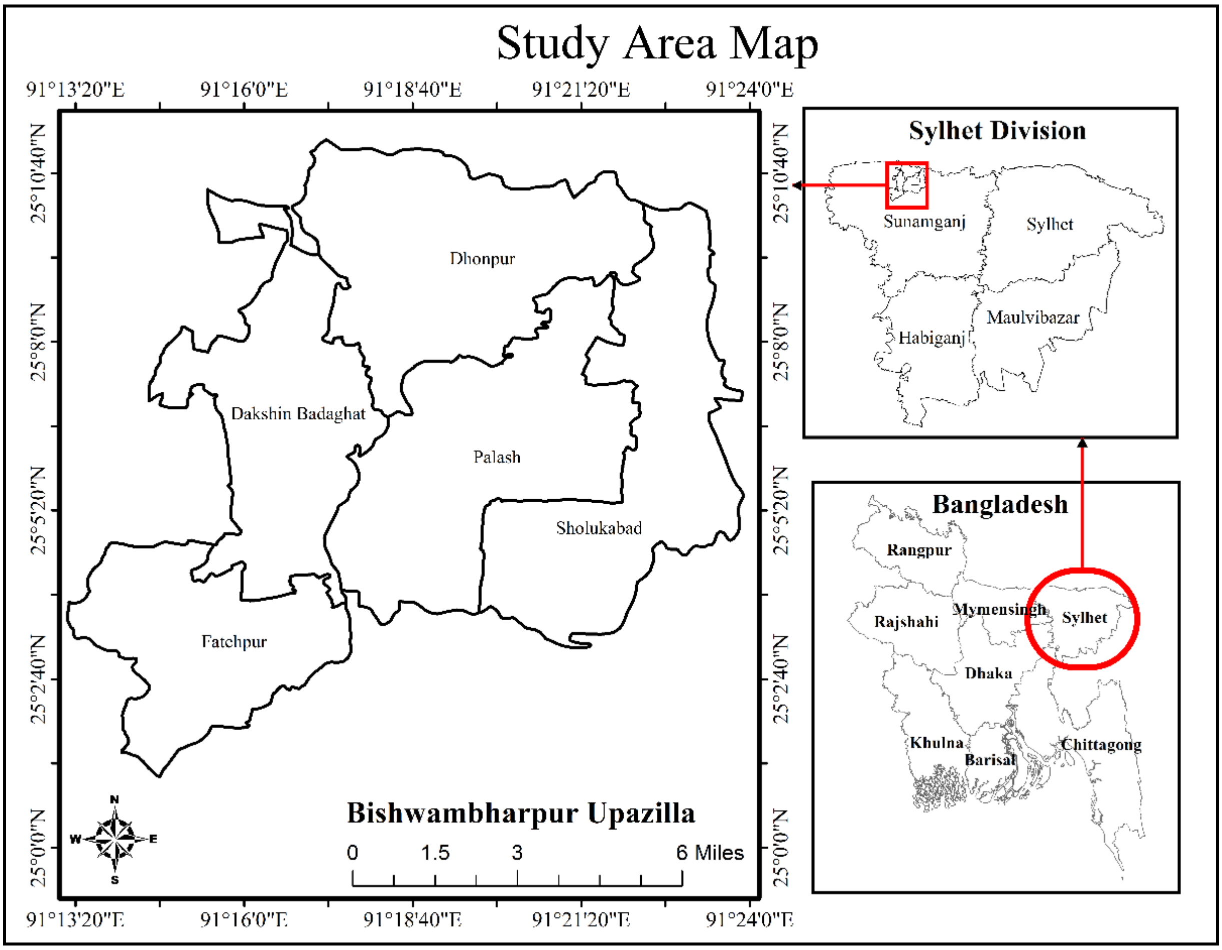
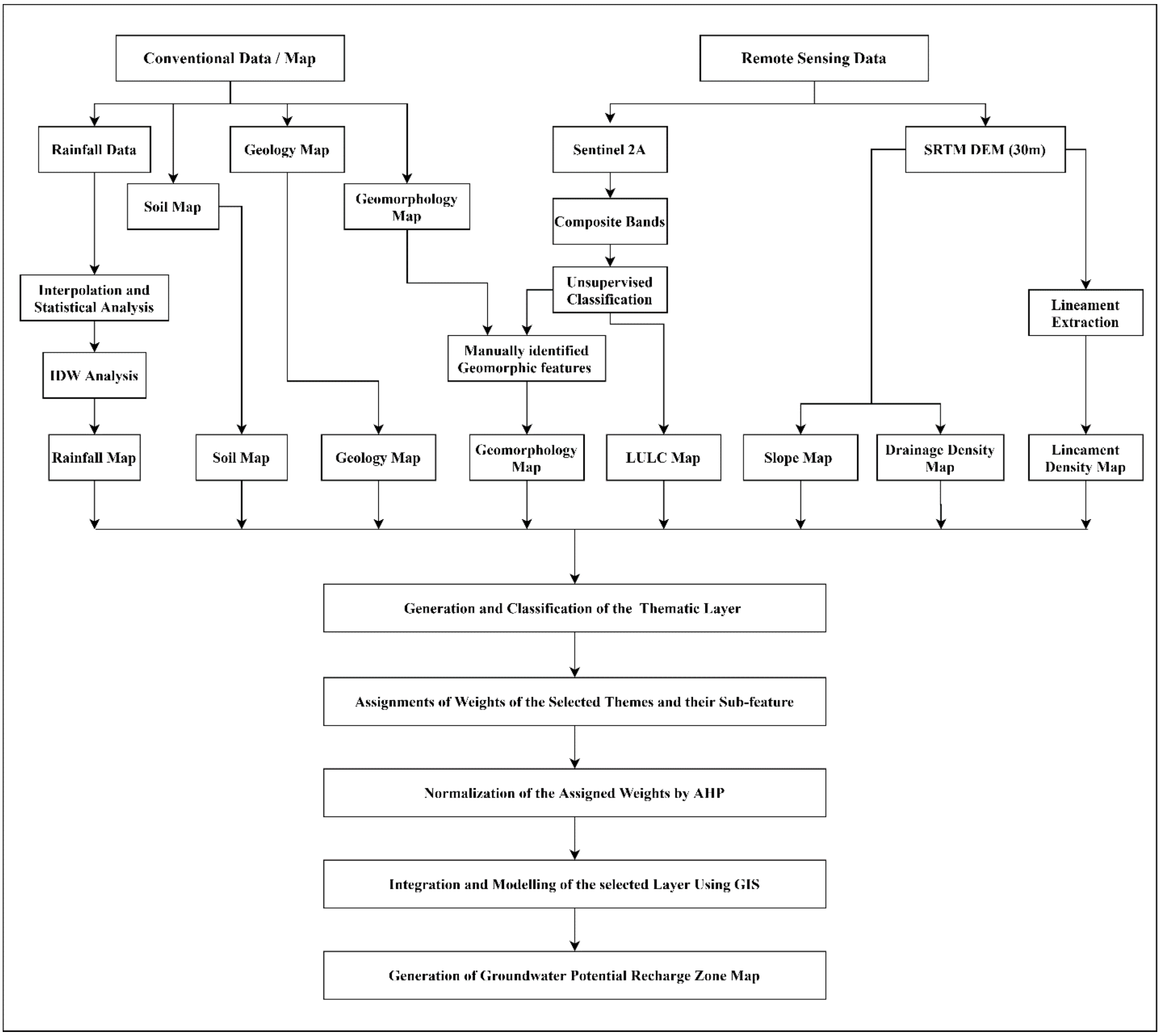


Figure 1. Location of the study area

Bishwambharpur Upazila, just like the rest of Bangladesh, falls under subtropical monsoon weather with huge seasonal fluctuations in precipitation, increased heat, and humidity. The mean annual temperature in Bishwambharpur Upazila is 24.95°C. January is the coldest month inside the year and August is the month with maximum temperature. As the study area is located in the North-eastern zone it gets appreciable amount of rain throughout the year especially during the rainy season. From May to September, the area gets most of the precipitation. This Upazila gets 3365 mm rainfall annually. The western portion of the Upazila is less precipitated than the eastern portion. 37 years of rainfall data was incorporated to observe the rainfall pattern of this area. The more the rainfall the more chances raise for groundwater recharge in an area. The relative humidity of Upazila is 72%. The average daylight hours that the Upazila gets is 12.15 hours, and in June, it is the highest 13.7 hours.

