Sustainability, Agri, Food and Environmental Research, (ISSN: 0719-3726), 12(2), 2024:
http://dx.doi.org/10.7770/safer-V13N1-art465

Analysis of Groundwater Potential Recharge Zones Using AHP, RS and GIS Techniques in Bishwamvarpur Upazilla, Sunamganj.

Análisis de zonas de recarga potencial de aguas subterráneas utilizando técnicas AHP, RS y GIS en Bishwamvarpur Upazilla, Sunamganj.

Md. Ashir Morshed Pial[*], Towfiqul Islam Khan[**] and Md. Nurul Islam[***]

[*]Graduate research student, Dept. of Geography and Environment, Shahjalal University of Science & Technology, Email: ashirmorshed29@student.sust.edu

[**]Assistant Professor, Dept. of Geography and Environment, Shahjalal University of Science & Technology, Sylhet-3114, Email: khan-gee@sust.edu

[***]Professor, Dept. of Geography and Environment, Jahangirnagar University, Savar-1342, Dhaka. Email: nurul.islam@juniv.edu

Corresponding Author

Towfiqul Islam Khan, Assistant Professor, Dept. of Geography and Environment, Shahjalal University of Science & Technology, Sylhet-3114, Email: khan-gee@sust.edu

ABSTRACT

This study presents the delineation of groundwater potential recharge zones in Bishwambharpur Upazilla in Sunamganj using integrated or combined geographic information system, remote sensing, and analytic hierarchy process techniques. Remote sensing and traditional data were collected from different sources and analyzed in GIS software to prepare thematic maps of different geospatial factors such as geology, geomorphology, slope, soil, land-use land-cover, drainage density, lineaments density and rainfall, as these factors having an impact on groundwater availability of an area, directly or indirectly. Integration of GIS and RS with AHP can embody as a process that transforms and balance geospatial data and weightage ranking to retrieve information for accurate decision-making. Weighted overlay analysis is applied to integrate all geospatial factors to generate groundwater potential recharge zone map of the study area. The result reveals that three groundwater potential recharge zones, namely 'good', 'moderate' and 'poor' and occupies 26.42 km² (10.7%), 195.92 km² (79.6%) and, 23.66 km² (9.6%) respectively. A significant change in the using of groundwater pattern, especially with continuously increasing demand for groundwater owing to growing population, expansion of area under irrigation, economic progress and climate change. The findings of the study have important allegations for designing sustainable groundwater plan in the study area.

Key words: Groundwater, Delineation, Potential recharge zone, GIS and AHP.

RESUMEN

Este estudio presenta la delimitación de las zonas de recarga potencial de aguas subterráneas en Bishwambharpur Upazilla en Sunamganj utilizando técnicas integradas o combinadas de sistemas de información geográfica, sensores remotos y procesos de jerarquía analítica. Los datos de teledetección y tradicionales se recopilaron de diferentes fuentes y se analizaron en un software GIS para preparar mapas temáticos de diferentes factores geoespaciales, como geología, geomorfología, pendiente, suelo, uso de la tierra, cobertura del suelo, densidad de drenaje, densidad de lineamientos y lluvia, como estos factores que tienen un impacto en la disponibilidad de agua subterránea de un área, directa o indirectamente. La integración de GIS y RS con AHP puede incorporarse como un proceso que transforma y equilibra datos geoespaciales y clasificación de ponderación para recuperar información para una toma de decisiones precisa. Se aplica un análisis de superposición ponderada para integrar todos los factores geoespaciales para generar un mapa de zona de recarga potencial de agua subterránea del área de estudio. El resultado revela que las tres zonas de recarga potencial de aguas subterráneas, a saber, 'buena', 'moderada' y 'mala', ocupan 26,42 km² (10,7 %), 195,92 km² (79,6 %) y 23,66 km² (9,6 %) respectivamente. Un cambio significativo en el patrón de uso de las aguas subterráneas, especialmente con el continuo aumento de la demanda de aguas subterráneas debido al aumento de la población, la expansión del área bajo riego, el progreso económico y el cambio climático. Los hallazgos del estudio tienen importantes argumentos para diseñar un plan de aguas subterráneas sostenible en el área de estudio.

Palabras clave: Aguas subterráneas, Delineación, Zona de recarga potencial, SIG y AHP.

INTRODUCTION

The water resource is something that makes the earth unique and habitat to life in the Solar System. Around 71% of the earth's surface is covered by water (Das & Pardeshi, 2018). Yet, there is a severe crisis of freshwater for drinking, agriculture, and industries because 97% water on earth is saltwater as seas and oceans, about 2% water is glaciers in the polar region, and remaining 1% is in the form of stream channels and groundwater (WWAP, 2009; Das & Pardeshi, 2018). Stream channels and groundwater are the only sources for freshwater (Das & Pardeshi, 2018). Global water use has increased by six fold throughout the past 100 years and persists to grow gradually at a rate of about 1% per year as a consequence of increasing population, economic development and shifting consumption patterns (UNESCO, UN-Water, 2020). Climate change also affects global water resources in several ways, with complex spatiotemporal patterns, feedback effects, and anthropogenic (Bates, et al., 2008). Variations in precipitation and temperature will directly affect the surface water budget (Schewe, et al., 2014); especially in those regions where rainfall volumes will drop off, this indicates decreasing streamflow volumes and a decrease of freshwater availability in different seasons (IPCC, 2018). Hence, surface water in countless places is not a good option for the human consumption and economic activities (Todd & Mays, 2005; Babiker, et al., 2007; Hoque, et al., 2009; Mogaji, et al., 2015; Das & Pardeshi, 2018). About 4 billion people live under severe physical water scarcity conditions for at least one month per year (Mekonnen & Hoekstra, 2016). Around 1.6 billion people, or nearly a quarter of the world's population, confront economic water shortage that implies they lack the necessary infrastructure to access freshwater and have to fetch water from river (UN-Water, 2014). Groundwater is an invaluable resource that play a part in sustaining terrestrial and aquatic ecosystems, as well as the well-being of human civilizations (Arshad, et al., 2020). In nature freshwater is allocated all over the place. It also plays a lead role in maintaining ecological balance, human well-being, and economic development (IPCC, 2001). Worldwide, around 36%, 42% and 27% of the total groundwater are withdrawn (Taylor, et al., 2013). The continuously increasing demand for groundwater due to growing population size, expanding area of irrigated cultivation and economic progress with less importance to the environment has mounted increasing pressure on groundwater resources. As a result, overexploitation of groundwater, as well as deterioration in water quality, occurs (Watto & Mugera, 2015; Mondal & Dalai, 2017). The groundwater storage fluctuates in different places and there is need to detect recharge zones through geospatial technology as a crucial approach for water management system (Prabhu & Venkateswaran, 2015). Absence of planned groundwater withdrawal can result in failure to find water while drilling bore wells (Gupta & Srivastava, 2010). Unplanned and unmanaged groundwater extraction in the Ganga plain area has resulted in aquifer-stress syndrome-like falling groundwater depth (Patra, et al., 2018).

