**ORIGINAL ARTICLE**

# Groundwater potential zone identification using an analytic hierarchy process in Dhaka City, Bangladesh

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## Abstract

Water scarcity is increasing throughout the world due to the effects of increasing groundwater abstraction and climatic change. The present study was undertaken to evaluate groundwater potential zones (GP) in Dhaka city using GIS and remote sensing (RS) techniques. A weighted linear combination (WLC) was used in association with GIS techniques to identify GP zones for an area that encompassed the city to 5 km outside of the city boundaries. Declining groundwater levels are a significant issue for the city, and these are influenced by the rate of groundwater abstraction, potential evapotranspiration (PET), rainfall, land use/land cover pattern, surface lithology, drainage pattern, recharge conditions, and geomorphology. Seven thematic layers were used for the GP calculation, where drainage density and infiltration zone maps were modified for the settlement area to reduce the negative influence on the final result. The GP calculation indicated that 188 km$^2$ (24%) had a 'very low' groundwater potential; 150 km$^2$ (19%) had a 'low' potential; 138 km$^2$ (18%) had a 'moderate' potential; 143 km$^2$ (19%) had a 'high' potential; and 154 km$^2$ (20%) had a 'very high' potential. Surface lithology was found to be the most sensitive parameter. This parameter had standard deviations of 4.18% and 36.39% were found for a map removal sensitivity analysis (MRSA) and a single parameter sensitivity analysis (SPSA), respectively. The validation result shows that 93% area with a 'high' groundwater potential zone falls in the area where the groundwater depth is in the range 6–22 m below the land surface.

**Keywords** WLC · Thematic layers · Groundwater potential zone · MRSA · SPSA

## Introduction

The demand for potable water throughout the world for human use, agricultural needs, and industrial uses is increasing due to rapid population growth. Consequently, there is an increasing need to evaluate the groundwater resource potential and yielding capacity of aquifers.

Dhaka is one of the largest megacities in the world and now has a population that exceeds 14.1 million (BBS 2014). The population growth rate from 2001 to 2011 was 4.2% per year. Every day, each resident of Dhaka uses about 2.3 Mm$^3$ (Hassan and Zahid 2017). The Dhaka Water Supply and Sewerage Authority (DWASA) indicated that water demand in the city in 2008 approximately 2000 million liters per day (MLD), and this is expected to increase to nearly 4200 MLD in 2025. A large amount of this water demand is being met by groundwater abstraction.

Groundwater is being withdrawn at a rate of about 2.0 Mm$^3$ per day from the upper Plio-Pleistocene Dupi-Tila aquifer using 563 deep tube-wells belonging to DWASA and 2000 private tube-wells of varying depths from this aquifer. According to Rahman and Hasan (2016) and Bro (2007), about 87% of the water supply for Dhaka city comes from groundwater abstraction through 520 DTWs operated by DWASA, while the remaining 13% of water is supplied from treatment plants using surface water collection points situated at Saidabad and Chandnighat in Dhaka district, and Godnail in Narayanganj district.

The Department of Environment (DoE) (2016) found that, due to the dumping of municipal and industrial wastes into the river, surface water is highly polluted around the city. Therefore, to halt the water quality degradation of the Balu, Turag, Lakkya and Burigonga rivers, the government of Bangladesh has declared that Dhaka was an economically critical area (ECA) in 2009. Although investigations by Huq and Hossain (2013) have indicated that shallow groundwater

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quality beneath the city generally does not exceed World Health Organization (WHO) and Bangladesh standards for drinking water, deeper groundwater is typically unsuitable for potable use.

To reduce groundwater dependency in the city, several management measures have been recommended to the government by planners and independent non-government organizations. These include the use of rainwater harvesting (Rahman and Hasan 2016); and increased number of water treatment plants to increase the proportion of river water used to 70% instead of the current level of 22% (WASA 2016); the implementation of an integrated water resource management (IWRM) system to increase groundwater infiltration; the implementation of rainwater storage; valid pricing of consumptive water; and the use of reclaimed water meets the deficit of the current supply system through the efficient use of the scarce resources available (Biswas et al. 2010).

Some organizations, including the Global Water Partnership (GWP-established in 1996) and the Network of Basin Organizations (INBO-established in 1994), have been established to foster integrated water resources management (IWRM). These have worked with government agencies to improve water resource management at local to national scales (GWP and INBO 2009). Groundwater has defined by scientists (Oseji and Ovini 2010; Todd 2004; Bear 1979; Bear and Verruijt 1987; Patra et al. 2018).

