

Chapter 7

Analysis of Groundwater Potentiality Zones of Siliguri Urban Agglomeration Using GIS-Based Fuzzy-AHP Approach



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Abstract Availability of sustainable potable water and its efficient utilisation is one of the major challenges in urban planning to meet the everincreasing demand for expanding urban population. In the present study, the groundwater resource potential zones were evaluated based on integrated GIS-based Fuzzy Analytical Hierarchy Process (AHP) approach on Siliguri urban agglomeration (SUA), West Bengal, India. For that purpose, eight different thematic layers (DEM, slope, soil, LULC, annual precipitation, lineament density, moisture index and geology) were integrated by geospatial techniques, and the resulting values are put into the Saaty's AHP to detect Groundwater Potentiality Zone (GPZ). Finally, five major classes of GPZ were identified based on water potentiality, namely, low, medium, medium-high, high and very high. The results were validated through a standard method namely precision Receiver Operating Characteristics (ROC) curve and the calculated AUC value was 87.7%. The study area had 33.19% good groundwater potentiality area at the South-Western and Western part, and low potentiality zone had shared 6.76% of the total area. The study concludes that the overall study area has carried out suitable groundwater potentiality. The zonation of groundwater potentiality may be useful for urban area development over Siliguri in the near future.

Keywords Groundwater potential zone · Precision accuracy assessment · Saaty's AHP · Thematic layers · Urban planning

7.1 Introduction

The growing population in India with increasing unpredicted human demand on water becomes a critical issue, while we have only 4% freshwater availability (Aayog 2017). Annually, India has available replenishable groundwater resources, but the maximum volume of groundwater is used for agriculture purposes and the

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rest of the groundwater resources are used through domestic and natural discharge purposes (CGWB 2017). Consequently, surpass withdrawal of groundwater and deficiency of surface water resources has created a negative impact on the environment, resulting in water stress in major parts of India (Jha et al. 2010).

Moreover, cities or urban areas have certain limited resources, and majority of people are attracted towards the urban areas to find their job and better livelihood, thus expanding cities promptly. Census survey report of India shows at the beginning of the twentieth century (1901) only 1/10 of the population of India lived in urban areas, but now (2011), 1/3 of the population of India lived in urban areas (Chandramouli and General 2011). Therefore, sustainable potable water and its efficient use is one of the major challenges in urban planning to ensure sufficient demand for the growing population in an urban area. The number of people with increasing demand on water, including poor management, has become an issue for any urban bodies. Potential groundwater aquifers help the urban areas to sustain good quality of water supply for drinking purposes throughout the year, including available surface water resources (Singh et al. 2013).

Although it is crucial that each and every urban body must have efficient use of groundwater resource, it still requires Groundwater Potential Zone (GPZ) assessment to identify the site suitability for urban residential zone development in the future. Availability of the groundwater in any urban region has been influenced by the different climatic and hydrological features and its interrelationship (Tiwari et al. 2019). This hydrological feature depends on physical settings like slope, elevation, soil type, geology, geomorphology, drainage and lineament, etc. (Ozdemir 2011; Rahmati et al. 2014). The climatic features such as precipitation and moisture have governed the physical attributes for the analysis and mapping of GPZ (Tiwari et al. 2019).

Since the 1970s, geospatial techniques of remote sensing (RS) and geographical information system (GIS) have been fruitfully projected for mapping on physical structures and their features (altitude and slope), geological structures, land use/land cover, drainage system, recharge and discharge, geomorphology, soil, etc. (Mogaji 2016). Satellite images can be effectively handled by GIS. RS and GIS both are used as spatial evaluation measures associated with beleaguered spatial decision problems. GIS can also integrate with the multi-criteria decision analysis (MCDA) method which generates an influential tool for spatial decision-making processes. Past few decades, the MCDA has been established and denoted to the developmental decisions through accuracy assessment, structure analysis and suitability analysis (Ozdemir 2011; Tiwari et al. 2019). Saaty's analytic hierarchy process (AHP) is one of the worldwide conventional MCDA-based numerical method to resolve problems of multiple attribute-based domains such as site suitability analysis and mapping (Saaty 1980), healthcare assessment (Reddy et al. 2014; Thokala et al. 2016), hazard mapping (Matori et al. 2014; Hoque et al. 2017), mapping on groundwater delineation (Jenifer and Jha 2017), etc. In the beginning of the twenty-first century, various new approaches have emerged in addition to AHP, such as data-driven model using fuzzy logic (Liggett and Talwar 2009; Boughriba et al. 2010), knowledge-driven model-like statistical index (SI) (Nag and Ghosh 2012), frequency ratio

(FR) (Ozdemir 2011; Park et al. 2013), weights of evidence (WoE) (Machiwal et al. 2011), artificial neural network (ANN) (Lee et al. 2012) and support vector machines (SVMs) (Naghbi et al. 2017), which are used to study the geospatial data for generating groundwater potentiality zone map which has a great role to develop urban land use site suitability.

A knowledge-driven model like Fuzzy-based mapping is a kind of model where users are often faced with some difficulties in selecting a membership function (Al-Abadi et al. 2018). Even some statistical models such as SI and WoE have shown some problems in measuring the interrelationship between training factors and groundwater event (Yilmaz 2009; Ozdemir 2011). Moreover, the modified advance data-driven machine learning techniques, such as ANN, RF, SVM and BRT, have some restrictions, namely, the neural network opacity and its dependency on outliers of logistic regression for understanding (Tiwari et al. 2019). But, AHP technique can agree the amalgamation of fundamental elements (Rahmati et al. 2014). Furthermore, it can decompose the observation into hierarchy and ensure that the combining aspects of qualitative and quantitative analysis have been integrated. Hence, AHP deals with the issues of generalisation in human decision-making processes (Emrouznejad and Marra 2017). In recent times, Fuzzy-based MCDA (Ishizaka and Labib 2011; de FSM Russo and Camanho 2015) combined with AHP is established as a parsimonious and an appropriate tool to delineate groundwater zone and its management (Pani et al. 2016; Pinto et al. 2017; Kumar and Krishna 2018). So, we have concentrated on the Fuzzy-based AHP approach using geospatial and statistical techniques to delineate GPZ of Siliguri urban agglomeration (SUA).