Groundwater recharge is an aspect of the hydrologic cycle that is important in the water balance calculation (Lentswe & Molwalefhe, 2020). Aquifers containing groundwater in the sub-surface are confined and change spatially (Satapathy & Kanung, 1976). Throughout the Bengal Basin, the floodplains of the Ganges, Brahmaputra, and Meghna (GBM) rivers are underlain by the Bengal Aquifer System (BAS) which is the largest aquifer in Southern Asia (Burgess, et al., 2010). For domestic use and irrigation of the rice crop more than 10 million tubewells throughout the basin provide water from BAS and the source of water to over 100 million people (Ravenscroft, et al., 2005); these include hand-pumped tubewells, normally between 15 to 30m depth below ground level, for domestic use, and tubewells installed with motor-driven pumps to abstract water from between 50 to 75m depth below ground level, for irrigation of the dry season rice crop (January to April). Municipal water supplies commonly abstract year-round from depths between 200 to 300m depth below ground level (Shamsudduha, et al., 2012). Through recharge, it creates a balance between groundwater and its exploration. It is a water resource management tool, and it is important in balancing water demand and supply for development with special attention placed on semi-arid and arid regions (Cherry & Freeze, 1979; Chowdhury, et al., 2009; Jhariya, et al., 2016). Drilling test and stratigraphy investigation of the sub-surface are the most widely used methods for delineating the location of borehole and the thickness of the aquiferous materials to explore the groundwater resources (Jha, et al., 2010; Patra, et al., 2018). However, these traditional methods are very costly and time-consuming to find out the availability of groundwater resources in a region (Roscoe Moss Company, 1990; Ferrer, 2001). There are quite a few methods such as geological, hydrogeological, geophysical, and remote sensing techniques, which are employed to delineate groundwater potential zones where it gets recharged (Venkateswaran & Ayyandurai, 2015). In this 21st century, remote sensing and GIS techniques play a vital role in the evaluation of earth's natural resources (Das, et al., 2018). Remote sensing technique has an advantage of having accessibility to large coverage, even in inaccessible or remote areas (Venkateswaran & Ayyandurai, 2015). Remote sensing and GIS approaches are cost-effective and require much less time to assess a region's groundwater potential zone. (Murthy, 2000; Prasad, et al., 2008; Das, et al., 2017). Remote sensing data along with conventional survey maps or data, is very helpful in delineating groundwater recharge zones (Harinarayanan, et al., 2000; Chowdhury, et al., 2000). Integration of different geospatial factors to delineate groundwater potential zone gave satisfactory results for many previous works (Krishnamurthy, et al., 1996; Khan, et al., 2006; Das, et al., 2017; Das & Pardeshi, 2018). Groundwater availability depends on numerous elements such as geomorphology, geology, drainage density, slope, soil texture, rainfall, lineament density and land use of an area (Sander, et al., 1996; Solomon & Quiel, 2006; Das, et al., 2017; Das & Pardeshi, 2018). The lack of conceptual understanding of analytic geospatial frameworks makes recharge determinations insufficiently successful as indicated by numerous previous studies across the globe (Scanlon, et al., 2006; Xu & Beekman, 2019). Thus a sincere evaluation of the parameters can help to get a good and clear conception about groundwater potential of an area. Also, a good understanding of the study area is necessary for getting the most out of this technique and an accurate result. For making the analysis more constructive and accurate researchers have adopted various techniques or methods along with GIS and RS such as multi-criteria decision (Mukherjee, et al., 2012; Das, et al., 2017), frequency ratio model (Moghaddam, et al., 2015; Naghibi, et al., 2015), logistic regression model (Ozdemir, 2011; Pourtaghi & Pourghasemi, 2014), multi influence factor analysis (Selvam, et al., 2014), fuzzy logic analysis (Al-Abadi, et al., 2017), decision-tree model (Lee & Lee, 2015), weights of evidence (Ghorbani, et al., 2015; Madani & Niyazi, 2015), artificial neural network (Lee, et al., 2017) and random forest model (Naghibi, et al., 2015) etc. In this context, analytic hierarchy process (AHP) is considered as a simple, transparent, effective, and reliable technique to deilineate the groundwater potential recharge zones and it can be used as the technique or method alongside with GIS and RS (Tiwari, et al., 2017) for delineating the groundwater potential recharge zone in a particular area.

The study's main aim is to delineate groundwater potential recharge zones in Bishwambharpur Upazilla, Sunamganj using AHP, RS and GIS. The specific objectives are the following: A) To assess the current status of groundwater usage in agriculture and daily life. B) To form an overlay analysis using geology map, geomorphology map, slope map, rainfall map, lineament density map, soil map, drainage density map and land use land cover map. C) To delineate the groundwater potential recharge zones in Bishwambharpur.

MATERIAL AND METHODS

Data use and methodology

Preparation of Geospatial database

In order to determine the groundwater potential recharge zones in the study area, 8 geospatial factors have been used and prepared as thematic maps, viz. geology, geomorphology, soil, rainfall, land use-land cover, drainage density, slope and lineament density. These maps were generated using satellite images and various conventional data and map sets. Rainfall data for 33 years (1983 -2016) were collected from BARC (barc.gov.bd/) and BMD (bmd.gov.bd/); the rainfall map was prepared using IDW analysis method. Digitized soil, geology and geomorphology data was collected from BARC website. For slope, drainage density and lineament density, SRTM DEM obtained from Earthdata (earthdata.nasa.gov/) was used and prepared using ArcGIS 10.6.1 and Geomatica 2013. All the physical linear features were traced using lineament extraction tool in Geomatica 2013, and the density was calculated in ArcGIS 10.6.1 using line density tool. Drainage network and drainage density were delineated employing hydrology and line density tools in ArcGIS 10.6.1 software. SRTM DEM 30-meter resolution imagery was employed to prepare the Slope map of the study area. Land use-land cover map was prepared using Sentinel-2A imagery of 10m spatial resolution obtained from Sentinel Open Access Hub (sentinel.esa.int/) which provides crisp and sharp images and was carried out using unsupervised classification in ERDAS Imagine 2014 software.

Assignments of weights and normalization based on the analytic hierarchy process (AHP) model

AHP methodology

The analytic hierarchy process (AHP) is a structured method based on mathematics and psychology to organize and analyze complex decisions. In AHP, for constructing judgment or pair-wise comparison matrices to allocate weights to the geospatial factors (thematic layer) of each level (criteria classes) and measuring their relative importance by using Saaty's 1-9 scale (Table 2). Assigning of weights to different criteria was finalized based on field experiences and review of existing literature. The basic steps to determine the indicator's weight and consistency ratio (CR) are as follows:

Step 1. Establishment of judgment matrices (P) by pair-wise comparison

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

Where, p_n denote the n^{th} indicator element with p_{nn} being the judgment matrix element.

Step 2. Calculation of Normalized weight

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

Where, the geometric mean of the i^{th} row of the judgment matrices is calculated as

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

Step 3. Calculating a consistency ratio (CR) in order to validate the coherence of the judgements.

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

Consistency Index (CI) is represented as follows

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

λ_{max} is the eigenvalue of the judgment matrix and it is calculated as

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

Where W is the weight vector (column). Random consistency index (RCI) can be obtained from standard tables (Alonso & Lamata, 2006). CR value must be about 0.10 or less to be accepted (Patra et al., 2018).

Table 1: Scale of Relative importance

Intensity of importance	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 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)

Delineation of groundwater potential recharge zones

The individual geospatial factors are reclassified, and ranks are assigned according to its significance 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, weighted overlay analysis (WOA) has been used for generating groundwater potential recharge zones map in ArcGIS platform. The methodology used to delineate groundwater potential recharge zones combining RS, GIS and AHP techniques is depicted in Figure 1. Groundwater potential recharge zone is calculated as:

GWPRZ = 17% x geology map + 8% x geomorphology map + 10% x soil map + 6% x rainfall map + 27% x lineament density map + 6% x drainage 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	0.06
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

Table 4: Pair-wise comparison matrix for geology.

	Young Gravelly and Sand	Dupitila and Dihing Formation	Marsh Clay and Peat
Young Gravelly and 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

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

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

Table 7: Pair-wise comparison matrix for LULC.

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

Source: Compiled by Author

Table 8: Pair-wise comparison matrix for lineament density.