Groundwater availability in an aquifer depends on its lithology, climate, geomorphology, properties of overlying soils, topography, land use/land cover type, and drainage density. How these factors interact with the hydrology of a system can be analyzed through the use GIS and RS applying weighting factors to the applied raster classes (Patra et al. 2018; Elbeih 2015; Venkateswaran and Ayyandurai 2015; Yeh et al. 2016; Ibrahim-Bathis and Ahmed 2016; Senanayake et al. 2016; Akinlalu et al. 2017; Singha et al. 2018).

In this study, seven basic layers, viz. geomorphology, infiltration, drainage density, lithology, groundwater abstraction information, land use/land cover, rainfall data were applied to evaluate groundwater recharge potentiality and to determine responsive layers. The groundwater table depth was then used to validate the determined groundwater potential (GP) zones.

Other geological, hydrogeological, geophysical methods have also been applied in other parts of the world for groundwater resource potential investigations. The use of databases and GIS layers containing information such as satellite images, lithology, drainage data, and meteorological data are useful for mapping the groundwater potential zones (Srivastava et al. 2012). Many methods are available for mapping of potential zones such as the weighted linear combination (WLC) method (Madrucci et al. 2008),

AHP (Pradhan et al. 2009), and the Index Overlay Method (Muthukrishnan et al. 2013). Several methods can be used to explore groundwater and have been categorized into two significant groups one is the conventional methods and the second is the advanced methods.

Conventional investigation methods that can support the identification of the groundwater potential zone include using field surveys (viz. ground sensitivity determination method using resistivity, ground-penetrating radar and probabilistic models of logistic regression method). Advanced techniques comprise AHP, the weighted overlay method (WOM), the frequency ratio model (FRM) and the weighted aggregation method (WAM). The Analytic Hierarchy Process (AHP) method is widely used in multicriteria decision-making theories that choose appropriate property from different criteria.

Based on these methods, this study aims to

- ensure accurate decisions are made by providing the decision-making process is formal and systematic for Dhaka city,
- implement a pairwise comparison matrix (PWCM) for class range selection through the Analytic Hierarchy Process (AHP).
- detect groundwater potential zones for Dhaka city using a weighted linear combination (WLC) method,
- identify sensitive parameters for the groundwater potential zone classification using MRSA and SPSA.

The present study will provide information for hydrogeologists to better understand groundwater resource availability in the region and should help improve the management of the resource.

## Study area description

The proposed area is located along the central portion of Bangladesh and partially covering the Madhupur tract of Plio-Pleistocene age. Turag, Balu, Lakkya, and Burigonga are significant rivers of the proposed area. The proposed location has fallen along the equatorial region and occupying 773 km$^2$ area. It is located between geographical coordinate system 90° 16′ 13″ E to 90° 33′ 86″ E and 23° 56′ 44″ N to 23° 37′ 27″ N. Figure 1 shows the proposed area map. Turag and Dhaleswari Rivers merge at the Amin Bazar area that forms the Burigonga River. Two other rivers Turag and Dhaleswari are the branches of Brahmaputra River. Lakkya and Balu Rivers are also the branches of Brahmaputra River. The water availability depends on the water flow on Brahmaputra River.