A large number of studies on delineation of GPZ using Fuzzy-AHP had been done by Murthy (2000), Jaiswal et al. (2003), Anbazhagan et al. (2005), Kumar et al. (2007), Gupta and Srivastava (2010), Rahmati et al. (2016), Tiwari et al. (2019), etc. The result helps us to identify the water potential area to support future urban commercial and residential land use planning.

7.2 Study Area

Siliguri, a metropolitan city, is basically known as the gateway of north-east India. In 1901, it was a mere village, but within a few decades it has developed as the largest urban agglomeration of North Bengal. The Siliguri urban agglomeration (SUA) is located at the junction of New Jalpaiguri district and the foothills of Darjeeling Himalaya on the bank of Mahananda and Balason River extending from $88^{\circ}23'15''$ E to $88^{\circ}28'01''$ E longitude and from $26^{\circ}40'38''$ N to $26^{\circ}46'40''$ N latitude (Fig. 7.1), with an average elevation of 120 metres from the mean sea level (MSL). Urbanisation is gradually going on throughout the entire North Bengal, but in the case of Siliguri it is faster mainly due to its geographical location and communication importance. The study area is covered by 99.60 sq. km (Census 2011). The total population of SUA is 1,057,438 with the population density of 11,171 per square

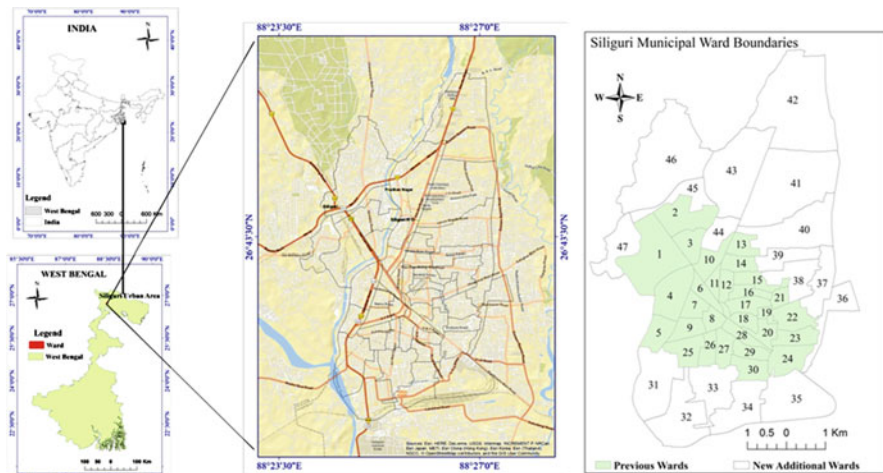


Fig. 7.1 Location map of the Siliguri urban agglomeration (SUA) with open street map and increasing ward boundaries

Table 7.1 Detail information of Landsat-8 imagery and ASTER DEM data

Acquisition date	Satellite	Path/row	Resolution	Referencing system
07/03/2018	Landsat-8 OLI	139/42	30 m, 100 m	UTM 45°N and WGS 84
15/03/2011	ASTER DEM	NA	30 m	

km. The sharp increase in population occurred due to the partition of Bengal in 1947 and further during the political unrest in 1971. Also, due to administrative problems in Nepal and China, people started to settle permanently in Siliguri. It was given a status of Municipal Corporation by the government in 1994, while 17 new wards were added with existing 30 wards in SUA and the total scenario has been changed (Fig. 7.1). Although the whole area was developed over the alluvium flood plain but some portion in the northern part of the study area was covered by the impervious surface. As various urban issues are coming in the forefront with the increasing trends of urban population, groundwater has become one of the issues.

7.3 Materials and Methods

7.3.1 Data Used

In this study we have applied multi-spectral satellite imagery of Landsat-8-(OLI/TIRS) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)-digital elevation model (DEM) data obtained from satellite. Table 7.1 provides detail information about the data acquisition. Landsat data and DEM data

were derived from the US Geological Survey (USGS) Earth Explorer web portal (<http://earthexplorer.usgs.gov>).

7.3.2 Data Processing and Creation of Thematic Layers

Methodological flow chart was used in this present study to give the better understanding for developing groundwater potential zone map (Fig. 7.2). Firstly, we had used the ASTER DEM data to generate the slope map. The generated slope map was categorised into five specified land classes using natural break method. Then Landsat-OLI/8 image had been composed, clipped and finally classified using supervised maximum likelihood classification method and categorised into six predetermined classes, water body, bare surface, crop land, open pasture, vegetation cover and built-up, to generate the LULC map. Moisture index map was obtained from the Landsat-OLI/8 satellite data of 2018 using modified normalised difference moisture index (MNDMI) to show the soil moisture content rate instead of drainage density. The geological map was prepared with the help of Geological Survey of India (GSI), Kolkata. Firstly, the scanned image was rectified and then digitised using ArcGIS software. With the help of density module in ArcGIS spatial analyst tool, lineament density map also was prepared in the similar way. The soil map was collected from the National Bureau of Soil Survey and Land Use Planning