	0-0.12	0.12-1	1-2	2-3	3-5
0-0.12	1	3	5	7	9
0.12-1	1/3	1	3	5	7
1-2	1/5	1/3	1	3	5
2-3	1/7	1/5	1/3	1	3
3-5	1/9	1/7	1/5	1/3	1

Source: Compiled by Author

Table 9: Pair-wise comparison matrix for drainage density.

	0-5.66 km/km²	5.67-11.33 km/km²	11.34-17.00 km/km²	17.01-22.67 km/km²	22.68-28.34 km/km²
0-5.66 km/km²	1	3	5	5	7
5.67-11.33 km/km²	1/3	1	3	3	5
11.34-17.00 km/km²	1/5	1/3	1	3	5
17.01-22.67 km/km²	1/5	1/3	1/3	1	3
22.68-28.34 km/km²	1/7	1/5	1/5	1/3	1

Source: Compiled by Author

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

Table 11: 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

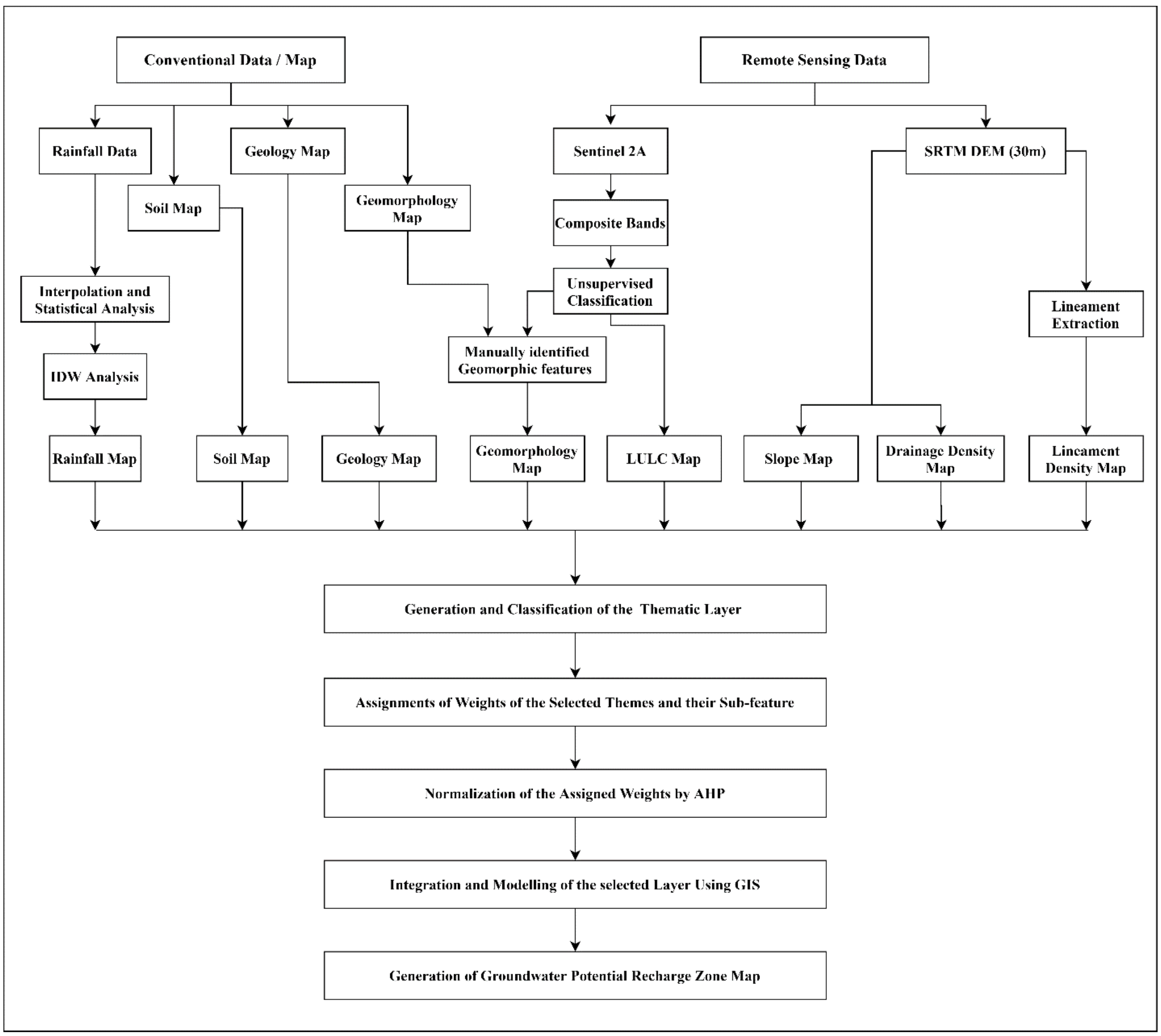

Figure 1: Schematic flowchart for groundwater potential recharge zone methodology

Study area

Bishwambharpur Upazilla 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 Upazilla. In East Sunamganj Sadar Upazilla and the Meghalaya state of India. In West Jamalganj and Tahirpur Upazilla. Figure 2 represents the study area for this study and shows its relative location. The study area covers about 246 km² and supporting 629 people per km² with a total population of 1,56,381 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.

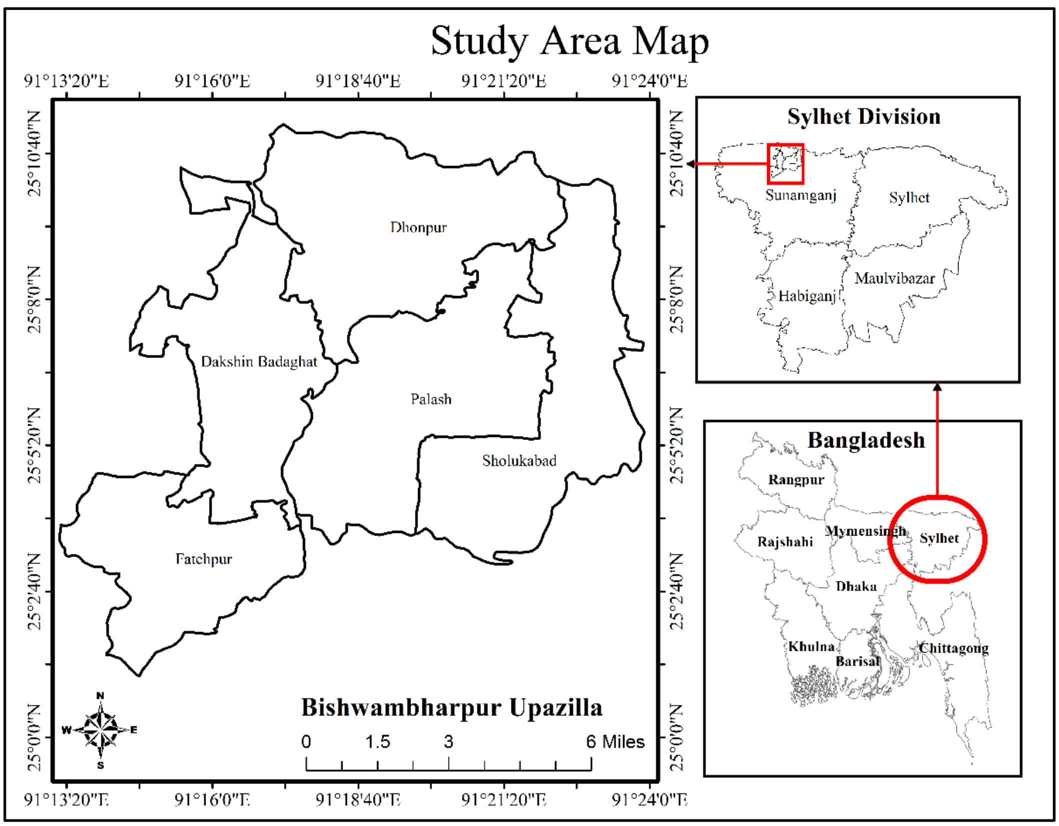

Figure 2: Location of the study area

Bishwambharpur Upazilla like other parts of Bangladesh falls under subtropical monsoon climate characterized by wide seasonal variations in rainfall, high temperatures and humidity. The average annual temperature is 24.95 °C. January is the coldest month in the year whereas August is the hottest month. From May to September, the region receives most of the precipitation. The annual rainfall of the upazilla is 3365 mm. The eastern part of the upazilla receives more rainfall than the western part (Sarkar, et al., 2001). The relative humidity of the upazilla is 72%. The average daylight hours that the upazilla gets is 12.15 hours, and in June it is the highest 13.7 hours.