Figure 2. Schematic flowchart for PZGWR methodology



3. Methodology

3.1 Data Collection and Preparation of Geospatial database

In the research area, for identifying the potential zones wherein groundwater can be recharged, 8 geospatial factors have been used and prepared as thematic maps, collectively with land-use land-cover, rainfall, geomorphology, soil, geology, slope, lineament density, and drainage density. These maps have been generated with the use of satellite imagery in addition to numerous conventional data and map sets, collected from various sources.

Rainfall data for the extent of 37 years (1983 -2020) have been gathered from BARC (barc.gov.bd/) and BMD (bmd.gov.bd/); the rainfall map has been prepared using Inverse Distance Weighting (IDW) interpolation calculation method. Digitized soil, geology, and geomorphology maps were collected from the BARC website and were manually evaluated for the correct output. For drainage density and lineament density, SRTM DEM has been obtained from Earthdata (earthdata.nasa.gov/) that was used to extract lineaments in the region and was prepared using

ArcMap 10.6.1 and Geomatica 2013. All the bodily linear functions had been traced by the usage of the lineament extraction device in Geomatica 2013, and the density was analysed in ArcMap 10.6.1. Drainage network and drainage density were delineated incorporating the hydrology and line density tools in ArcMap 10.6.1 software. Land use-land-cover map has been prepared using Sentinel-2A imagery of 15m spatial resolution, acquired from Sentinel Open Access Hub (sentinel.esa.int/), which presents crisp and sharp photographs and is processed using unsupervised classification in ERDAS Imagine 2014 software. SRTM DEM 30-meter resolution imagery has been employed to make the slope map of the research region. The slope of the region was generated in degrees to better understand the output.

After all the geospatial factors have been prepared, each of the sub-factors in all the factors has been assigned with weightage based upon its influence compared to the other sub-factors on the capability of recharge. Then all the weights are normalized with the help of the analytic hierarchy process (AHP) and overlay analysis tool. And the final result is groundwater recharge zones potential.

3.2 Weighting and normalization on the basis of the analytic hierarchy process (AHP) framework

3.2.1 Analytic Hierarchy Process methodology

The analytic hierarchy procedure is taken into consideration as a well-prepared technique primarily on the basis of arithmetic and psychology to arrange and examine complicated decisions. In AHP, constructing judgment or pair-wise judgement matrices is employed to assign weights to the geospatial factors of each rank (classes within factors) and evaluate their perceived value utilizing Saaty's consistency scale (Table 2). The weighting of various factors has been decided using field observations along with an understanding of previous works of literature. The following are the fundamental steps for determining the factors weight and consistency ratio (CR):

Step 1. Pair-wise comparison for the development of judgment matrices (P)

$$P = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ p_{21} & p_{22} & \cdots & p_{2n} \\ \vdots & \vdots & & \vdots \\ p_{1n} & p_{2n} & \cdots & p_{nn} \end{bmatrix}$$

Where the judgment or pair-wise comparison matrix element p_n denote the n^{th} indicator element with p_{nn}.

Step 2. Normalized weight Calculation for factors:

$$w_n = \left(GM_n \,/\, \Sigma_{n=1}^{Nf} GM_n\right)$$

Here, the calculation of the geometric mean of the i^{th} row of the judgment matrices is:

$$GM_n = \sqrt[N_f]{p_{1n}p_{2n}\cdots p_{nNf}}$$

Step 3. Validating the coherence of the judgments by calculating the consistency ratio (CR).

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

The following is the Consistency Index (CI):

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

λ_{max} denotes judgment matrix's eigenvalue, and it is calculated as:

$$\lambda_{max} = \sum_{n=1}^{Nf} \frac{(Pw)_n}{N_f w_n}$$

Where weight vector (column) is represented by "W". Standard tables can be used to calculate the random consistency index (RCI) [57]. To be accepted, the consistency ratio has to be as much as or less than 0.10 [20].

Table 1. Scale of Relative importance.

Importance intensity	1	3	5	7	9	2, 4, 6, 8
Definition	Equal importance	Somewhat more important	Much more important	Very much more important	Absolutely more important	Intermediate values

Source: (Saaty, 1980, p.21)

Table 1 dictates the relative importance of the factors and sub-factors for each parameter that has been used in the study to demarcate the recharge zones potential for groundwater.

Table 2. Index of consistency for random judgements (RCI).

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Source: (Saaty, 1980, p.21)

A comparison of the consistency index and the random consistency index is known as the consistency ratio. Inconsistency is permitted if the consistency ratio value is less than or equivalent to 10%. If the consistency ratio is larger than 10%, the subjective judgment must be revised. The consistency ratio for this study was obtained 8%.

3.3 Delineation of potential zones for groundwater recharge

The geospatial elements are reclassified, and ranks are assigned consistent with their importance in groundwater recharge. Study area's each geospatial factor is sub-divided into multiple classes to figure out the best possible variations in a particular criterion. For each geospatial factor, a pair-wise comparison matrix has been formulated consisting of its sub-features. For this important task author's field experience and existing literature is essential. At the final stage, for generating PZGWR map, weighted overlay analysis (WOA) has been incorporated. Figure 2 depicts the methodology used to demarcate potential zones for groundwater by integrating AHP, GIS, and RS methods. Potential zones for groundwater recharge is calculated as:

PZGWR = 17% x geology map + 8% x geomorphology map + 10% x soil map + 6% x rainfall map + 8% x drainage density map + 27% x lineament density map + 6% x land use land cover map + 18% x slope map

Table 3. Pair-wise comparison matrix developed for weightage calculation for geospatial factors.

	Geology	Soil	Lineament density	Slope	Rainfall	Drainage Density	Geomorphology	LULC	Normalized Weights
Geology	1	3	1/3	1/3	2	3	3	3	0.17
Soil	1/3	1	1/3	2	2	1	1	1	0.10
Lineament density	3	3	1	1	2	5	5	5	0.27
Slope	3	1/2	1	1	2	3	3	3	0.18
Rainfall	1/2	1/2	1/2	1/2	1	1	1	1/2	0.06
Drainage Density	1/3	1	1/5	1/3	1	1	1	2	0.08
Geomorphology	1/3	1	1/5	1/3	1	1	1	2	0.08
LULC	1/3	1	1/5	1/3	2	1/2	1/2	1	0.06

Source: Compiled by Author

Each of the factors having an influence on the occurrence of groundwater in the suitable zone has been assigned with relative importance and normalized weights have been calculated in table 3. These normalized weights have been incorporated along with the designated geographical parameter to get the zones with potential recharge ability for groundwater.

Table 4. Pair-wise comparison matrix for geology.

	Young Gravelly and Sand	Dupitila and Dihing Formation	Marsh Clay and Peat
Young Gravelly Sand	1	3	5
Dupitila and Dihing Formation	1/3	1	3
Marsh Clay and Peat	1/5	1/3	1

Source: Compiled by Author

Among the geological features Young Gravelly Sand is the most suitable and has been assigned with the highest importance whereas Marsh Clay and Peat was assigned with the lowest importance due to its low significance on recharge capability of groundwater (Table 4).