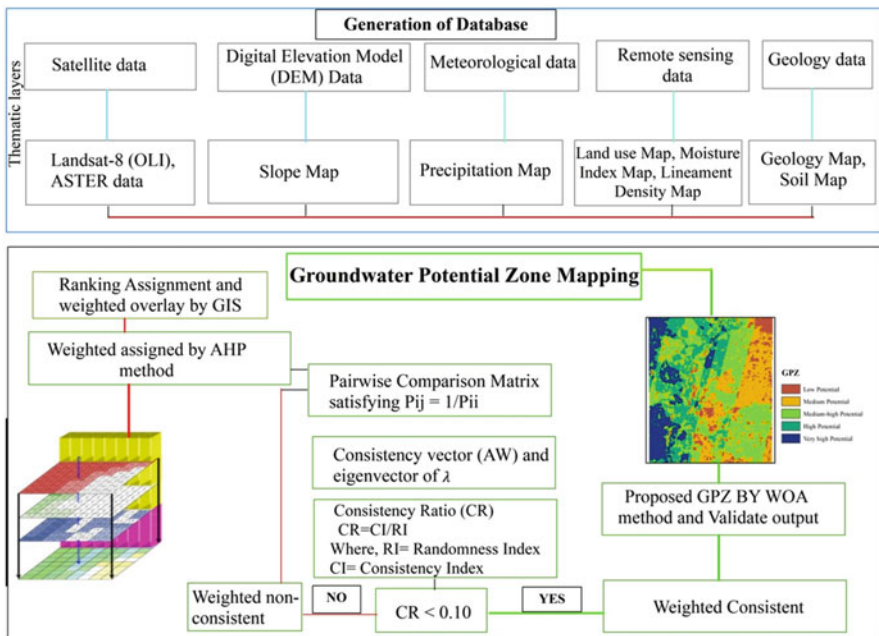


Fig. 7.2 Flowchart of the study

(NBSS&LUP), Kolkata, West Bengal. Then, station data for rainfall distribution over 17 years (2001–2018) was obtained from India Meteorological Department (IMD) to generate the annual rainfall distribution map using spatial interpolation method like nonlinear inverse distance weighting (IDW). IDW is used to represent the proximity of an unobserved point which is computed in reverse considering the distance to the points (Wu et al. 2010) classification. Various maps were validated with Siliguri perspective plan 2025 proposed by Siliguri Jalpaiguri Development Authority (SJDA).

7.3.3 Fuzzy-AHP and Assignments of Normal Weighted Overlay of the Selected Thematic Layers

Analytic hierarchy process (AHP) is applied to define the weights of the thematic layers (Saaty 1980). Remarkably, the GIS-based Fuzzy weighted overlay analysis (WOA) method including AHP has been an essential technique to evaluate the multifaceted longitudinal decision problems. The judgement rating value is ranged between 1 and 9 scales (Saaty 1980) shown in Table 7.2. Therefore, weighted values of each thematic layer are needed for developing GPZ with the help of ArcGIS software.

Firstly, the problem was designed based on criteria and objectives in a hierarchical process. Secondly, comparison and gradation numbers had been given into the weighted criteria to assume its intensities with specific importance. Weights were given to each category of selected layers from earlier knowledge of the factor characteristics, local experts, personal observation (Machiwal et al. 2011) and

Table 7.2 Comparison and gradation number for alternatives in AHP (Saaty 1980)

Intensity of importance ^a	Characteristics	Explanation
1	Not suitable	Two activities contribute equally to the objective
3	Moderately suitable	Judgement slightly favours one activity over another
5	Suitable	Judgement strongly favours one activity over another
7	Very suitable	Activity is favoured very strongly over another
9	Extremely suitable	Highest possible order of favouring one activity over another
2, 4, 6, 8	Judgemental value	When compromise is needed
Reciprocals of the above numbers	If it is assigned one of the numbers when comparing with j , then j has the reciprocal value when compared with i	Reasonable assumption

^aLess importance <- (1/9-1/8-1/7-1/6-1/5-1/4-1/3-1/2-1-2-3-4-5-6-7-8-9) -> More importance

urban planning expert of Siliguri Municipality Corporation. Thirdly, relative weightage was allocated to each factor, and in this way, pairwise comparison matrix had been formed (Table 7.5). Then, the allocated value of every factor was normalised into 1 by eigenvector method of AHP, and finally, the summation of one column value was divided by column total. In this way, normalisation of pairwise matrix was completed. Thereafter, the influence of the allocated weights of the thematic layers was examined for consistency measurement through the normalisation processes (Saaty 1980). Thereafter, each standard corresponding weight was given based on average value of individual row; thus final normalised pairwise weighted matrix has been formulated (Table 7.6).

$$AW = \begin{pmatrix} P_{11} & P_{12} & P_{13} & \dots & P_{1n} \\ P_{21} & P_{22} & P_{23} & \dots & P_2 \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ P_{n1} & P_{n2} & P_{n3} & \dots & P_{nn} \end{pmatrix} \times \begin{pmatrix} W_1 \\ W_2 \\ \dots \\ \dots \\ W_n \end{pmatrix} = P_{ij} \times W_i \quad (7.1)$$

where P_{ij} ($i = 1, 2, 3, \dots, n$) and ($j = 1, 2, 3, \dots, n$) denote pairwise comparison matrix; $P_{ii} = 1$ and $P_{ij} = 1/P_{ji}$. W_i ($i = 1, 2, \dots, n$) denotes ranking weight.