**Fig. 1  a** Map of Bangladesh, **b** study area Dhaka city, **c** DEM of Dhaka city
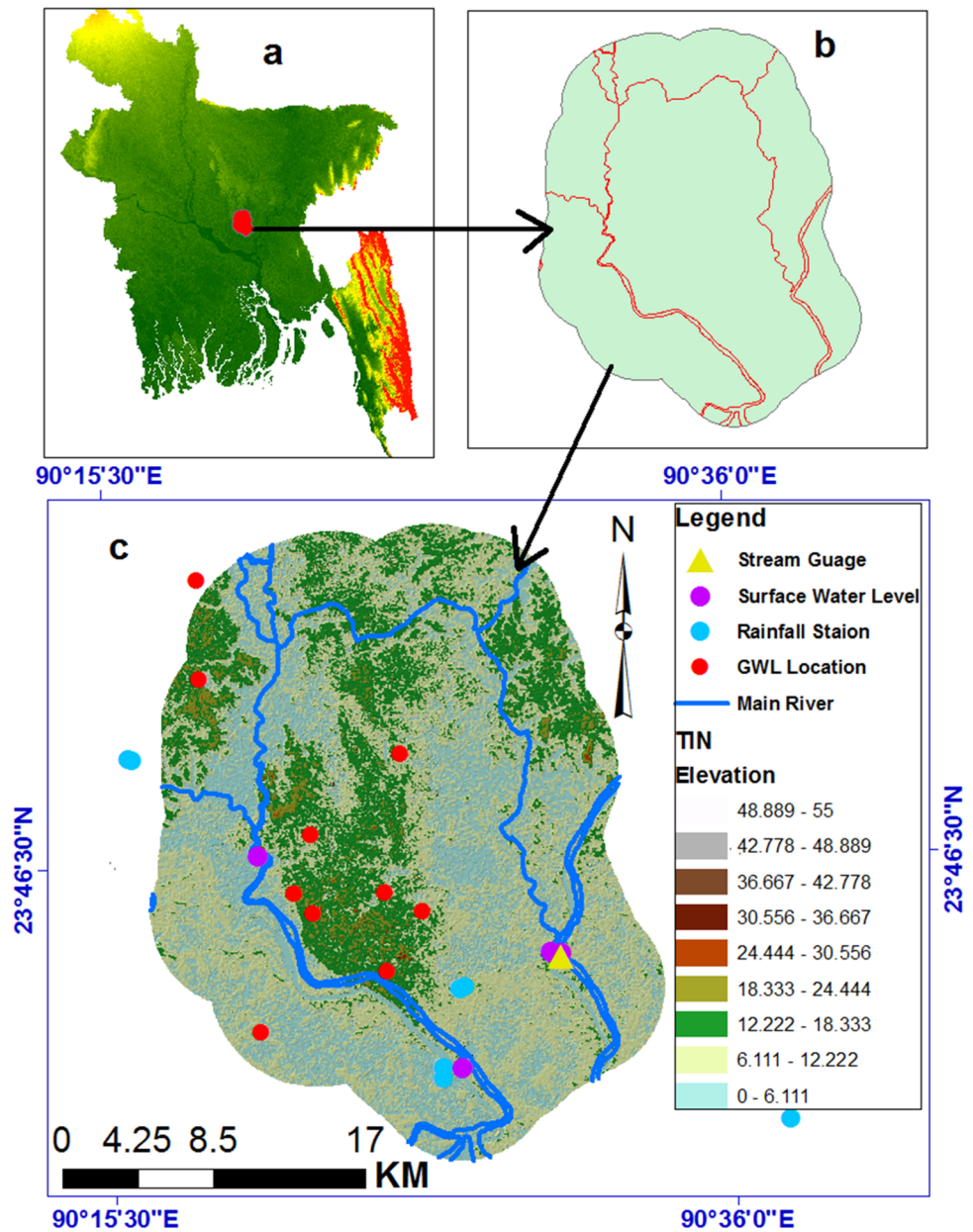


## Climatology

The Dhaka city is located in the tropics and, therefore, sunshine falls perpendicularly during the summer season in this region. The proposed area experiences a hot, wet, and humid tropical climate with the distinct monsoonal season. Annual evapotranspiration is high in this region and has averaged 1617 mm during the period 1980–2013. Annual precipitation in this region ranges from 1942 to 2059 mm. The annual average temperature is 25 °C (77 °F) with monthly means that vary between 18 °C (64 °F) in January and 29 °C (84 °F) in August.