Table 5. Pair-wise comparison matrix for geomorphology.

	Point Bar	Haor Basin	Meghalaya Foothills	Sylhet Depression
Point Bar	1	5	7	9
Haor Basin	1/5	1	3	5
Meghalaya Foothills	1/7	1/3	1	3
Sylhet Depression	1/9	1/5	1/3	1

Source: Compiled by Author

Point bar is a fantastic feature found in nature that portrays a significant part in the groundwater recharge. Thus, Point Bar has been assigned with the highest importance among all other geomorphic features and is followed by Haor Basin, Meghalaya Foothills, and Sylhet Depression (Table 5).

Table 6. Pair-wise comparison matrix for slope

	0°-2°	**2°-5°**	**5°-9°**	**9°-15°**	**15°-52°**
0°-2°	1	3	5	7	9
2°-5°	1/3	1	3	5	7
5°-9°	1/5	1/3	1	3	5
9°-15°	1/7	1/5	1/3	1	3
15°-52°	1/9	1/7	1/5	1/3	1

Source: Compiled by Author

The less the slope the better it is for recharge of groundwater. Therefore, respective gentle slopes have been assigned with much more important numbers than the steeper slopes (Table 6).

Table 7. Pair-wise comparison matrix for LULC.

	Vegetation	**Agricultural Land**	**Buildup Area**	**Water Body**	**Barren Land**
Vegetation	1	1/3	5	1/5	3
Agricultural Land	3	1	7	1/3	5
Buildup Area	1/5	1/7	1	1/9	1/3
Water Body	5	3	9	1	7
Barren Land	1/3	1/5	3	1/7	1

Source: Compiled by Author

Land use land cover has its own effect on the groundwater recharge sometimes by altering the natural settings. Waterbody has been found with the most potential to recharge groundwater and followed by agricultural land, vegetation, barren land, and buildup area (Table 7).

Table 8. Pair-wise comparison matrix for lineament density

	0.015 – 0.026 km/km²	**0.01 - 0.015 km/km²**	**0.005 – 0.01 km/km²**	**0.0006 - 0.005 km/km²**	**0 – 0.0006 km/km²**
0.015 – 0.026 km/km²	1	3	5	7	9
0.01 - 0.015 km/km²	1/3	1	3	5	7
0.005 – 0.01 km/km²	1/5	1/3	1	3	5
0.0006 - 0.005 km/km²	1/7	1/5	1/3	1	3
0 – 0.0006 km/km²	1/9	1/7	1/5	1/3	1

Source: Compiled by Author

Lineaments possess a proportionate relationship with the capacity to recharge groundwater. These lines of fractures are considered as the pathways to groundwater recharge to aquifers. So, the densest part was given the highest value of importance whereas the lowest value was assigned to the least dense part of the study area (Table 8).

Table 9. Pair-wise comparison matrix for drainage density

	0 – 0.48 km/km²	**0.48 – 0.96 km/km²**	**0.96 - 1.44 km/km²**	**1.44 – 1.92 km/km²**	**1.92 – 2.40 km/km²**
0 – 0.48 km/km²	1	3	5	5	7
0.48 – 0.96 km/km²	1/3	1	3	3	5
0.96 - 1.44 km/km²	1/5	1/3	1	3	5
1.44 – 1.92 km/km²	1/5	1/3	1/3	1	3
1.92 – 2.40 km/km²	1/7	1/5	1/5	1/3	1

Source: Compiled by Author

As the drainage density has disproportionate relation with the capacity to recharge groundwater, thus, the lowest dense region has been assigned with the lowest importance whereas the highest dense region was given the lowest importance (Table 9).

Table 10. Pair-wise comparison matrix for soil

	Non-Calcareous Brown Flood Plain	Non-Calcareous Grey Flood Plain	Grey Piedmont Soils	Acid Basin Clays
Non-Calcareous Brown Flood Plain	1	1	3	9
Non-Calcareous Grey Flood Plain	1	1	3	9
Grey Piedmont Soils	1/3	1/3	1	5
Acid Basin Clays	1/9	1/9	1/5	1

Source: Compiled by Author

Both the Non-Calcareous Brown Flood Plain and Non-Calcareous Grey Flood Plain have a great impact on the groundwater recharge and are given the highest importance above other categories. Acid Basin Clays are not so helpful in terms of groundwater recharge thus assigned with the lowest importance (Table 10).

Table 1 1. Pair-wise comparison matrix for rainfall.

	3130-3207 mm	3207-3284 mm	3284-3361mm	3361-3438mm	3438-3515mm
3130-3207 mm	1	1/3	1/5	1/7	1/9
3207-3284 mm	3	1	1/3	1/5	1/7
3284-3361 mm	5	3	1	1/3	1/5
3361-3438 mm	7	5	3	1	1/3
3438-3515 mm	9	7	5	3	1

Source: Compiled by Author

Greater the rainfall greater the chance of groundwater recharge in the respective region, hence, it shows a proportionate relationship between the rainfall and capacity of groundwater recharge. Therefore, the importance was assigned according to the relationship, and the region with the highest rainfall was given the most value and the lowest rainfall region with the least value (Table 11).

4. Results and Discussion

4.1 Geospatial factors used for GWPRZ determination

Geology: Groundwater occurrence and movement rely on the rock composition and its parameters that are different depending on the type of rock, such as its porosity and permeability [58-59]. In Bishwambharpur, three types of geology can be identified. Dihing and Dupitila occupy 41.45 km² (16.85%) of the study area. Dihing and Dupitila formation is a predominantly sand-rich unit of Pliocene-Pleistocene age. The lithology of this region is dominantly sandstone and siltstone with interbeds of claystone. Dihing formation is a Pleistocene rock unit. The unit lies uncomfortably between Dupitila and alluvium. The Dupitila and Dihing formation can't be separated as the formation are mainly sandy with the nature of Dupitila and signatures of Dihing formation, the igneous, metamorphic gravel beds [60]. Young gravelly sand occupies 88.42 km² (35.94%) and was discovered withinside the middle of the region. This young gravelly sand area is highly porous with low permeability and has moderate agricultural potentiality. 116 km² (47.15%) area is made up of marsh clay and peat that is mainly composed of the clay; thus, water permeability is very low. This region in the south and south-western part is also identified as a low agricultural productivity zone (Figure 3a).

Rainfall: Rainfalls are a crucial part of the hydrological cycle and are the main supply for groundwater recharging [61]. The magnitude and geographical extent of precipitation are mainly affected by hydrogeology. The quantity of rainfall and different mixed supportive situations assist to delineate capability zones for groundwater recharge. If the precipitation is high, the probability of groundwater recharge is high, and if the rainfall is poor, the opportunity of groundwater recharge is low. The rainfall charge varies temporally and spatially. Thus, figuring out the effect of rainfall is critical in terms of capability zones for groundwater. For the term 1983-2020, the geographical distribution of the common annual rainfall map become evolved through the use of the Inverse Distance Weighting (IDW) interpolation technique. The study area's rainfall map has been categorized into 5 different categories (Figure 3b). Very high (3,438 – 3,515 mm) zone covers 48.61 km² (19.8%) area. High (3,361 – 3,438 mm) zone covers 66.40 km² (27.0%) area. Moderate (3,284 – 3,361 mm) zone covers 64.71 km² (26.3%) area. Poor (3,207 – 3,284 mm) zone covers 46.80 km² (19.0%) area. Very poor (3,130 – 3,207 mm) zone covers 19.47 km² (7.9%) area. Therefore, the highest rainfall has been assigned with the highest importance and the lowest rainfall with the lowest importance (Table 11).