The consistency vector can be denoted by the term AW which is measured with the help of equivalent weight values of λ . The sum of AW when divided by ranking weights is called λ_{max} (Tiwari et al. 2019).

$$\lambda_{max} = \frac{1}{n} \sum_{W_i=0}^n \frac{AW}{W_i} \quad (7.2)$$

where W denotes the corresponding eigenvector of λ_{max} , W_i ($i = 1, 2, 3, \dots, n$) denotes the ranking weight (Machiwal et al. 2011), AW denotes the consistency vector and n represents the number of classes (Table 7.3).

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (7.3)$$

where n represents the frequency of classes, λ_{max} is the maximum eigenvalue and CI is the consistency index.

$$CR = \frac{CI}{RI} \quad (7.4)$$

Table 7.3 Random index for different values of n (Saaty 1980)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.89	1.12	1.24	1.32	1.41	1.45	1.49

where the CR (consistency ratio) represents the denominator of CI and RI. The CR value should be less than 0.10 that reflects the consistency in each of the factors' weightage during pairwise comparison matrix (Sener et al. 2011).

7.3.4 Delineation of the GPZ

Groundwater potentiality zones were delineated using geospatial and statistical approach. Weighted overlay analysis (WOA) method is used to calculate the GPZ by combining all the possible factors and giving weightage to each of the selected factors (Eq. 7.5).

$$GPZ = \sum_{W=1}^m \sum_{i=1}^n (W_i \times X_j) \quad (7.5)$$

where W_i is the normalised weight of the i thematic layer and X_j is the rank value associated with the j layer, while m and n denote the entire number of selected thematic layers and overall classes used in each thematic layer, respectively. The GPZ is calculated with the help of Eq. 7.6 below:

$$GPZ = E_w E_r + SL_w SL_r + S_w S_r + LULC_w LULC_r + P_w P_r + LD_w LD_r + MI_w MI_r + G_w G_r \quad (7.6)$$

where w and r represent the normalised weight index and AHP rating of the individual classes, respectively. E is the elevation, SL is denoted as slope, S represented the distribution of soil, $LULC$ is denoted land use land cover of SUA, P specifies volume of rainfall, LD is the lineament density, MI is the moisture index and G represented geological and topographical condition of the study area (Table 7.2).

7.4 Result and Discussion

7.4.1 Thematic Layers

Various important factors were incorporated to classify the GPZ in SUA, viz. elevation, geological structure, land use/land cover (LULC), annual precipitation, soil, moisture index and lineament density for GPZ analysis (Jaiswal et al. 2003). These thematic layer factors were calculated by giving importance gradation score (Table 7.5.) and then used the value for pairwise comparison matrix (Table 7.6). Moreover, each significant weight of assigned value was used to calculate and validate each of the individual factor. We used the consistency index (CI) and consistency ratio (CR) to mitigate the validation problem. Detailed information of

each thematic layer and its sub-classes, including groundwater suitability rating, was used to identify the GPZ map (Table 7.7). The detailed information about the individual thematic layer is as follows.

7.4.1.1 DEM

Digital elevation model (DEM) is the 3-D digital illustration of any kind of topography (Fig. 7.3). The current DEM showed mostly South-Western and Southern parts of SUA have almost flat topography. Therefore, maximum weight had been given to that part of the urban area due to the high potentiality of recharge including minimum runoff, while the northern part had highest elevation and it had very high opportunities of runoff rather than groundwater recharging. For that reason, it was given minimum weight.

7.4.1.2 Slope

Slope is the degree of inclination of any topographical surface, and aspect denoted the directions of the physical slope faces. Slope map was generated with the help of ASTER-DEM data of SUA. Plane areas are able to control the precipitation and supply groundwater recharge compared to the steep slope area. The area was categorised into five classes, which were (1) 0–0.45, (2) 0.45–1.21, (3) 1.21–2.15, (4) 2.15–3.19 and (5) 3.19–5.32 (Fig. 7.3). The maximum percentage of the slope was ranged from 1.21 to 2.15 degree. Higher rank was assigned to the gentle slope or flat slope, where the class was ranged from 3.19 to 5.32 degree and was assigned into lowest rank due to the steep slope.

7.4.1.3 Soil

Soil component was used to find out the actual moisture content into the soil and its nature. In this study area, four major soil classes were identified, i.e. (1) Clay loam, (2) Inceptisols-I, (3) Inceptisols-II and (4) Entisols (Fig. 7.3). Clay loam had constituted the most extensive soil, covering approximately 22.13% of area along the Mahananda basin at the north to the Balason basin at the South-west. Inceptisols-I-type soil basically falls under *tropest* sub-groups, more or less freely drained Inceptisols of humid tropics. It was found in the South-eastern part of the Mahananda basin with a thin to moderately deep profile (50–120 cm), developed mostly on steep slopes along the northern hilly area and the foothill around Marionbari and Panighatta. Inceptisols-II was found at the whole Debagram census town and adjacent part of the study area. The Inceptisols, including both I and II types, were covering 39.96% of the study area. But, Entisols have held a little evidence of soil profile development due to inadequate deposition of new alluvium layer at Balason and Mahananda basin area, and thus, it was given less weight. The