RESULTS AND DISCUSSION

Geospatial factors used for GWPRZ determination

Geology: Occurrence and movement of groundwater depends on the nature of rocks, and it's parameters for example porosity, and permeability are different for each rock type (Ghasemizadeh, et al., 2012; Etikala, et al., 2019). 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 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 nature of Dupitila and signatures of Dihing formation, the igneous, metamorphic gravel beds (Alam, et al., 2003). Young gravelly sand occupies 88.42 km² (35.94%) of the study area which is found in the north. This 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 is mainly composed of the clay; thus, water permeability is very low. It is also identified as low agricultural productivity zone in the south and south-western parts (Figure 3).

Rainfall: Rainfall comprises an important constituent of the water cycle and is the major source of groundwater recharge (Keng, et al., 2017). The amount and spatio-temporal distribution of rainfall largely influenced on the hydrogeological condition. However, rainfall intensity and combination of other favorable condition help to identify the groundwater potential recharge zones. The possibility of more groundwater recharge is high if the rainfall is high and low if the rainfall is low. The rainfall differs both spatially and temporally. Hence, it is necessary to determine the influence of rainfall to identify groundwater potential recharge zones. The spatial distribution of average annual rainfall map is generated by Inverse Distance Weighting (IDW) interpolation method for the 1984-2014 time periods (Patra, et al., 2018). The rainfall map of the study area can be divided into 5 classes (Figure 4). 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.

Slope: The slope of the land is an important parameter which influences the water retention and intensity of infiltration from precipitation (Rahman, et al., 2012). There is an inverse relation between ground slope and infiltration rate. The gentle slope gives more residence time for rainwater to percolate than the steep slopes. Thus, it is an indicator for suitability for groundwater occurrences. The study area has been divided into five classes (Figure 5). Nearly level (0-2°) covers 64.28 km² (26.1%) area. Very gentle slope (2-5°) covers about 106.21 km² (43.2%) area.

Gentle slope (5-9°) covers 65.85 km² (26.8%) area. Moderate slope (9-15°) covers 8.88 km² area, and Very strong slope (15-52°) covers 0.78 km² (0.3%) of the study area.

Land use land cover: Groundwater resources development and occurrence are greatly influenced by human-induced activities and land use land cover changes are one of the main activities (Patra, et al., 2018). As Bishwambharpur is situated in the Meghalaya foothill and is a haor region, it is also known as one of the few upazillas of Sunamganj which are under intensive crop cultivation. The study area has been categorized into five distinctive classes (Figure 6). 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%). Agricultural land, water bodies and vegetation are excellent sources of groundwater recharge. In contrast, barren land and buildup areas are considered to be less significant (Patra, et al., 2018). Therefore, the highest weightage is assigned to water bodies, agricultural lands and lowest for the buildup areas.

Lineament density: Lineaments developed by the tectonic activity and they describe the surface topography and sub-surface structural features as well as increased secondary porosity where the fault and fracture are more (Magesh, et al., 2012). It is assumed that lineaments have disproportionate relation with the intensity of fractures. The intensity of fractures increases with decreasing distance from lineaments. Groundwater movements are much higher in hard rock terrain lineaments and are considered as pathways. High lineament segments are indicated as high potential groundwater zones (Haridas, et al., 1998). Lineaments are identified from Hi-res terrain image provided by Vertex. The study area was divided into 5 lineament density zones (Figure 7). Very low dense zone (0-0.12) comprises 18.69 km² (7.6%) area. Low dense zone (0.12-1) comprises 56.95 km² (23.2%) area. Moderate dense zone (1-2) comprises 88.50 km² (36.0%) area. High dense zone (2-3) comprises 62.85 km² (25.5%) area. Very high dense zone (3-5) comprises 19.01 km² (7.7%) area. As the densest area indicates more suitable for groundwater recharge, weightage was assigned accordingly from higher density to lower density.

Drainage density: The stream pattern reflects the rate (Khadri & Pande, 2016); that precipitation infiltrates compared with the surface runoff (Edet, et al., 1998). Drainage density indicates how dissected the landscape is by channels; thus, it reflects both the tendency of the drainage basin to produce surface runoff and the permeability of the surface materials. Regions with high drainage density will have limited infiltration, promote considerable runoff and vice versa. Hence the low-density value is more favorable for higher groundwater potential recharge zone and assigned the higher weigh (Patra, et al., 2018). The study area was divided into five drainage density classes (Figure 8). Very low dense zone (0-5.66 km/km²) covers 158.94 km² (64.6%) area. Low dense zone (5.67-11.33 km/km²) covers 70.66 km² (28.7%) area. Moderate dense zone (11.34-17.00 km/km²) covers 14.46 km² (5.9%) area. High dense zone (17.01-22.67 km/km²) covers 1.35 km² (0.5%) area. Very high dense area (22.68-28.34 km/km²) covers 0.59 km² (0.2%) area.

Soil: Soil (texture) is an important criterion in assessing the soil's physical conditions and is clearly related to soil properties like structure, porosity, adhesion and consistency (McGarry, 2006). Infiltration and permeability of water by soils is directly dependent on soil texture and therefore, texture influences to identify groundwater potential recharge zones (Patra, et al., 2018). Coarse-grained soils have high infiltration rate, whereas fine-grained soils have a higher retention rate. The study area consists of 4 types of soil (Figure 9). 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 productive soils for agriculture in the country. Non-calcareous Brown Floodplain occupy 36.41 km² (14.8%) area and occurs largely on the old Himalayan piedmont plain. This soil texture can be identified as sandy loam to silty loam and falls under Inceptisols (USDA soil taxonomy) and Cambisols (Universal soil classification), which is indicated as moderately well-drained soils. Grey piedmont soils occupy 90.14 km² (36.6%) area and occur on alluvial outwash fans at the foot of the northern and eastern hills. The texture of this soils can be identified as silty and clayey which are poorly drained. Acid basin clays occupy 98.55 km² (40.1%) area and identified as very poorly drained soils. This soil falls under Inceptisols (USDA soil taxonomy), and Gleysols (Universal soil classification) and the soil texture is silty clay loam (Alaam, et al., 1993). 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 plays a vital role in the occurrence of groundwater. The geomorphologic map helps to identify the type of geomorphic units, various landforms, and underlying geology to understand the processes, materials, structures,and geologic controls relating to groundwater prospects (Patra, et al., 2018). Geomorphologically, 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 feature and stores surface water for a particular time being and plays a crucial role in groundwater recharge. Meghalaya foothills which are considered not so suitable for groundwater recharge. Sylhet depression is a part of greater Sylhet basin, and its capacity for groundwater recharge is very poor (Figure 10).