Slope: The slope is an essential element affecting the accumulation of water and the rate of precipitation infiltration [62]. The correlation between slope and groundwater recharge rate is inversely related. So, the higher importance has been assigned to gentle slopes and lower importance to steeper slopes (Table 6). Gentle slope allows rainwater to percolate for a prolonged period of time than steep slopes. Thus, slope serves as a predictor of suitability for groundwater availability. The study area's slope has been classified into 5 different classes (Figure 3c). Nearly level (0-2°) covers 64.28 km² (26.1%) area. A very gentle slope (2-5°) covers about 106.21 km² (43.2%) area. Gentle slope (5-9°) covers 65.85 km² (26.8%) area. The moderate slope (9-15°) covers 8.88 km² area, and the very strong slope (15-52°) covers 0.78 km² (0.3%) of the study area.

Lineament density: The tectonic interest traces offer a reason for the ground topography and structural tendencies of the sub-ground along increased secondary permeability in which there can be the fault and fracture are higher [63]. It is assumed that lineaments have disproportionate relation with the intensity of fractures. The intensity of fractures increases with decreasing distance from lineaments. Groundwater actions are tons better in difficult rock terrain lineaments and are taken into consideration pathways. In difficult rock terrain lineaments, groundwater actions are significantly better and as a consequence taken into consideration as pathways. Significant capacity groundwater zones are maximum in all likelihood to be determined in excessive lineament segments and regularly used as an indicator [64]. Lineaments are prominent from the Hi-res terrain photo furnished through Vertex. The study area's lineament density has been classified into 5 different zones (Figure 3d). Very low dense zone (0-0.0006 km/km²) comprises 18.69 km² (7.6%) area. Low dense zone (0.0006 – 0.005 km/km²) comprises 56.95 km² (23.2%) area. Moderate dense zone (0.005 – 0.01 km/km²) comprises 88.50 km² (36.0%) area. High dense zone (0.01 – 0.015 km/km²) comprises 62.85 km² (25.5%) area. Very high dense zone (0.015 – 0.026 km/km²) comprises 19.01 km² (7.7%) area. As the densest place suggests extra appropriate for groundwater recharge, weightage changed into assigned as a result from better density to decrease density. Lineament density of the location has been determined by incorporating the following expression:

$$L_d = \sum_{i=1}^{n} \frac{L_i}{A}$$

where lineament density is denoted as L_d, the total length of all lineaments (km) is L_i and A is the area of the location (km²).

Land use land cover: Development and prevalence of groundwater assets are substantially prompted with the aid of using human-triggered activities, and one of the most important practices is the shift in land utilization and land cover. As Bishwambharpur is situated in the Meghalaya foothill and is a haor region, it is also known as one of the few Upazila of Sunamganj which are under intensive crop cultivation. The survey region's land use land cover has been categorized into five different groups (Figure 3e). Buildup area occupies 11.44 km² (4.6%) area, and barren land occupies 28.99 km² (11.8%) area, vegetation occupies 73.36 km² (29.8%) area, agricultural land occupies 121.5 km² (49.2%) area and Water Body with 11.06 km² (4%). For groundwater recharge, water bodies, agricultural land, and vegetation land use, and land covers are considered great sources. In contrast, barren land and buildup areas are considered to be less significant. Therefore, water bodies and agricultural lands are given the most weight, while built-up areas are given the least.

Drainage density: The stream pattern reflects the rate [65] as compared to surface runoff and infiltration of rainfall water [66]. Drainage density reveals the permeability of the riverbed as well as the propensity of the watershed to generate surface runoff, and overall, it implies how channels dissect the terrain of a region. Regions having low drainage density promote a reduced amount of surface runoff and seem to have infiltration rate to a greater extent as well and vice versa. Therefore, the high-density value has been assigned the lower weight as it is not much suitable for groundwater to recharge in that zone (Table 9). The study area's drainage density has been categorized into 5 distinctive categories (Figure 3f). Very low dense zone (0 – 0.48 km/km²) covers 158.94 km² (64.6%) area. Low dense zone (0.48 – 0.96 km/km²) covers 70.66 km² (28.7%) area. Moderate dense zone (0.96 – 1.44 km/km²) covers 14.46 km² (5.9%) area. High dense zone (1.44 – 1.92 km/km²) covers 1.35 km² (0.5%) area. Very high dense area (1.92 – 2.40 km/km²) covers 0.59 km² (0.2%) area. The drainage density of the location has been determined by incorporating the following expression:

$$D_d = \sum_{i=1}^{n} \frac{D_i}{A}$$

where lineament density is denoted as L_d, the total length of all lineaments (km) is L_i and A is the area of the location (km²).

Soil: Soil constitutes a precious parameter for the bodily evaluation of the soil and is strongly associated with the traits of the soil, which includes texture, permeability, adhesion, and coherence [67]. The rate of infiltration and soil permeability relies heavily on soil characteristics, and ultimately, texture affects the identification of groundwater recharge potential. Fine-grained soils come up with a higher retention rate, whereas coarse-grained soils are with high infiltration rate. There are four varieties of soil diagnosed inside the investigation area (Figure 3g). Non-calcareous Grey Floodplain Soils occupy 20 km² areas (8.5%) and can be found within the old Himalayan piedmont plain and indicated as moderately well-drained. Non-calcareous grey floodplain soils texture is silty clay loam and silty clay, which falls under Inceptisols (USDA soil taxonomy) and Gleysols (Universal soil classification) class, one of the most agriculturally viable soils in the region. Non-calcareous Brown Floodplain occupies 36.41 km² (14.8%) of the land area and is found mostly on the old Himalayan piedmont plain. This soil texture may be recognized as sandy loam to silty loam that falls below Inceptions (USDA soil taxonomy) and Camisoles (Universal soil classification), which is indicated as fairly well-tired soils. Grey piedmont soils occupy 90.14 km² (36.6%) area and appear on alluvial outwash enthusiasts at the bottom of the easterners and northern hills of Meghalaya. The texture of grey piedmont soils can be recognized as silty and clayey, which may be poorly tired. Acid basin clays occupied 98.55 km² (40.1%) vicinity and are recognized as very poorly tired soils. This soil falls under Inceptions (USDA soil taxonomy), and Glycols (Universal soil classification), and the soil texture is silty clay loam [68-69]. Non-calcareous brown flood plain soil is assigned to the highest weightage. Acid basin clays and grey piedmont soils are not much significant for groundwater recharge; hence lowest weightage was assigned to these soil types.

Geomorphology: Geomorphology is critical while detecting groundwater. The geomorphologic map facilitates identifying the one-of-a-kind geomorphic structures, landforms, and inherent geology in order to further recognize the processes, resources, structures, and geologic controls associated with groundwater prospects. Geo-morphologically, the study area consists of 37.63 km² (19%) Haor basin, Meghalaya foothills 137.78 km² (69%), point bar 0.64 km² (0.1%), and Sylhet depression 60.67 km² (30.9%). Point bar is an excellent feature known for groundwater storage capability. This feature is found along the rivers throughout the study area. Haor basin is a depression-like function and stores groundwater for a selected time being and performs an essential part in groundwater recharge. Meghalaya foothills are taken into consideration but not so appropriate for groundwater recharge. Sylhet depression is part of the bigger Sylhet basin, and its ability for groundwater recharge could be very poor (Figure 3h).