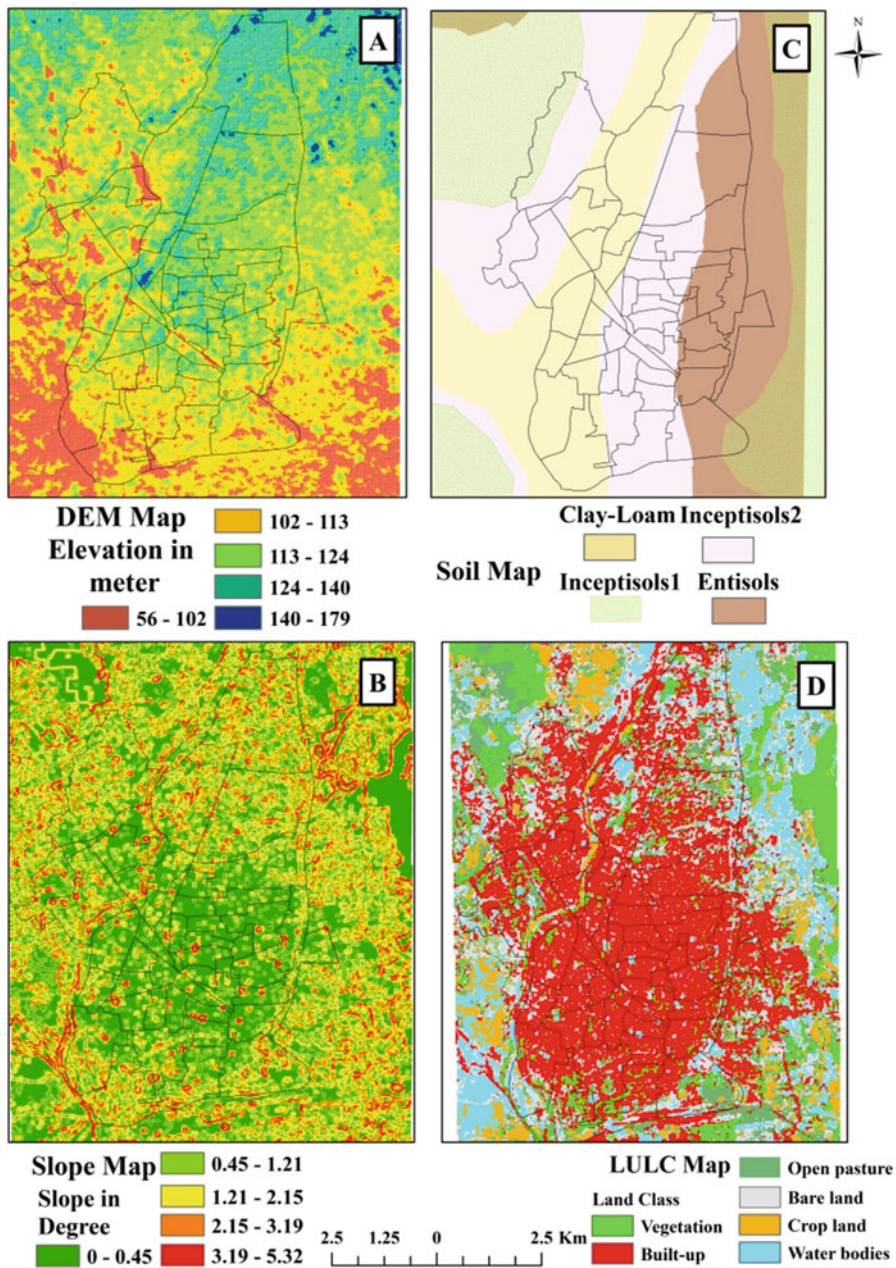


Fig. 7.3 Thematic layers: (a) DEM map; (b) slope map; (c) soil map; (d) LULC map of the study area

whole SMC was under this type of soil groups. These soils are typical humid soils possessing a wide variety of physical and chemical properties which are varying with depth, colour, texture, structure, organic carbon, porosity and permeability. Significance of soil characteristics was controlled by the infiltration level, and depending on local geological structure, the weightage was assigned (Table 7.7). Clay soil had greater control capacity which was extended from 0.00 to 0.06 inch/hour; hence, clay soil had assigned less importance and highest weightage than Inceptisols-I soil.

7.4.1.4 Land Use and Land Cover (LULC)

The land use and land cover (LULC) map of SUA 2018 was used to identify the distribution of total area including percentage of every land class (Figs. 7.3 and 7.4). LULC map was classified and generated using unsupervised and supervised processes using ERDAS 15.0 amalgamation with ArcGIS 10.1. Thus, six different types of LULC were found with a proportion of area shared by each land class, i.e. bare land (16.16%), built-up area (32.40%), crop land (10.91%), open pasture (15.72%), vegetation (12.66%) and water body (12.14%). Built-up area shared the maximum percentage (32.40%) and resulted into huge demand on water day by day. Consequently, water availability becomes a question, and urban people are facing some water stress (Table 7.4).

7.4.1.5 Precipitation

Precipitation or rainfall is a key factor for groundwater recharge. The nature of groundwater potentiality depends on duration and volume of precipitation which controls discharge and the balance between all the components of the hydrological cycle. Precipitation map was prepared using spatial interpolation method based on two meteorological stations data in around 15 km range. Nowadays, spline polynomial function has been carried out an important role to represent the interpolation of annual precipitation in monthly and yearly basis (Peel et al. 2009). Two precipitation zones 2500–3000 mm and above 3000 mm were identified in the annual precipitation map (Fig. 7.4). Southeast and western parts of Siliguri urban area were recorded above 3000 mm rainfall per annum that have been given maximum weightage.