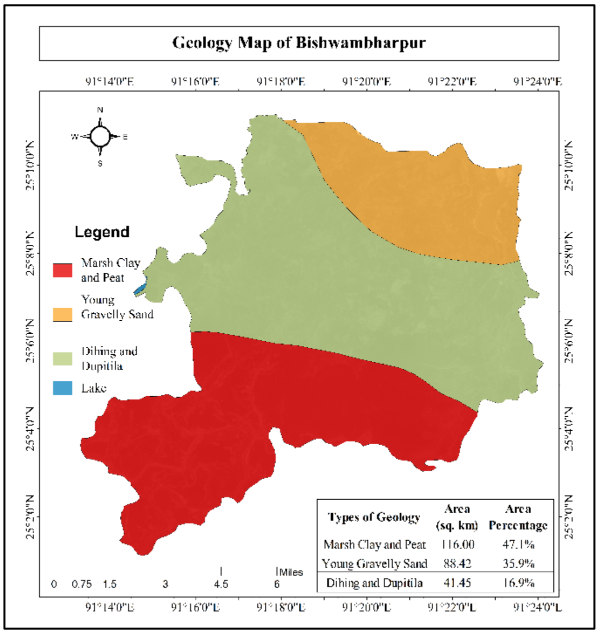

Figure 3: Geology map of Bishwambharpur

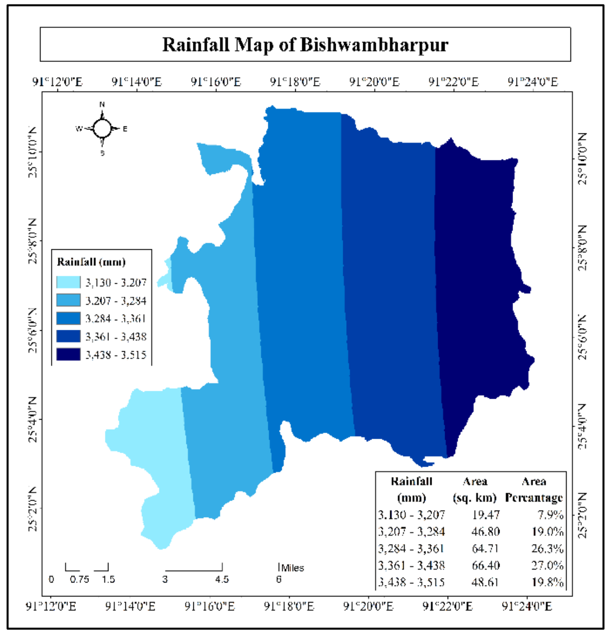

Figure 4: Rainfall map of Bishwambharpur

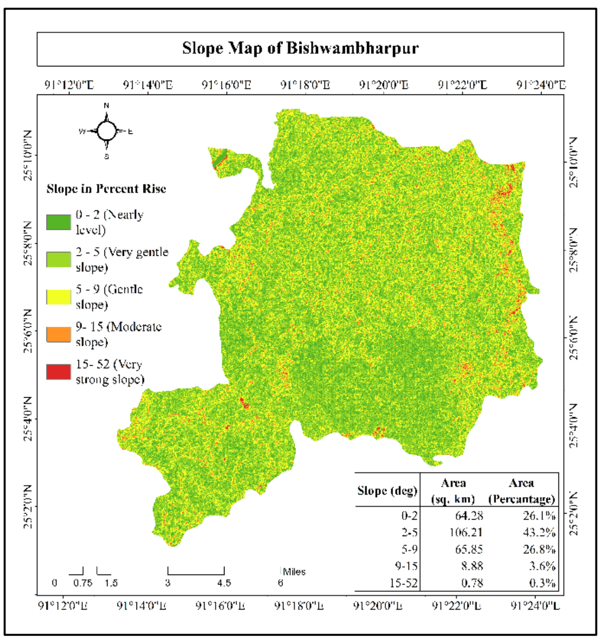

Figure 5: Slope map of Bishwambharpur

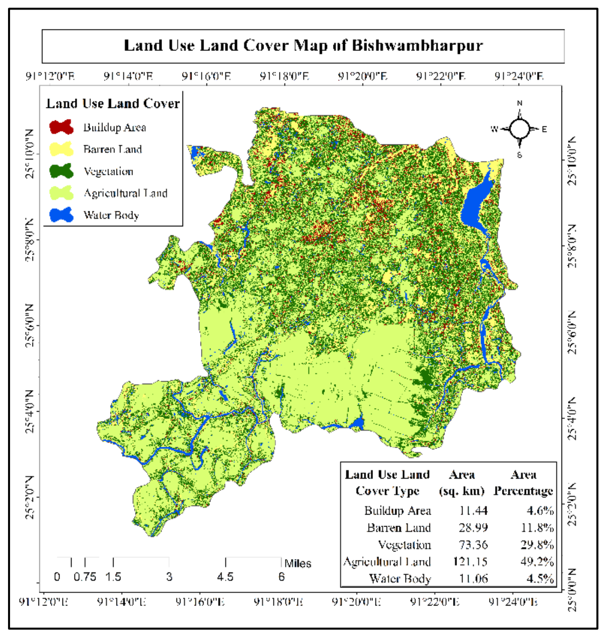

Figure 6: LULCmap of Bishwambharpur

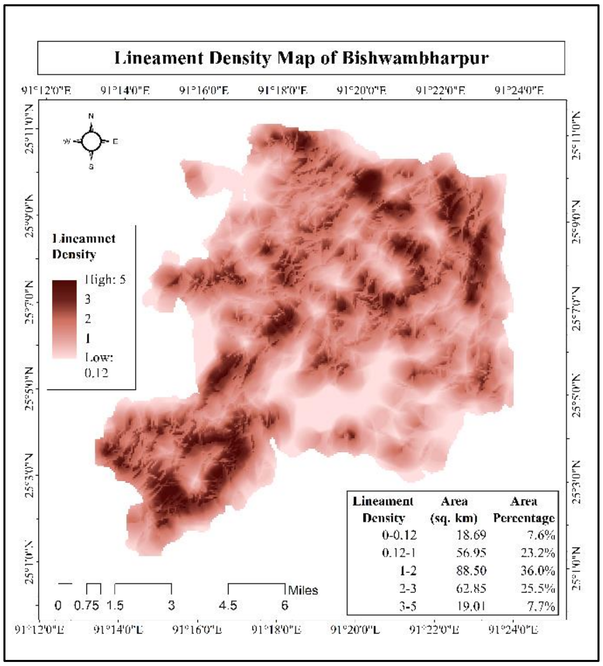

Figure 7: Lineament density map of Bishwambharpur

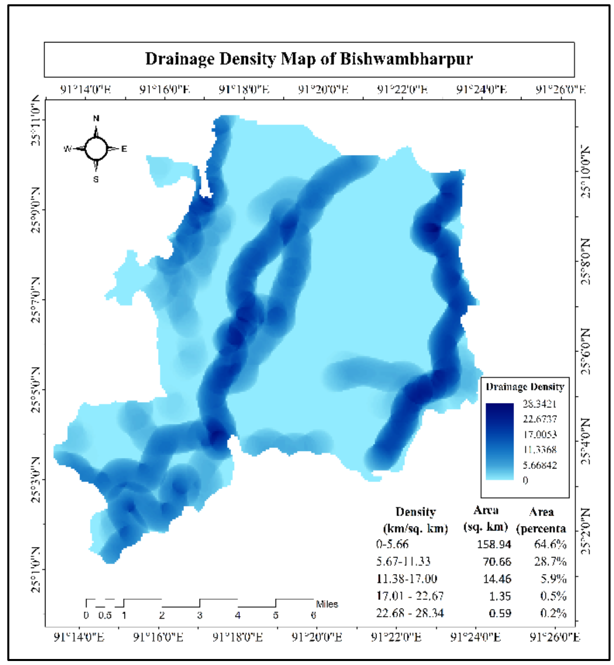

Figure 8: Drainage density map of Bishwambharpur

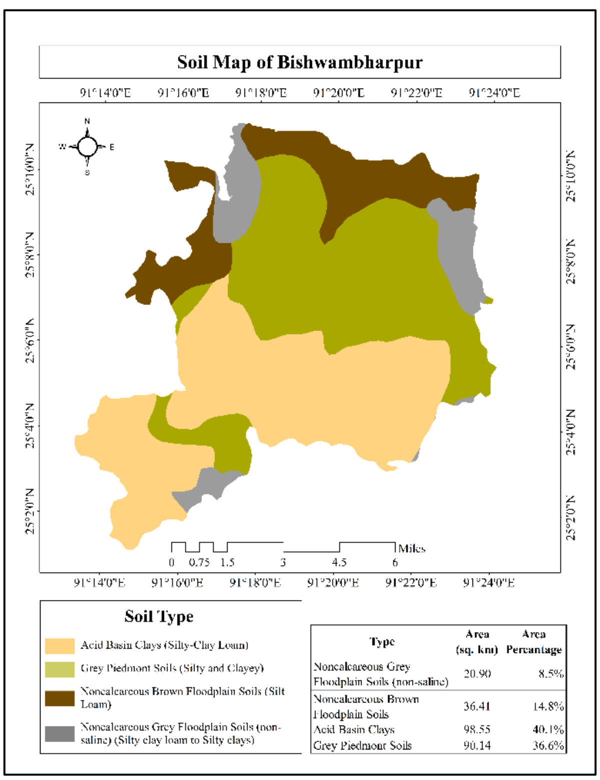

Figure9: Soil map of Bishwambharpur

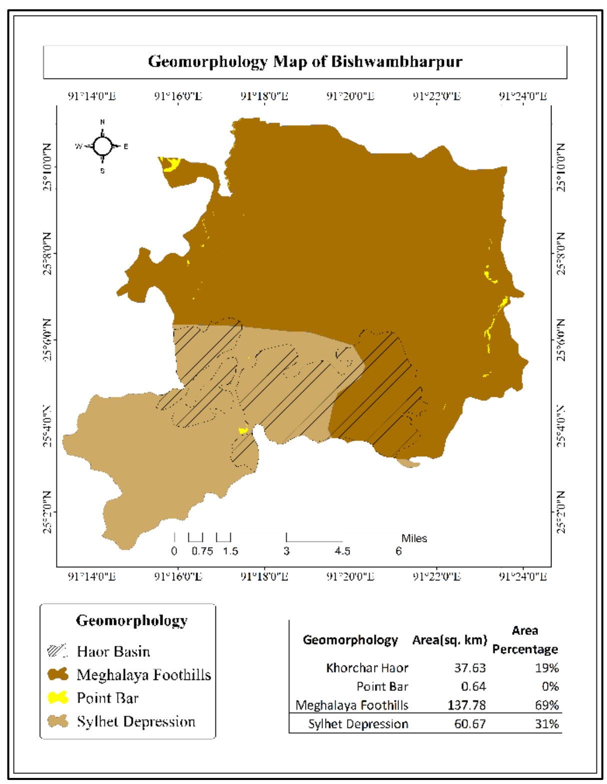

Figure 10: Geomorphology map of Bishwambharpur

Groundwater potential recharge zone map

The groundwater potential recharge zone of the Bishwambharpur upazilla (Figure 11) exposes three distinctive zones suggesting 'good', 'moderate', and 'poor' groundwater potential in the study area. Normally the "good" groundwater potential recharge zones coincide with high groundwater table, which is determined by various factors. It demarcates the areas where the terrain is most suitable 