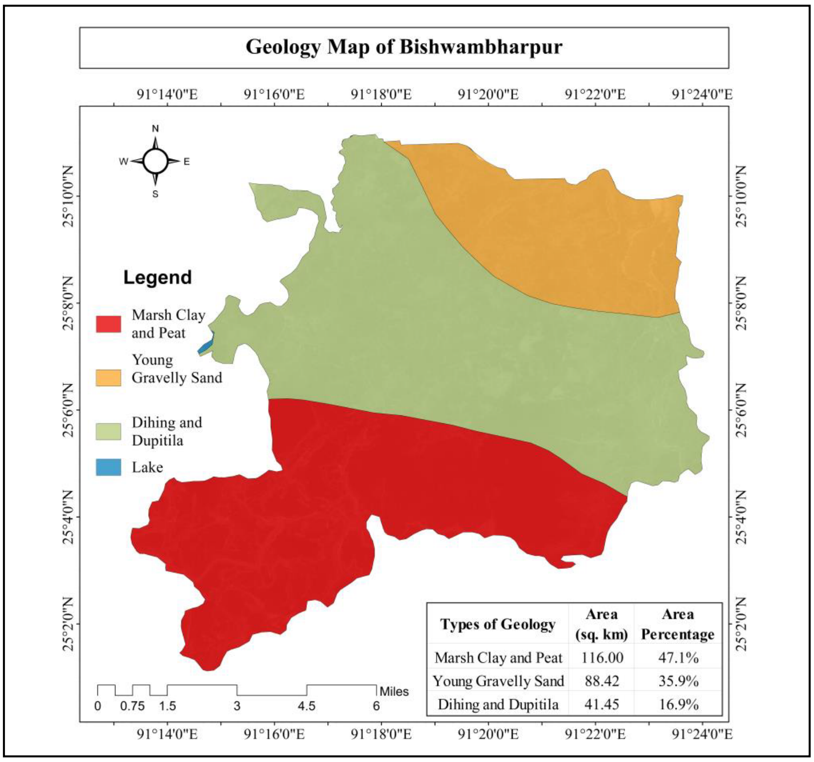


Figure 3a. Geology map of Bishwambharpur

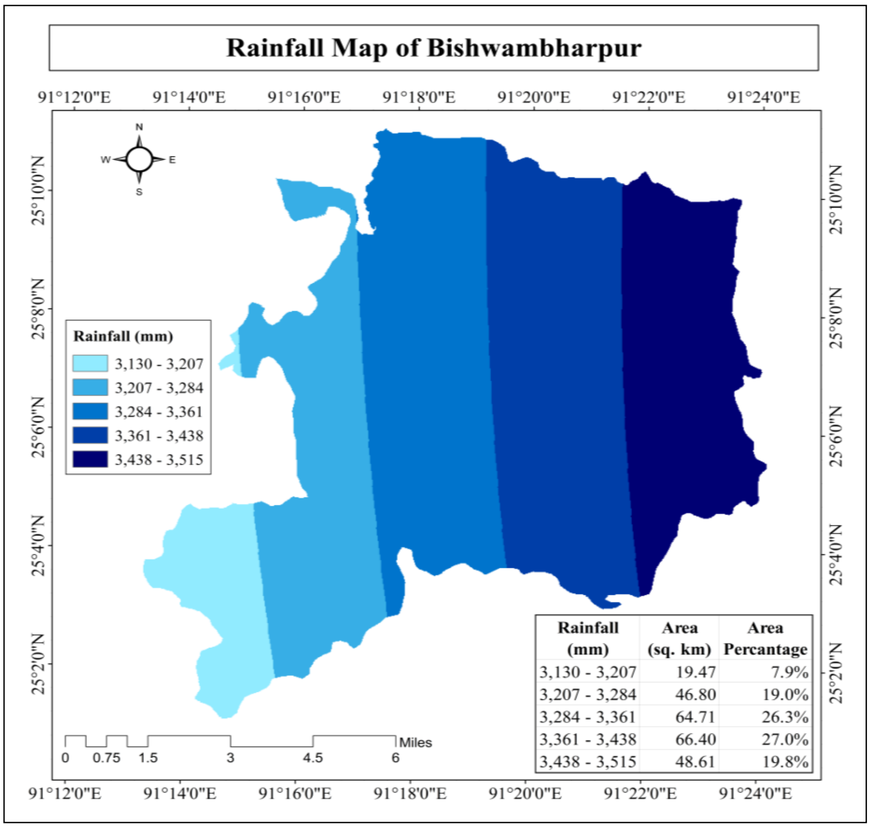


Figure 3b. Rainfall map of Bishwambharpur

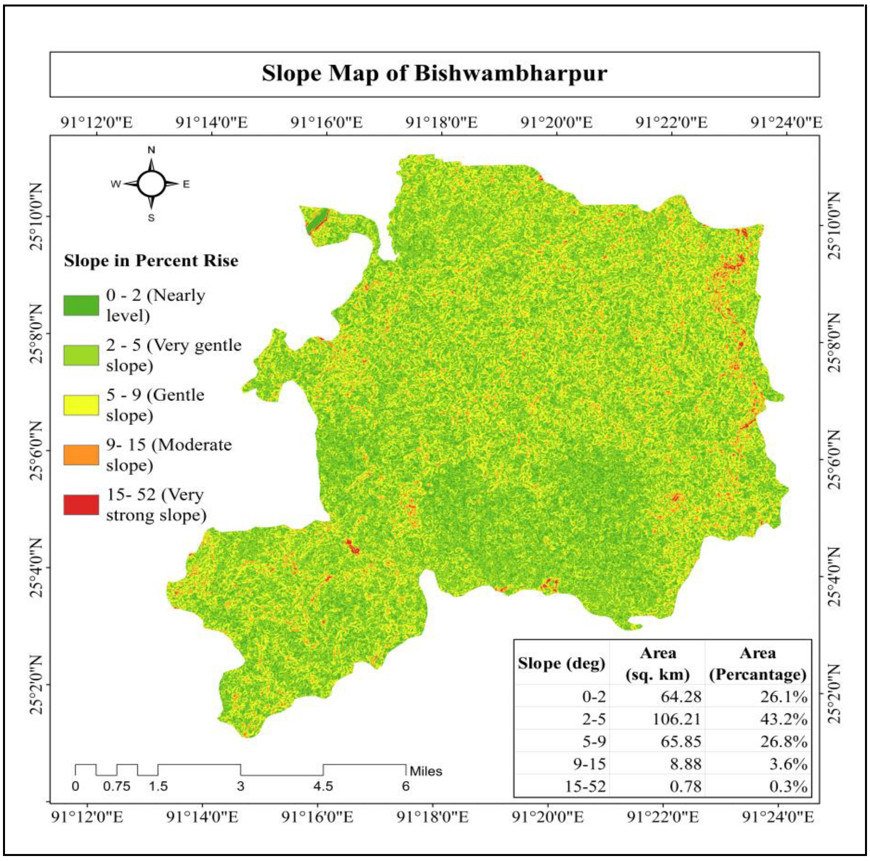


Figure 3c. Slope map of Bishwambharpur