7.4.1.6 Lineament Density

The lineament is a linear feature on the earth's surface defined as the fault with distortion in the geomorphic features due to adjustment of constant tension in the geological structure. It reflects a general surface expression of underground fractures like cracking, folding, faulting, etc. (Pradhan and Youssef 2010). Lineament is a key factor to determine the groundwater potentiality depending on the permeability and

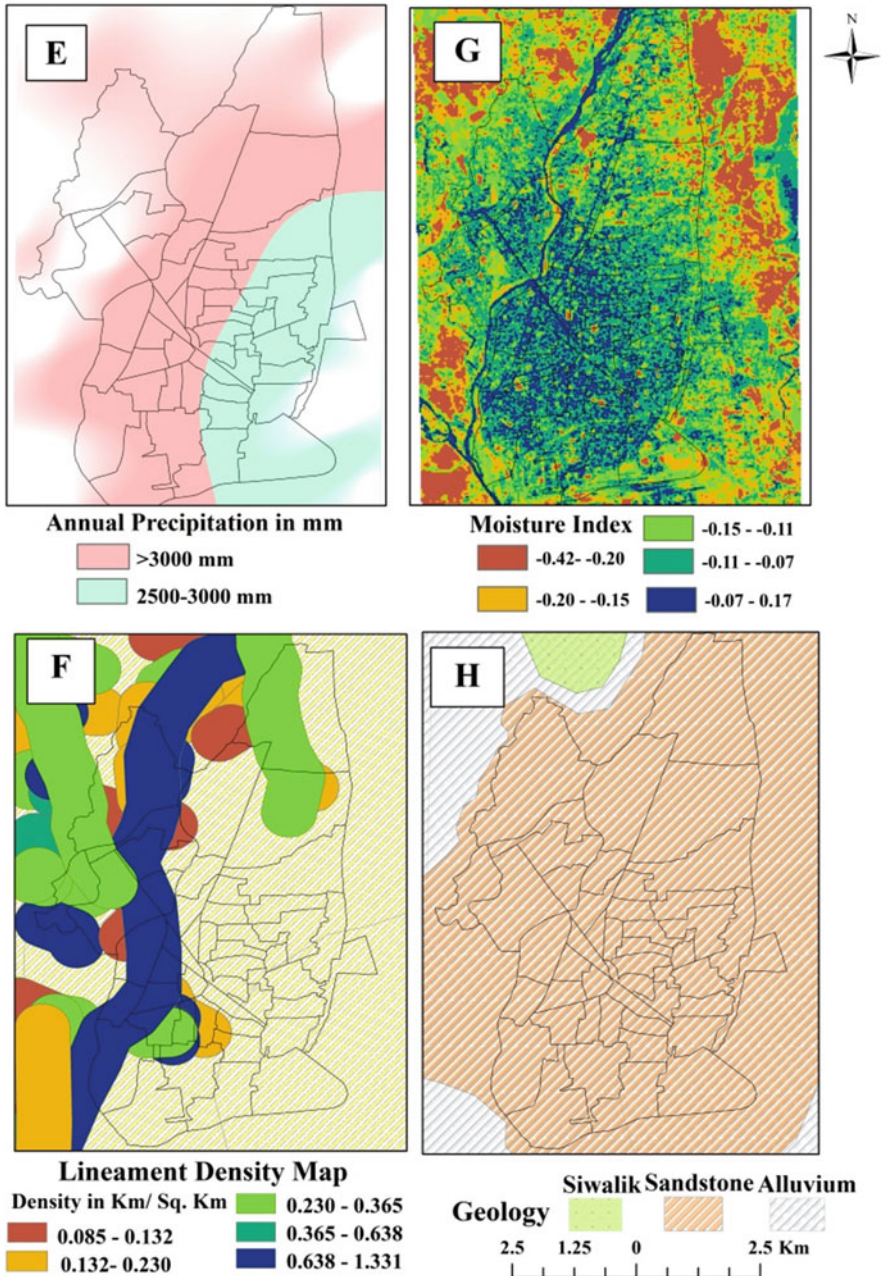


Fig. 7.4 Thematic layers: (e) precipitation map; (f) lineament density map; (g) moisture index map; (h) geology of the study area

Table 7.4 Land use/cover with percentage of land use share in 2018

LULC types	2018	
	Area	% of area
Bare land	16.10	16.16
Built-up area	32.27	32.40
Crop land	10.87	10.91
Open pasture	15.66	15.72
Vegetation	12.61	12.66
Water body	12.09	12.14
Total area	99.60	100.00

penetrability (Sreedevi et al. 2006). The lineament density (L_d) was formulated using the web linkage method which is shown in Eq. 7.7. Areas with higher lineament density values were denoted higher recharge zones, and thus lower value indicated the lower groundwater potential zone. The calculated lineament density values of the SUA were classified into five zones, 0–0.13 (very low), 0.13–0.23 (low), 0.23–0.36 (moderate), 0.36–0.63 (high) and 0.63–1.33 km/km² (very high) (Fig. 7.4), and weightage was also given as per nature of lineament.

$$L_d = \sum_{i=1}^{i=n} \frac{L_i}{A} \tag{7.7}$$

where $\sum L_i$ is represented the lineament length of i th class (km) and A is represented the area in km².

7.4.1.7 Moisture Index (MI)

Moisture index (MI) is a GIS-based bio-physical composition where we used Middle Infrared (MIR) instead of Near Infrared (NIR) because MIR is more absorbent of light giving clear identification of water bodies. Therefore, band 5 in OLI/8 was denoted the MIR. The high positive value represents the higher water or moisture content, and middle to zero value represents the bare land while value close to zero or negative shows the presence of vegetation or soil. It can be shown in Eq. 7.8.

$$MI = \frac{(\text{band3} - \text{band5})}{(\text{band3} + \text{band5})} \tag{7.8}$$

In this study, MI map was classified into five classes (Table 7.7) where the highest moisture value was 0.17, which was found along the Mahananda river basin, and the lowest moisture value was found at the northeast part of SUA.