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. The area covered by 'good' groundwater potential recharge zone is about 26.42 km² (10.7%). The 'good' zone can be found as the scattered patch in the north portion of the study area. The 'moderate' groundwater potential recharge zones of the study area cover about 195.92 km² (79.6%). The 'moderate' groundwater potential recharge zones are found throughout the study area and mostly in the northern part. The "poor" groundwater potential recharge zones occur with low groundwater table and demarcate the areas where the terrain is not suitable for groundwater recharge. Areas with high slope, high drainage density, low lineament density, low rainfall, unfavorable geology and geomorphology, presence of low soil porosity have low groundwater prospects. The 'poor' groundwater potential recharge zones of the study area cover about 23.66 km² (9.6%). The 'poor' groundwater potential recharge zones can be found in the south, south-eastern and south-western part of the study area, respectively.

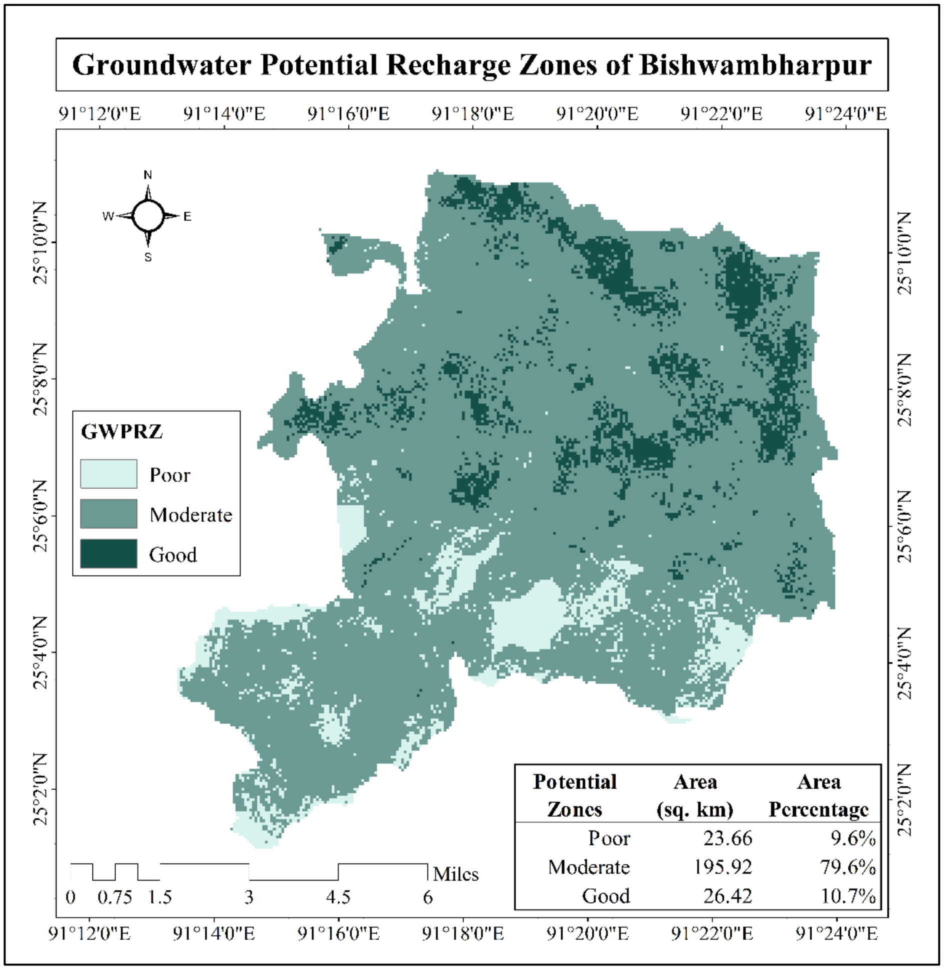

Figure 11: Groundwater potential recharge zones of Bishwambharpur.