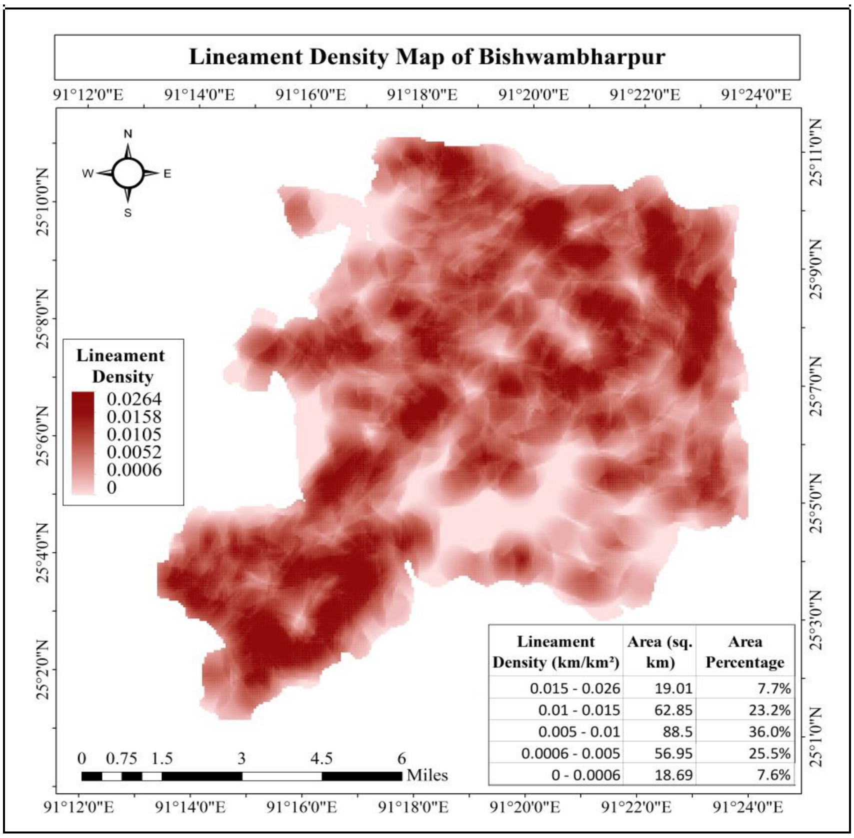


Figure 3d. Lineament density map of Bishwambharpur

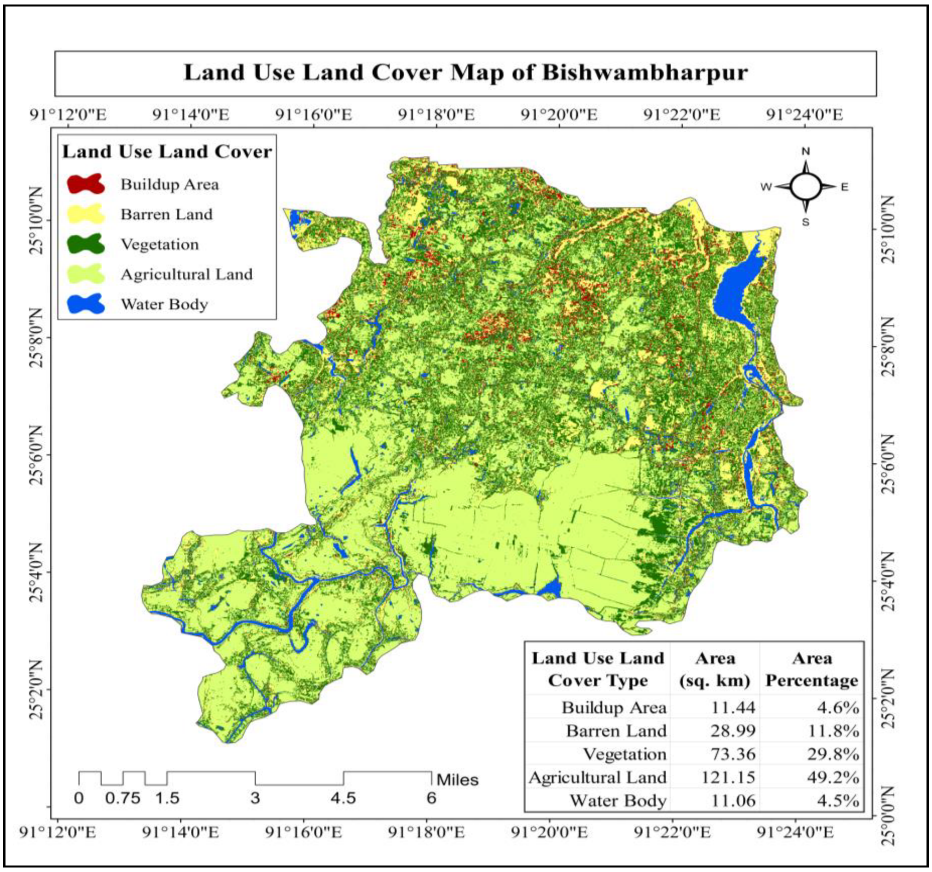
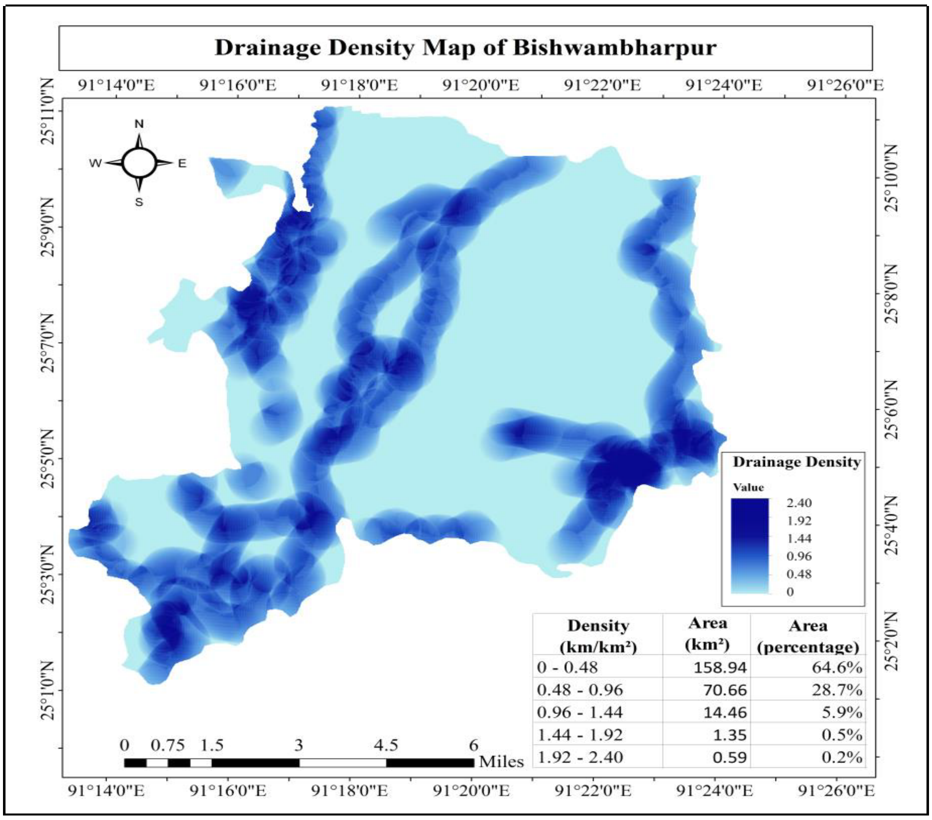
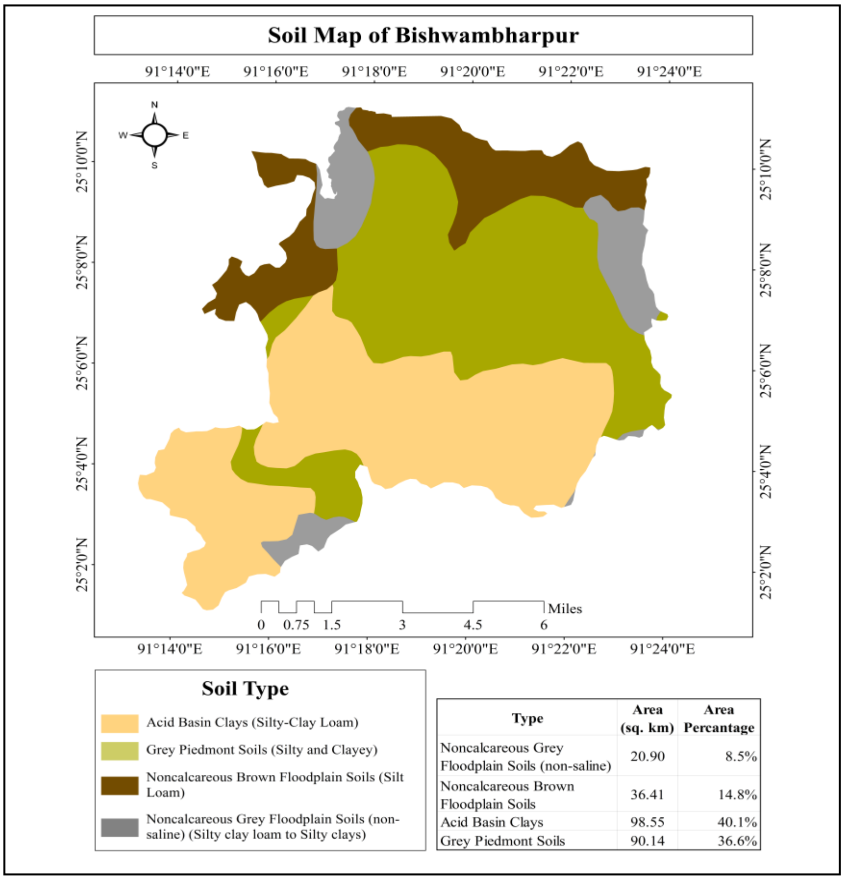