Table 7.5 Different factors and pairwise comparison matrix of eight thematic layers for GPZ

	E	Slope	Soil	LULC	P	LD	MI	G
DEM (E)	1	1/3	1/2	1/2	1/3	1/4	1/3	1/5
Slope	3	1	1/3	4	5	1/3	3	1/4
Soil	2	3	1	3	1/5	1/2	1/6	1/7
LULC	2	1/4	5	1	6	4	2	1/4
Precipitation (P)	3	1/5	2	1/6	1	6	1/2	2
Lineament density (LD)	4	3	6	1/4	1/6	1	1/5	3
Moisture index (MI)	3	1/3	7	1/2	2	5	1	2
Geology(G)	5	4	4	4	1/2	1/3	1/2	1

Table 7.6 AHP with normalised pairwise weight matrix of eight thematic layers for GPZ

	E	Slope	Soil	LULC	P	LD	MI	G	Weight	λ
DEM (E)	0.09	0.15	0.1	0.17	0.05	0.07	0.03	0.12	0.9	7.8
Slope	0.08	0.09	0.02	0.04	0.03	0.05	0.02	0.08	0.05	8.2
Soil	0.02	0.03	0.06	0.04	0.05	0.04	0.08	0.05	0.04	7.4
LULC	0.15	0.14	0.06	0.13	0.15	0.11	0.12	0.02	0.11	8.0
Precipitation (P)	0.12	0.08	0.19	0.21	0.09	0.02	0.05	0.06	0.1	8.2
Lineament	0.17	0.12	0.04	0.05	0.14	0.06	0.04	0.09	0.09	7.9
Moisture index (MI)	0.11	0.10	0.21	0.28	0.13	0.05	0.04	0.07	0.12	8.2
Geology(G)	0.05	0.12	0.22	0.08	0.07	0.02	0.21	0.15	0.11	8.4

Value of lambda max = 8.35, consistency index = 0.05, consistency ratio = 0.04

7.4.1.8 Geology

Geology is defined the solid features of earth surface and describes the structure of the earth on and beneath it. It has an important role to control the groundwater recharge including the infiltration of water. In this study, authors had found three types of geology, namely, alluvium, sandstone and Siwaliks (Fig. 7.4). Alluvium, mostly abundant and identical topographical layer, was characterised as typically fine-grained and greyish in colour. It was given maximum weightage because of maximum recharge possibility and holding capacity of groundwater was higher enough compared to sandstone and Siwaliks (Tables 7.5, 7.6, and 7.7).

7.4.2 GPZ Map

The groundwater potential zone (GPZ) map of SUA was prepared with Fuzzy weighted overlay analysis. Selected eight thematic layers were assigned in ArcGIS raster calculator. The GPZ result is shown in Fig. 7.5 and area is given in Table 7.8. The map was classified into five different classes based on weighted matrix analysis and AHP which were 3–7, 7–8, 8–9, 9–10 and 10–14 following the natural Jenks

Table 7.7 Different factors and classes with relative weighted index (W_i) of eight thematic layers for GPZ

Factors	Class/value	Potentiality for groundwater storage	Rating	W_i
DEM (m)	56–102	Very good	5	0.90
	102–113	Good	4	
	113–124	Moderate	3	
	124–140	Poor	2	
	140–179	Very poor	1	
Slope (degree)	0–0.45	Very good	5	0.05
	0.45–1.21	Good	4	
	1.21–2.15	Moderate	3	
	2.15–3.19	Poor	2	
	3.19–5.32	Very poor	1	
Soil	Clay-loam	Very good	5	0.04
	Entisols	Poor	4	
	Inceptisols-I	Very good	3	
	Inceptisols-II	Good		
LULC	Vegetation	Good	4	0.11
	Open pasture	Poor	2	
	Bare surface	Moderate	3	
	Crop lands	Very good	5	
	Water bodies	Very good	5	
	Built-up	Poor	1	
Lineament density (Km/Km ²)	0.08–0.13	Very poor	1	0.10
	0.13–0.23	Poor	2	
	0.23–0.36	Moderate	3	
	0.36–0.63	Good	4	
	0.63–1.33	Very good	5	
Precipitation (mm)	2500–3000	Good	4	0.09
	>3000	Very good	5	
Moisture index	–0.42–0.20	Very poor	1	0.12
	–0.20–0.15	Poor	2	
	–0.15–0.11	Poor	2	
	–0.11–0.07	Poor	2	
	–0.07–0.17	Good	4	
Geology	Alluvium	Very good	5	0.11
	Sandstone	Good	4	
	Siwaliks	Poor	2	

method. The GPZ value was presented in the form of low, medium, medium-high, high and very high potential zone categories. Medium potential groundwater zone and medium-high potential groundwater zone covering 33.89% and 26.02%, respectively, spread over the northern and eastern sections, while the western and south-western parts were a huge potentiality of groundwater till now.