## Hydrogeology

A stratigraphic model and fence diagram are shown in Fig. 2a, b. A comparison of groundwater level (all the groundwater level shows decreasing trend) among eleven stations located at and around the study area was determined (the depth has calculated from the surface) that has been given in Fig. 2c. The city is an integral part of the Madhupur tract, which is an easterly tilted fault block (Alam and Aurangzeb 1975; Alam 1988). Lineaments are vulnerable to ground motion if they coincide with the zones of high particle velocity (Shams 1999). Three fault lines below the
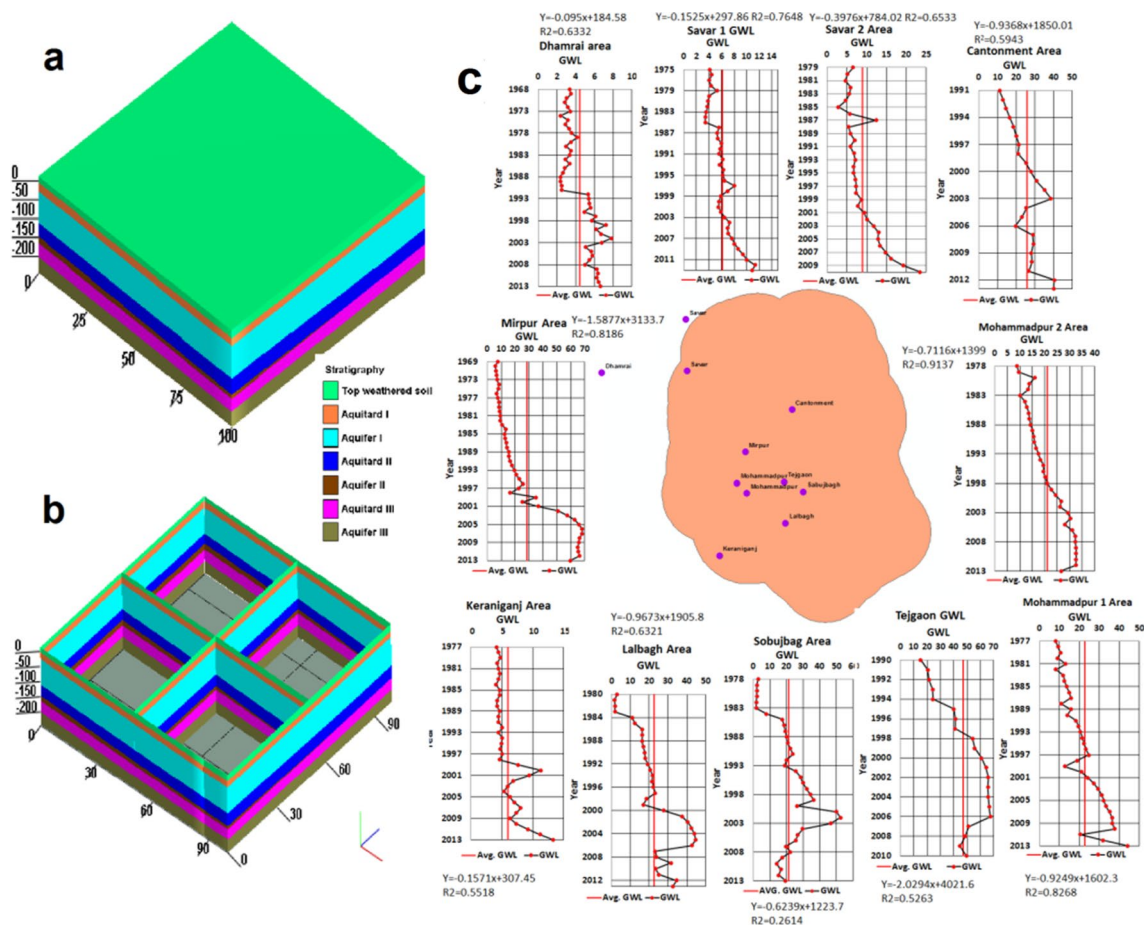
Fig. 2 **a** Stratigraphic model diagram, **b** fence diagram, **c** groundwater-level map

weathered soil have been identified in the study area. These fault lines trend in an NW–SE direction along the Burigonga River NW–SE. In the western part of the study area, the Baunia Fault has an N–S trend, and the Demra fault occurs in the eastern outskirts of Dhaka city (Ahmed et al. 1998). Figure 3 shows the lineament map of Dhaka city. The upper exposed sediments of the Plio-Pleistocene age consist of reddish-brown plastic clays with some silts and very fine sands. Additionally, recent alluvium consisting of river-borne deposits covers the relatively low-lying land.

The clayey sediments of the Plio-Pleistocene age are underlain by deposits of the Dupi-Tila Formation, which form the main three aquifers in the region. The upper aquifer consists of very fine to fine sand with traces of silt, which typically occurs at depths of 30–90 m. The middle aquifer is composed of fine to medium sand with some coarse sand. This aquifer occurs at depths of 100–240 m and has a thickness that varies from 50 to more than 200 m.

The lower aquifer consists of medium to coarse sands with some gravels that occur at depths between 95 and 260 m. This aquifer has a thickness of between 20 and 40 m. This aquifer has a transmissivity ($T$) value that varies from 270 to 1700 $m^2$/day, a storage coefficient ($S$) that ranges from 0.02 to 0.04, and hydraulic conductivity values that range from 6 to 15 m/day in the study area. Rainfall and river water is the primary source of groundwater recharge in this area. According to Bangladesh Agriculture Development Corporation (BADC) (1992) report, Dhaka city and adjoining area withdraw groundwater (2447 $m^3$/per day around Dhaka city and 4000 $m^3$/day in Dhaka city) using deep tube-wells that are operated 12 h per day in the dry season from January to mid-April for irrigation and water supply purpose (Akhter and Hossain 2017).