Figure 3e. LULC map of Bishwambharpur



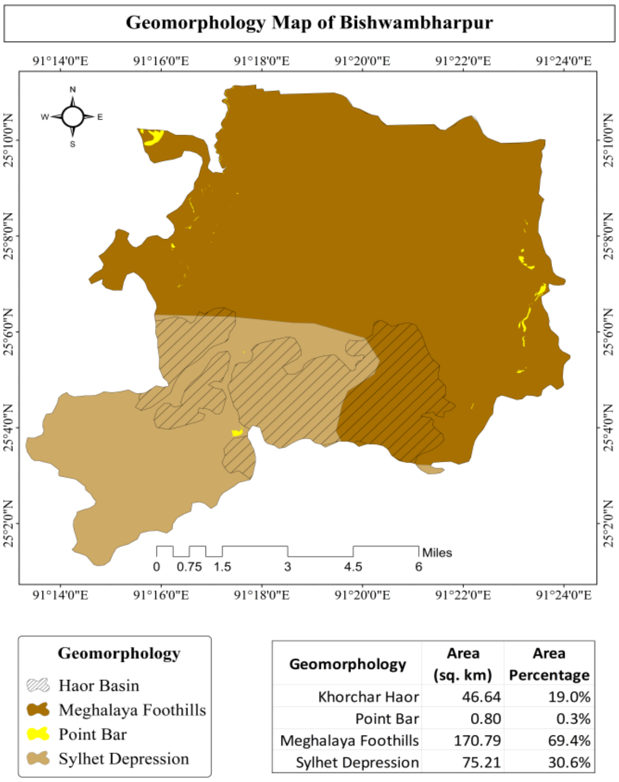
Density (km/km²)	Area (km²)	Area (percentage)
0 - 0.48	158.94	64.6%
0.48 - 0.96	70.66	28.7%
0.96 - 1.44	14.46	5.9%
1.44 - 1.92	1.35	0.5%
1.92 - 2.40	0.59	0.2%

Figure 3f: Drainage density map of Bishwambharpur



Type	Area (sq. km)	Area Percantage
Noncalcareous Grey Floodplain Soils (non-saline)	20.90	8.5%
Noncalcareous Brown Floodplain Soils	36.41	14.8%
Acid Basin Clays	98.55	40.1%
Grey Piedmont Soils	90.14	36.6%

Figure 3g. Soil map of Bishwambharpur



Geomorphology	Area (sq. km)	Area Percentage
Khorchar Haor	46.64	19.0%
Point Bar	0.80	0.3%
Meghalaya Foothills	170.79	69.4%
Sylhet Depression	75.21	30.6%

Figure 3h. Geomorphology map of Bishwambharpur

4.2 PZGWR map

To evaluate the capacity of groundwater recharge, multiple geo-environmental parameters from the research region including geology, rainfall distribution, slope, Lineament density, Land Use Land Cover, drainage density, soil, and Geomorphology have been incorporated into GIS and RS. Analytical Hierarchy Process (AHP) approach was used to assess the influence of each of these factors and discover distinct suitable sites. In the research area, a total of 3 special groundwater capacity recharge zones stated as 'good', 'moderate', and 'poor' (Figure 3i) have been recognized.

The "good" PZGWR usually coincide with excessive tiers of groundwater which are calculated through a whole lot of factors. It delineates the zones of the region that are well suited for groundwater recharge. The most suitable terrain can be described as low slope, optimum rainfall, low drainage density, high lineament density, favorable soil porosity, and considered good for groundwater prospects. 'Good' groundwater potential recharge zone covers about 26.42 km² (10.7%) area. This is due to the ‘Young Gravelly Sand’ and density of lineaments on the northern part make this site as 'good' zone and can be found as the scattered patch in the north to the middle part of Bishwambharpur.

The 'moderate' PZGWR on the study area cover about 195.92 km² (79.6%). The 'moderate' potential recharge zones for groundwater are found throughout the region and mostly in the northern and south-western parts. The appearance of ‘Meghalaya Foothills’ and ‘Haor basin’ in the north and middle part respectively make this site moderate to recharge potential. In the south-western part, extensive lineament density and slope play a vital role in terms of recharge capacity although this region has other poor characteristics such as the appearance of poorly tired soil ‘Acid basin clay’, high drainage density, and relatively low rainfall.

The "poor" PZGWR occur with a low groundwater table and define the zones where the landscape is not appropriate for the recharge of groundwater. Areas with low lineament density, high drainage density, high slope, low rainfall, unfavorable geology and geomorphology, presence of low soil porosity have low groundwater prospects. The zones representing 'poor' prospects for groundwater recharge on the study area cover about 23.66 km² (9.6%). The 'poor' groundwater ability recharge zones may be determined withinside the south and south-western region. An intriguing note here is that the soil type of the research region has a significant impact on groundwater potential. The majority of the Acid basin clay basins are recognized as moderate to poor potential zones.