As conclusion groundwater potential recharge zones provide a sustainable solution for the freshwater scarcity in a particular area. Sensible use of groundwater is necessary for sustaining long term agriculture as well as socio-economic development in the Bishwambharpur. In this paper, the integrated RS and GIS based AHP methodology is used to delineate the groundwater potential recharge zones in Bishwambharpur. The study area is classified into three distinct groundwater potential recharge zones' good', 'moderate', and 'poor' covering accordingly 10.7%, 79.6% and 9.6% of the total area. Groundwater potential recharge zones clearly dictate that most parts of the areas with favorable geology, soil texture, high lineament density slope, optimum rainfall condition have a high potential for groundwater recharge. In order to get the best output from RS and GIS application in determining the potential zone of groundwater, identification and selection of suitable geospatial factors and justifiable assignments of weights are essential.

The present study provides a sensible way for the planning of sustainable groundwater management in the region. The methodology used in the study is based on logical conditions, and it is generic in nature, the same methodology can also be applied to other regions of Bangladesh or abroad with/without suitable modifications.

REFERENCES

Alaam, M. L., Shaheed, s. M., Akio, S. & Miyauchi, N., 1993. Chemical Properties of General Soil Types of Bangladesh. Memoirs of the Faculty of Agriculture, Kagoshima University, pp. 75-87.

Al-Abadi, A. M., Shahid, S., Ghalib, H. B. & Handhal, A. M., 2017. A GIS-Based Integrated Fuzzy Logic and Analytic Hierarchy Process Model for Assessing Water-Harvesting Zones in Northeastern Maysan Governorate, Iraq. Arabian Journal for Science and Engineering, 42(6), pp. 2487-2499.

Alam, M. et al., 2003. An overview of the sedimentary geology of the Bengal Basin in relation to the regional tectonic framework and basin-fill history. Sedimentary Geology, Volume 155, pp. 179-208.

Alonso, J. & Lamata, M., 2006. Consistency in the analytic hierarchy process: a new approach. International Journal of Uncertainty. Fuzziness Knowledge Based Syst, 14(4), pp. 445-459.

Arshad, A., Zhang, Z., Zhang, W. & Dilawar, A., 2020. Mapping favorable groundwater potential recharge zones using a GIS-based analytical hierarchical process and probability frequency ratio model: A case study from an agro-urban region of Pakistan. Geoscience Frontiers.

Babiker, I. S., Mohamed, M. A. A. & Hiyama, T., 2007. Assessing groundwater quality using GIS. Water Resources Management, 21(4), pp. 699-715.

Bates, B. C., Kundzewicz, Z. W., Wu, S. & Palutikof, J. P., 2008. Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change. Geneva: IPCC Secretariat.

Burgess, W. G. et al., 2010. Vulnerability of deep groundwater in the Bengal Aquifer System to contamination by arsenic. Nature Geoscience, 3(2), pp. 83-87.

Cherry, J. A. & Freeze, R. A., 1979. Groundwater. 3rd ed. New Jersy: Englewood Cliffs.

Chowdhury, A., Jha, M. & Chowdary, V., 2000. Delineation of groundwater recharge zones and identification of artificial recharge sites in west Medinipur district, West Bengal, using GIS and MCDM techniques.. Environmental Earth Science, Volume 59, p. 1209.

Chowdhury, A., Jha, M. K., Chowdary, V. M. & Mal, B. C., 2009. Integrated remote sensing and GIS-based approach for assessing groundwater potential in West Medinipur district, West Bengal, India. International Journal of Remote Sensing, 30(1), pp. 231-250.

Das, S., Gupta, A. & Ghosh, S., 2017. Exploring groundwater potential zones using MIF technique in semi-arid region: a case study of Hingoli district, Maharashtra. Spatial Information Research, 25(6), pp. 749-756.

Das, S. & Pardeshi, S. D., 2018. Integration of different influencing factors in GIS to delineate groundwater potential areas using IF and FR techniques: a study of Pravara basin, Maharashtra, India. Applied Water Science, pp. 1-16.

Edet, A. E., Okereke, C. S., Teme, S. C. & Esu, E. O., 1998. Application of remote-sensing data to groundwater exploration: A case study of the Cross River State, south-eastern Nigeria. Hydrogeology Journal, 6(3), pp. 394-404.

Etikala, B., Golla, V., Adimalla, N. & Marapatla, S., 2019. Factors controlling groundwater chemistry of Renigunta area, Chittoor District, Andhra Pradesh, South India: A multivariate statistical approach. HydroResearch, Volume 1, pp. 57-62.

Ferrer, C. W., 2001. Applied Hydrogeology. 4th ed. Englewood Cliffs: Prentice Hall.

Ghasemizadeh, R. et al., 2012. Review: Groundwater flow and transport modeling of karst aquifers, with particular reference to the North Coast Limestone aquifer system of Puerto Rico. Hydrogeology Journal, 20(8), pp. 1441-1461.

Ghorbani, S. et al., 2015. Delineation of groundwater potential zones using remote sensing and GIS-based data driven models. Geocarto International, 32(2), pp. 167-187.

Gupta, M. & Srivastava, K. P., 2010. Integrating GIS and remote sensing for identification of groundwater potential zones in the hilly terrain of Pavagarh, Gujarat, India. Water International, 35(2), pp. 233-245.

Haridas, V., Aravindan, S. & G. G., 1998. Remote sensing and its applications for groundwater favourable area identification. Quarterly Journal of GARC, Volume 6, pp. 18-22.

Harinarayanan, P., G.S.Gopalakrishna & Balasubramanian, A., 2000. Remote sensing data for groundwater development and management in Keralapura Watersheds of Cauvery basin, Karnataka, India. The Indian Mineralogist, Volume 34, pp. 11-17.

Hoque, M. A. et al., 2009. Near surface lithology and spatial variation of arsenic in the shallow groundwater: south-eastern Bangladesh. Environmental Geology, 56(8), pp. 1687-1695.

IPCC, 2001. TAR Climate Change 2001: The Scientific Basis, Cambridge: UNIVERSITY OF CAMBRIDGE.

IPCC, 2018. Summary for Policymakers of IPCC Special Report on Global Warming of 1.5ºC approved by Governments, s.l.: IPCC.

Jha, M. K., Chowdary, V. M. & Chowdhury, A., 2010. Groundwater assessment in Salboni Block, West Bengal (India) using remote sensing, geographical information system and multi-criteria decision analysis techniques. Hydrogeology Journal, 18(7), pp. 1713-1728.

Jhariya, D. C. et al., 2016. Assessment of groundwater potential zone using remote sensing, GIS and multi criteria decision analysis. Journal of the Geological Society of India, 88(4), pp. 481-492.

Keng, C. Y. et al., 2017. Application of vector autoregressive model for rainfall and groundwater level analysis. AIP Conference Proceedings, 1870(1), p. 60013.

Khadri, S. F. R. & Pande, C., 2016. Ground water flow modeling for calibrating steady state using MODFLOW software: a case study of Mahesh River basin, India. Modeling Earth Systems and Environment, 2(1), p. 39.

Khan, M. A., Narain, P. & Moharana, P. C., 2006. Prospecting ground water resources using RS-GIS—A case study from arid western rajasthan of India. Journal of the Indian Society of Remote Sensing, 34(2), p. 171.

Krishnamurthy, J., Kumar, N. V., Jayaraman, V. & Manivel, M., 1996. An approach to demarcate ground water potential zones through remote sensing and geographical information system. International Journal of Remote Sensing, 17(10), pp. 1867-1884.

Lee, S. et al., 2017. Nano-sized metabolic precursors for heterogeneous tumor-targeting strategy using bioorthogonal click chemistry in vivo. Biomaterials, Volume 148, pp. 1-15.