## Soil thickness and slope

The clay unit is sub crops at depths of 2–15 m below the top alluvial silt and clay in the proposed area. Clay thickness varies from 15 to 30 m in the study area Shamsudduha et al. (2011). The low thickness of clay is suitable for groundwater abstraction and recharge. A thick overburden of soil with limited clay and high intergranular space is suitable for groundwater occurrence (Okhue and Olorunfemi 1991). Figure 4a shows the soil thickness map. Slopes with
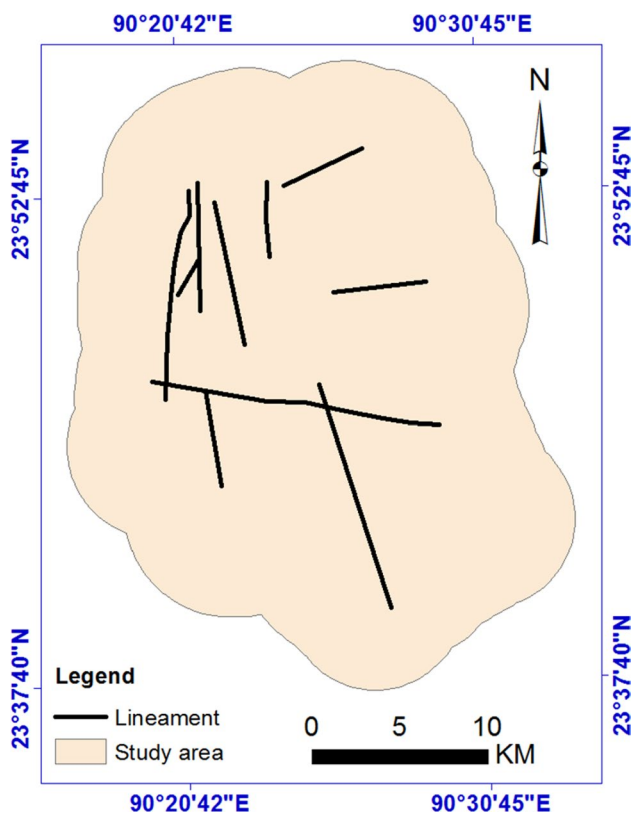
Fig. 3 Lineament map of the study area (Shams 1999)

flat (<5°) to gentle slopes (5°–12°) are more suitable for enhancing groundwater recharge compared areas with steep slopes. Slope ranges from 0 to 33° for the proposed area. These slopes were classified into the following classes: is 0–3°, 3–8°, 8–15°, 15–30° and 30–33°. Figure 4b shows the slope map of the study area.

## Land use/land cover (LULC) change

Dhaka city is a rapidly growing urban area. As a result of this, the water conservation area has reduced from 226 to 39 km$^2$ in the period 1999–2014. However, the dry land area has increased from 413 to 464 km$^2$, and the area under urban development has increased from 51 to 131 km$^2$ during the same time. The change of water conservation area has had a direct effect on the water storage capacity for the city. One consequence of this is that many residences in the city are suffering from waterlogging problems. The area around covered by vegetation in the city area has increased from 67 to 101 km$^2$. Figure 5 shows the LULC change map for Dhaka.
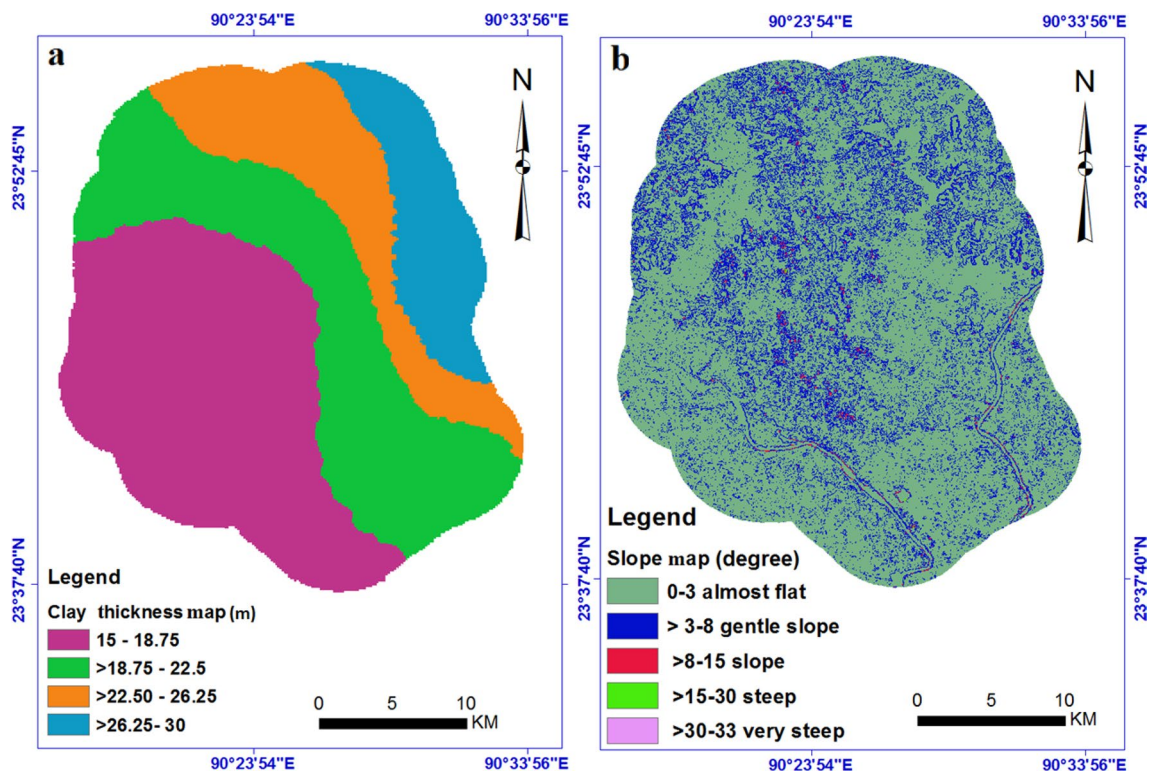