Lineament density which are the fractures found in surface throughout the study area and helps surface water to seep through them directly to the groundwater has the highest impact of 27% on the recharge capability of groundwater. In the final PZGWR map (Figure 3i) it can be seen that in the north-eastern portion the 'Good' zones are found along the highest lineament density areas. So many studies have backed that lineament density has a good impact on the delineation of PZGWR [1,19,21,48,63,71,73]. Geology also helps to identify the zones where groundwater most likely to be recharged as the characteristics of rocks defines the porosity and permeability of an area. 'Young gravelly sand' area is found in the northern part of the study area and that is where the most of the 'Good' PZGWR has been identified. In a study done in the Hoogly district has found out geology having the highest impact [20] and many other have found geology as one of the most important features for the identification of PZGWR [27,70-72]. Bishwambharpur Upazilla is situated on the foothills of Meghalaya and thus slope is an important feature in this area in terms of water flow on the surface. If the slope is strong, the water doesn't get much time to get retained in the soil. On the other hand, gentle slope helps the water to get retained in the soil by giving time. Very strong and moderate slope can be found in some part of north-eastern part and in the middle of study area. These zones affect the ability to recharge of groundwater. Almost all the similar studies have considered slope as an important factor [27,29,34,63,70-73]. Non-Calcareous brown flood plain soil is the most suitable for the functionality of groundwater recharge as it is moderately well drained and sandy loam to silty loam. Non-calcareous grey floodplain soil is also great for water infiltration and permeability. These two types of soil cover the lowest area and are found on the north, north-eastern and north-western part as patches and these areas are where 'Good' zones are identified. For its significance in the recharge of groundwater, many studies have incorporated soil to delineate the suitable zones [12,20-21,33,63]. As the north-eastern portion of the study area receives the most rainfall it helps this zone to become a 'Good' one for the recharge potentiality. Although rainfall has distinct effect on recharge ability but it was assigned with lower weights than most other factors since in this temperate region rainfall amount is good and almost similar throughout the study area. Though the buildup area in land use

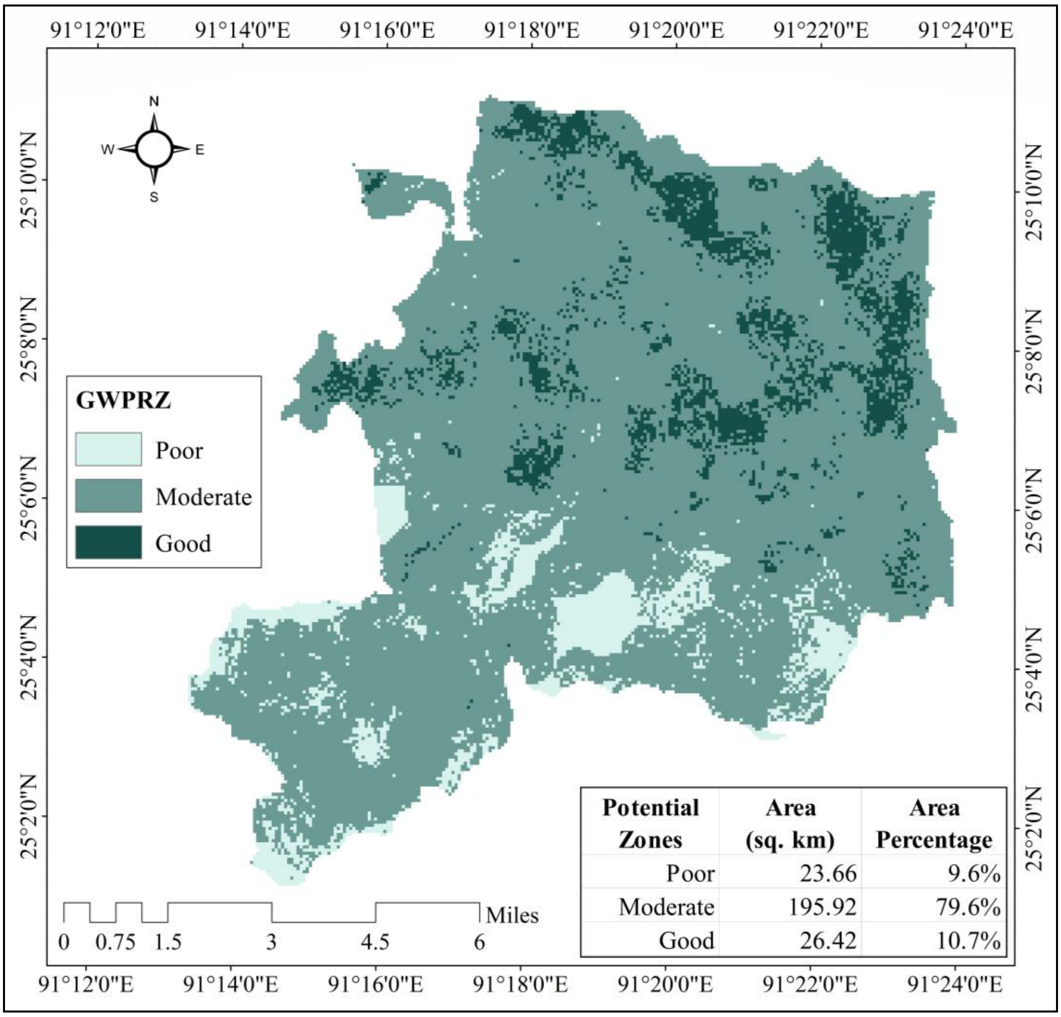


Figure 3i. PZGWR map of Bishwambharpur.

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land cover hinders the capability of recharge for groundwater, most of the ‘Good’ and ‘Moderate’ zones are found where the densest buildup area is located in Dhonpur, Dakshin Badaghat, Palash and Sholukabad villages. This exception may have caused as the haor basin in the middle portion and Sylhet depression on the southern portion of the study area is less suitable for the recharge action of groundwater and is identified as the ‘Poor’ zone for the potential of groundwater recharge. Rainfall, drainage density, geomorphology and LULC are the least weighted factors but altogether they have 26% impact on the recharge potentiality. Thus, these factors were used in several studies and found their significant impact [20-21,27-29,34,48,63,70].

The result indicates that geology, lineament density, slope, and soil type play a significant role in the prospect of the recharge capacity of groundwater in this region. These factors are the primary controlling factor of the infiltration process in this diverse geomorphic zone. The influence of geomorphology shows a relatively low influence of recharge capability comparing the other factors. Although rainfall plays a vital role, the whole region has quite a similar amount of rainfall and it helps to make a huge area as moderate recharge zone.

To better understand the local condition regarding the use of groundwater and its recharge the 5 villages were analyzed in Bishwambharpur Upazilla. The upper part of the study area is the zone only where the ‘Good’ potential for groundwater has been identified. Upper part of Daksin Badaghat, Palash and Sholukabad along with the whole Dhonpur villages where ‘Good’ zones are found and are suitable for well and tube-well types of irrigation and artificial groundwater recharge [33]. The rest lower part of Daksin Badaghat, Palash and Sholukabad is dominant with ‘Moderate’ and ‘Poor’ zones could be sidestepped for agronomic practices. Fathehpur is the village where no ‘Good’ zone could be identified due to its physical characteristics.

5. Conclusions

Groundwater recharge zones potentiality provide a sustainable solution for the freshwater scarcity in a particular area. Sensible use of groundwater is crucial for sustaining protracted socio-economic development along with agriculture in Bishwambharpur. The blended AHP with GIS and RS approach has been employed to decide the capacity zones for groundwater recharge in Bishwambharpur. The research region has been categorized into three separate capacity zones wherein groundwater can recharge and has been recognized as 'good', 'moderate' and 'poor', and that they cover up about 10.7%, 79.6%, and 9.6% of the whole territory. The result of PZGWR clearly dictates that almost all parts of the regions with favorable optimum rainfall conditions, soil texture with good water retention, gentle slope, geology, and high lineament density have a great possibility for the recharge of groundwater. The upper part of the study area is contained with ‘moderate’ and ‘good’ zones whereas the lower part of the study area is contained with ‘moderate’ and ‘poor’ recharge zones. As most of the study area, 79.6% to be exact is covered with ‘moderate’ zones where groundwater can be moderately recharged thus these areas might not experience severe drought conditions. To find out the potential zones or spots where groundwater can recharge and obtain the best output using AHP with GIS and RS, identification and selection of suitable geospatial factors, as well as justifiable assignments of weights, are essential.

The present study gives a practical evaluation for the right control of groundwater inside the research area. The method this is included in this study is on the idea of rational reasoning and familiarity in nature, this system can as nicely be implemented to greater areas of Bangladesh or away with/without suitable adjustments.

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