Lee, S. & Lee, C.-W., 2015. Application of Decision-Tree Model to Groundwater Productivity-Potential Mapping. Sustainability, 7(10), pp. 13416-13432.

Lentswe, G. B. & Molwalefhe, L., 2020. Delineation of potential groundwater recharge zones using analytic hierarchy process-guided GIS in the semi-arid Motloutse watershed, eastern Botswana. Journal of Hydrology: Regional Studies, Volume 28.

Madani, A. & Niyazi, B., 2015. Groundwater potential mapping using remote sensing techniques and weights of evidence GIS model: a case study from Wadi Yalamlam basin, Makkah Province, Western Saudi Arabia. Environmental Earth Sciences, 74(6), pp. 5129-5142.

Magesh, N. S., Chandrasekar, N. & Soundranayagam, J. P., 2012. Delineation of groundwater potential zones in Theni district, Tamil Nadu, using remote sensing, GIS and MIF techniques. Geoscience Frontiers, 3(2), pp. 189-196.

McGarry, D., 2006. A Methodology of a Visual Soil - Field Assessment Tool to Support, Enhance and Contribute to the LADA Program, Rome, Italy: Food and Agriculture Organization.

Mekonnen, M. M. & Hoekstra, A. Y., 2016. Four billion people facing severe water scarcity. Science Advances, 2(2).

Mogaji, K. A., Lim, H. S. & Abdullah, K., 2015. Regional prediction of groundwater potential mapping in a multifaceted geology terrain using GIS-based Dempster–Shafer model. Arabian Journal of Geosciences, 8(5), pp. 3235-3258.

Moghaddam, D. D. et al., 2015. Groundwater spring potential mapping using bivariate statistical model and GIS in the Taleghan Watershed, Iran. Arabian Journal of Geosciences, 8(2), pp. 913-929.

Mondal, P. & Dalai, A. K., 2017. Sustainable Utilization of Natural Resources. 1st Edition ed. Boca Raton: CRC Press.

Mukherjee, P., Singh, C. K. & Mukherjee, S., 2012. Delineation of Groundwater Potential Zones in Arid Region of India-A Remote Sensing and GIS Approach. Water Resources Management, 26(9), pp. 2643-2672.

Murthy, K. S. R., 2000. Ground water potential in a semi-arid region of Andhra Pradesh - a geographical information system. International Journal of Remote Sensing, 21(9), pp. 1867-1884.

Naghibi, S. A., Pourghasemi, H. R. & Dixon, B., 2015. GIS-based groundwater potential mapping using boosted regression tree, classification and regression tree, and random forest machine learning models in Iran. Environmental Monitoring and Assessment, 188(1), p. 44.

Ozdemir, A., 2011. GIS-based groundwater spring potential mapping in the Sultan Mountains (Konya, Turkey) using frequency ratio, weights of evidence and logistic regression methods and their comparison. Journal of Hydrology, 411(3), pp. 290-308.

Patra, S., Mishra, P. & Mahapatra, S. C., 2018. Delineation of groundwater potential zone for sustainable development: A case study from Ganga Alluvial Plain covering Hooghly district of India using remote sensing, geographic information system and analytic hierarchy process. Journal of Cleaner Production, Volume 172, pp. 2485-2502.

Pourtaghi, Z. S. & Pourghasemi, H. R., 2014. GIS-based groundwater spring potential assessment and mapping in the Birjand Township, southern Khorasan Province, Iran. Hydrogeology Journal, 22(3), pp. 643-662.

Prabhu, M. V. & Venkateswaran, S., 2015. Delineatin of Artificial Recharge Zones Using Geospatial Techniques In Sarabanga Sub Basin Cauvery River, Tamil Nadu. Aquatic Procedia, Volume 4, pp. 1265-1274.

Prasad, R. K. et al., 2008. Deciphering potential groundwater zone in hard rock through the application of GIS. Environmental Geology, 55(3), pp. 467-475.

Rahman, M. A. et al., 2012. A new spatial multi-criteria decision support tool for site selection for implementation of managed aquifer recharge. Journal of Environmental Management, Volume 99, pp. 61-75.

Ravenscroft, P. et al., 2005. Arsenic in groundwater of the Bengal Basin, Bangladesh: Distribution, field relations, and hydrogeological setting. Hydrogeology Journal, 13(5), pp. 727-751.

Roscoe Moss Company, 1990. Handbook of Ground Water Development. s.l.:Wiley.

Saaty, T. L., 1980. The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation (Decision Making Series). 1st ed. New York: McGraw-Hill.

Sander, P., Chesley, M. M. & Minor, T. B., 1996. Groundwater Assessment Using Remote Sensing And GIS In A Rural Groundwater Project In Ghana: Lessons Learned. Hydrogeology Journal, 4(3), pp. 40-49.

Sarkar, D., Das, T., Chattopadhyay, T. & Velayutham, M., 2001. Soils of Hooghly District for Optimizing Land Use. NBSS and LUP, Nagpur: s.n.

Satapathy, B. N. & Kanung, D. N., 1976. GROUNDWATER EXPLORATION IN HARD-ROCK TERRAIN-A CASE HISTORY*,. Geophysical Prospecting, 24(4), pp. 725-736.

Scanlon, B. R. et al., 2006. Global synthesis of groundwater recharge in semi-arid and arid regions. Hydrological Processes, 20(15), pp. 3335-3370.

Schewe, J. et al., 2014. Multimodel assessment of water scarcity under climate change. Proceedings of the National Academy of Sciences of the United States of America, Volume 111, pp. 3245-3250.

Selvam, S. et al., 2014. Deciphering of groundwater potential zones in Tuticorin, Tamil Nadu, using remote sensing and GIS techniques. Journal of the Geological Society of India, 84(5), pp. 597-608.

Shamsudduha, M., Taylor, R. & Longueverge, L., 2012. Monitoring groundwater storage changes in the highly seasonal humid tropics: Validation of GRACE measurements in the Bengal Basin. Water Resources Research, 48(2).

Solomon, S. & Quiel, F., 2006. Groundwater study using remote sensing and geographic information systems (GIS) in the central highlands of Eritrea. Hydrogeology journal, 14(5), pp. 729-741.

Taylor, R. G. et al., 2013. Ground water and climate change. Nature Climate Change, 3(4), pp. 322-329.

Tiwari, A. K. et al., 2017. Identification of artificial groundwater recharging zone using a GIS-based fuzzy logic approach: a case study in a coal mine area of the Damodar Valley, India. Applied Water Science, 7(8), pp. 4513-4524.

Todd, D. K. & Mays, L. W., 2005. Grundwater Hydrology. 3rd ed. Hoboken: Wiley.

UNESCO, UN-Water, 2020. The United Nations World Water Development Report 2020: WATER AND CLIMATE CHANGE, Paris: United Nations Educational, Scientific and Cultural Organization.

UN-Water, 2014. International Decade for Action 'WATER FOR LIFE' 2005-2015. [Online]

Venkateswaran, S. & Ayyanurai, R., 2015. Groundwater Potential Zoning in Upper Gadilam River Basin. s.l., Elsevier B.V., pp. 1275-1282.

Watto, M. A. & Mugera, A. W., 2015. Efficiency of irrigation water application in sugarcane cultivation in Pakistan. Journal of the Science of Food and Agriculture, 95(9), pp. 1860-1867.

WWAP, W. W. A. P., 2009. Water in a changing world. World Water Devlopment Report 3., Paris: UNESCO.

Xu, Y. & Beekman, H. E., 2019. Review of groundwater recharge estimation in arid and semi-arid Southern Africa. Hydrogeology Journal, 27(3), pp. 929-943.

Received: 13th March 2021; Accepted: 12th December 2022; First distribution: XXth December 2022