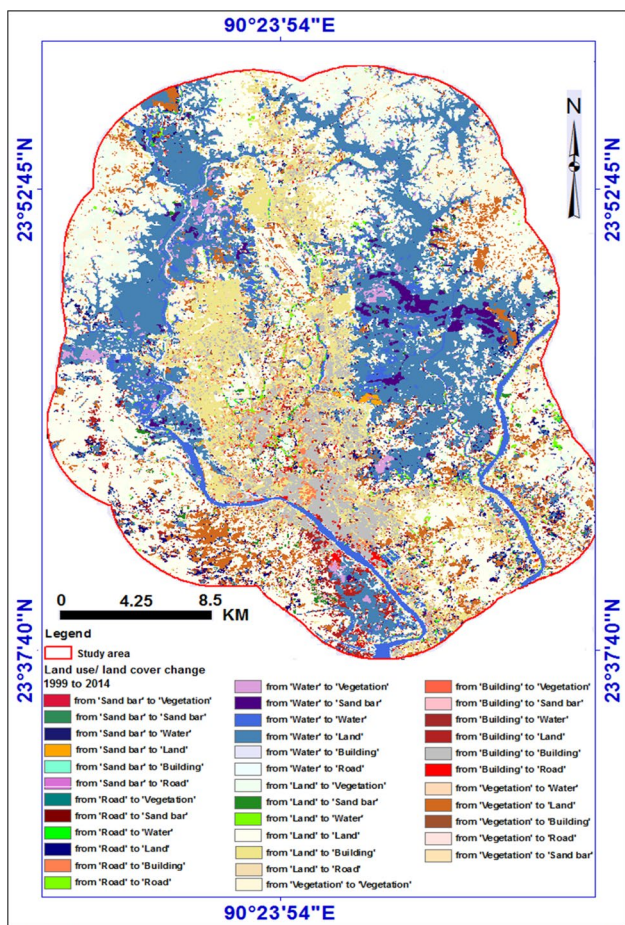Fig. 4 **a** Clay thickness map and **b** slope map of the study area

**Fig. 5** Land use/land cover change detection map

# Data sources and methodology

## Data sources

The datasets that were used to calculate groundwater potential were collected from different secondary sources which are shown in Table 1. The digital elevation model (DEM), Landsat image, drainage density, deep tube-well location, slope, and geomorphology information was collected as a raster file. The information on lithology was collected as a shape file, but a lineament map, clay layer thickness map, and groundwater recharge maps were collected in JREG format that was geo-referenced and rectified using Arc GIS. A rainfall map was prepared using averaged annual data that were obtained by the summation of daily data for the period 1968–2013 for station CL9 (Dhaka_PBO); the period 1968–2013 for station CL31 (Savar); and for the period 1993–2013 for station CL42 (Dhaka_Banani). The groundwater table depth map was obtained by averaging weekly and monthly data from monitoring wells (the depth was given in meters from existing ground level—EGL).

## Methodology

A hybrid approach AHP (for class rate and thematic layers weight assessment) and WLC were applied for groundwater potential zone identification.

### Analytic hierarchy process (AHP)

Analytic hierarchy process (AHP) values for each layer class were calculated (Saaty 1980). Table 2 shows the Saaty's assumption that helps to determine the class weight and consistency ratio (CR) values. Different steps are applied for the class weight and consistency ratio calculations. The steps used are as follows.

*Step 1* PWCM was calculated using the following equation:

$$\text{Judgment matrix } (Y) = \begin{bmatrix} Y_{11} & Y_{12} & \cdots & Y_{1n} \\ Y_{21} & Y_{22} & \cdots & Y_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ Y_{n1} & Y_{n2} & \cdots & Y_{nm} \end{bmatrix}, \tag{1}$$

where $Y_{nn}$ is the indicator of the judgment matrix element.