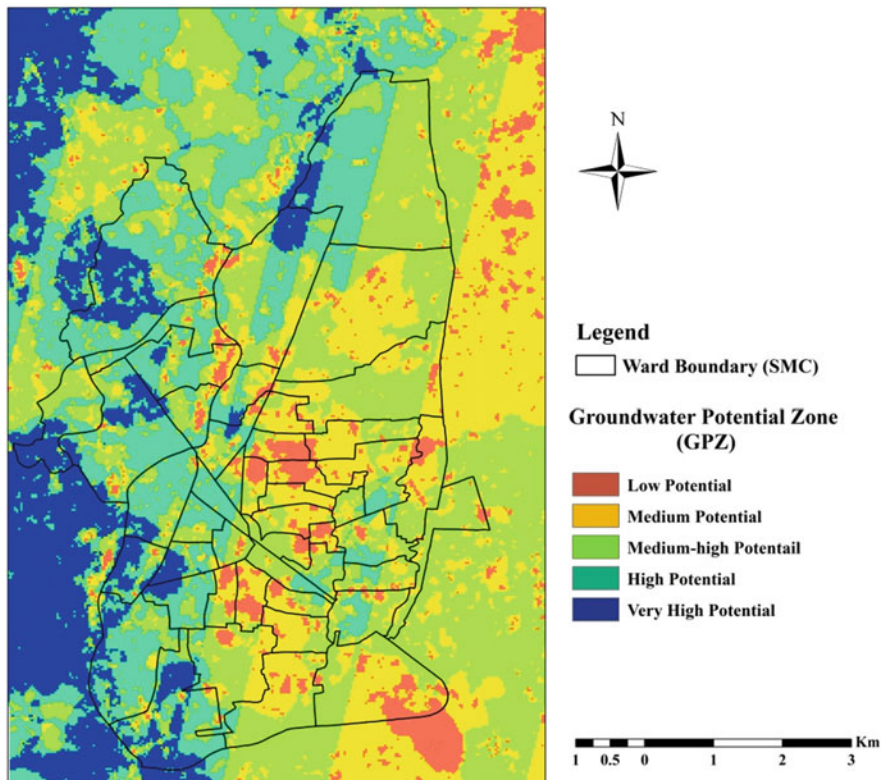


Fig. 7.5 Calculated GPZ map of Siliguri urban area

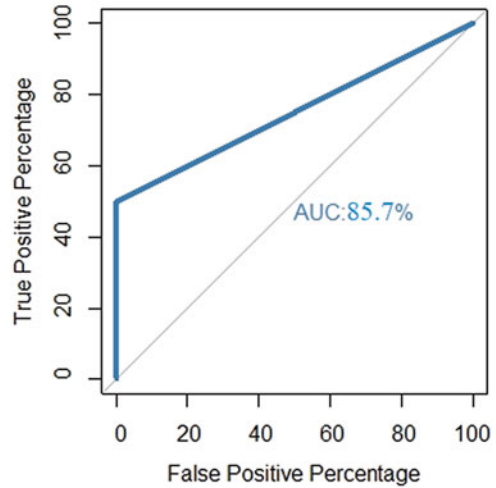
Table 7.8 Calculated GPZ with area and percentage of area shared of each zone

GPZ	Area (Km ²)	Percentage of area
Low potential	6.73	6.76
Medium potential	33.76	33.89
Medium-high potential	25.92	26.02
High potential	16.67	16.74
Very high potential	16.52	16.59

7.4.3 Validation of GPZ Map

Validation is the most important technique for any kind of model for the assessment of the accuracy of the result. For the validation of GPZ, we used Mahananda and Balason river water data and bore well data derived from West Bengal Pollution Control Board (WBPCB) and then analysed the yield data with the groundwater potentiality values. The collected groundwater yield data was classified accordingly as high (above 0.6 litres per second), medium (3–6 litres per second) and low (below 3 litres per second) categories (Tiwari et al. 2019). The GPZ result was validated

Fig. 7.6 Validation of GPZ using precision ROC curve



using Precision Accuracy through Receiver Operating Characteristics (ROC) curve (Fig. 7.6). Assessment (PAA) techniques.

Area Under Curve (AUC)

$$\begin{aligned}
 &= (\text{Number of observed water samples and expected water samples}) \\
 &\quad / (\text{Number of groundwater sample data collected through GPS}) \\
 &= 12/14 * 100 = 85.71\%
 \end{aligned}$$

The calculated AUC value replicates that the classified GPZ may be relevant for the residential planning and development over SUA in the near future. This method was used by different scholars (Tehrany et al. 2013; Rahmati et al. 2014; Tiwari et al. 2019).

7.5 Conclusion

In this study, authors demonstrated the distributed groundwater potential zones of Siliguri urban agglomeration (SUA), West Bengal, India, with the help of MCDA like GIS-based Fuzzy-AHP approach. Here, eight thematic layers were chosen for the delineation GPZ, and these were elevation (DEM), slope, soil, LULC, precipitation, lineament density, moisture index and geology assigning different weightage on the basis of field experience and expert's knowledge. These layers were brought a high consistency index that was 0.05 with consistency ratio of 0.04 denoting strong interrelation between climatic variables and physical attributes. On the basis of result, we delineated the GPZ of SUA into five water potentiality zones. The area

has had 16.74% (16.67 Km²) of high potential water and 16.59% (16.52 Km²) of very high potential water at the south-western part. But, the low potential groundwater zone (6.73 km²) at the city centre and near to New Jalpaiguri Junction area needed some proper management due to less resistivity, the sandy nature of soil with less permeability, groundwater susceptibility and steep slope. The total 58.68 sq.km areas have covered by medium potential groundwater and medium-high potential groundwater zone which is covered by the northern and southern portion of SUA. Thus, SUA has carried out suitable groundwater potentiality due to enormous source of the groundwater recharge and physical characteristics of the land. The PAA value of the classified GPZ was 85.71% that reflected excellent arrangement of groundwater zonation (Hasmadi et al. 2017).

The combination of modern GIS-based and AHP techniques provided a comprehensive outcome of GPZ that is really helpful for urban land use residential planning, industrial development and city development planning of SJDA-2030 with the growing urban population and expansion of the urban area. But still the quality of water, specially drinking water, becomes a question. Therefore, the achievement of sustainable groundwater utilisation can assist decision-makers to convey the effective and efficient groundwater management through rooftop rainwater harvesting and establishment of different groundwater recharge and recovery solutions of Mahananda and Balason river basin and that will be the best strategy for the management of future groundwater of this urban area.

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Conflict of Interest The authors declare that they have no conflict of interest.

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