*Step 2* Calculation of normalized weight:

$$\sigma_W = \left( \frac{\alpha_n}{\sum_{n-1}^{N_f} \alpha_n} \right), \tag{2}$$

where $\alpha_n$ is the geometric mean of $n$th row of judgment matrix $(Y)$; $\alpha_n$ was calculated by

$$\alpha_n = \sqrt[n]{Y_{1n} Y_{2n} \cdots Y_{nN_f}}. \tag{3}$$

*Step 3* Consistency ratio (CR) to verify the coherence of the judgments:

$$\text{CR} = \frac{\text{CI}}{\text{RI}}, \tag{4}$$

where CI is the consistency index, RI is the Saaty's ratio index. CI was quantified as

$$\text{CI} = \frac{\lambda_{\max} - N_f}{N_f - 1}, \tag{5}$$

$\lambda_{\max}$ is an eigenvalue of the judgment matrix and calculated as

$$\lambda_{\max} = \sum_{n-1}^{N_f} \frac{(YN)_n}{N_f \sigma_w}. \tag{6}$$

### Preparation of thematic layers

**Surface lithology (SL)** Lithology reflects the soil characteristics such as structure, porosity, adhesion, and consistency

**Table 1** Data source for the proposed study

| Data | Sources | |
|---|---|---|
| Digital elevation model (DEM) | (USGS 1 arc second), UTM-45, WGS 1984 | |
| Lithology | Geological Survey of Bangladesh | |
| Lineament map | From Shams (1999) | |
| Landsat image (land use map) | GloVis, Landsat 8 OLI, 2014 row/path-43/138 | |
| Drainage density | DEM (USGS 1 arc second), UTM-45, WGS 1984 | |
| Clay layer thickness map | Shamsudduha et al. (2011) | |
| Slope | DEM (USGS 1 arc second), UTM-45, WGS 1984 | |
| Geomorphology | DEM (USGS 1 arc second), UTM-45, WGS 1984 | |
| Infiltration zone map | DEM (USGS 1 arc second), UTM-45, WGS 1984 | |
| Bore log data | Institute of Water Modelling (IWM) | |
| Aquifer properties | Bangladesh Agriculture Development Corporation (BADC) | |
| Rainfall data | Bangladesh Water Development Board (BWDB) | |
| Groundwater level data | Bangladesh Water Development Board (BWDB) | |
| | Well name | Data |
| | Well ID GT2608001 (Cantonment) | From 1991 (11 m)to 2013 (40 m) |
| | Well ID GT2614002 (Dhamrai) | From 1968 (3 m) to 2013 (7 m), |
| | Well ID GT2638008 (Keranigonj) | From 1977 (4 m) to 2013 (13 m) |
| | Well ID GT2642009 (Lalbagh) | From 1980 (3 m) to 2013 (33 m) |
| | Well ID GT2648010 (Mirpur 1) | From 1970 (7 m) to 2013 (59 m) |
| | Well ID GT2650011 (Mohammadpur 1) | From 1977 (8 m) to 2013 (44 m) |
| | Well ID GT2650012 (Mohammadpur 2) | From 1978 (9 m) to 2013 (26 m) |
| | Well ID GT2668019 (Sobujbag) | From 1978 (3 m) to 2013 (19 m) |
| | Well ID GT2672017 (Savar 1) | From 1975 (4 m) to 2013 (11 m) |
| | Well ID GT2672018 (Savar 2) | From 1979 (7 m) to 2013 (23 m) |
| | Well ID GT2616005 (Tejgaon) | From 1990 (15 m) to 2013 (50 m) |

**Table 2** Relative class rate identification scale according to Saaty (1980)

| Definition | Equally important | Extremely less important | Strongly less important | Less important | Moderately less important | Moderately important | Strong important | Very strong | Extremely important |
|---|---|---|---|---|---|---|---|---|---|
| Intensity of importance | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

(Okhue and Olorunfemi 1991). The type of soil is considered to be an essential parameter that controls the infiltration process and the aquifer recharge (Chenini et al. 2015). Soil with intergranular space such as sand permits water percolation into the aquifer, but impervious materials such as clay do not allow water percolation into the aquifer. Shape file of surface lithology was collected from the Geological Survey of Bangladesh (GSB) that was later converted to raster with WGS 1984 datum and the class rate was assigned to this layer.

**Geomorphology (GM)** Geomorphologic feature identification can help delineate the hydro-morphological char-acteristics of a watershed. A geomorphological feature of an area depends mainly on the morphological and lithological factors. DEM and SRTM data can be used to develop a detailed description of landforms that are useful for groundwater potential assessment (Solomon and Ghebreab 2008).

**Drainage density (DD)** The drainage density of a basin depends on topography, slope, and the underlying lithology. The drainage density indicates the fraction of the length of streams to the drainage basin area. In situations where there is a high drainage density, the runoff will be high, and there will be limited groundwater recharge (Rajaveni et al. 2017).

**Rainfall (RF)** Rainfall is an important factor in the hydrological cycle. Rainfall measured using rain gauge at a particular point that may not indicate the actual precipitation of the study area. Therefore, it is crucial to get appropriate rainfall information for an entire region. The areal depth of rainfall in the catchment was estimated using a simple interpolation method using GIS. Available rainfall water is the primary source of groundwater recharge that percolates through the open land surface and river bottom in the study area (Gintamo 2015).

**Infiltration zone map (IZM)** Several different methods are available for assessing groundwater recharge, but the water-table fluctuation (WTF) technique was used to estimate net groundwater recharge in this study (Solomon and Ghebreab 2008). Shamsudduha et al. (2011) undertook an assessment of annual recharge in the study area using the water-table fluctuation method and found that the net recharge is highest in the southwest side of the areas. In this study, the areal extent of the recharge area was determined from the drainage density and stream frequency maps (Faniran 1968). Areas with a high drainage density typically have a low recharge potential as incident rainfall is mostly carried in the surface runoff to lower lying areas. Therefore, these areas generally have low recharge potential.

**Groundwater abstraction (GWA)** Groundwater abstraction map was prepared based on the information obtained from the Dhaka Water Supply and Sewerage Authority (DWASA). Spatial distribution of deep tube-wells was detected using Arc GIS from the image file. The average discharge rate of shallow tube-wells is 0.5 cusec at and around Dhaka city (Akhter and Hossain 2017). Demand and water supply for Dhaka city have been carried and given by Akhter and Hossain (2017). A total of 563 deep tube-wells were detected in the study area after DWASA data. The buffer zone was created in 500-m intervals up to 1000 m for GP calculation.

**Land use/land cover (LULC)** Land use/land cover mapping is an important function of remote sensing. Land use plays a significant role in the development of groundwater resources (Healy and Cook 2002). LULC influences infiltration, evapotranspiration, and surface runoff. Vegetation provides roughness to the surface, reduces discharge, and thereby increases the infiltration. In the forest area, infiltration is more and runoff is low, but in urban areas, the infiltration rate is relatively low due to infrastructure development on the open land surface.

### Groundwater potentiality calculation

Finally, the GP index map was generated using GIS by WLC of thematic layers. Layer class rank and weight were multiplied to get the probable individual layer that was added to get the groundwater potential zone (GP) map. The following equation shows the required calculation:

$$GP = \sum_{i=1}^{n} W_i R_i, \tag{7}$$

where GP is the groundwater potential zone, $W_i$ is the weight for each layer, and $R_i$ is the rate for each class of each layer.

### Sensitivity analysis

SPSA and MRSA calculation was carried out for GP map validation. Equation 8 shows the SPSA calculation. Equation 9 shows MRSA the calculation:

$$SPSA = \frac{W_i R_i}{GP} \times 100, \tag{8}$$

where $W_i$ is the weight for each layer, $R_i$ is the rate for each class of each layer, and GP is the groundwater potential zone;

$$MRSA = \frac{\left| \frac{GP}{N} - \frac{GP'}{n} \right|}{GP} \times 100, \tag{9}$$

where $N$ is the number of total thematic layer, $n$ is the number of layer removed, and GP′ is the groundwater potential zone after removing a layer.
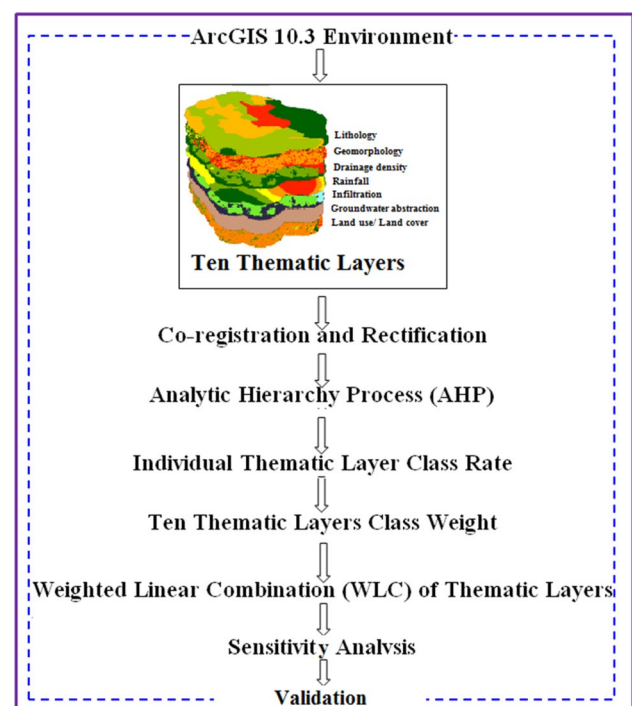


**Fig. 6** Flow chart shows the study methodology

Figure 6 shows the flowchart for the groundwater potential zone identification study in Dhaka city.

## Results and discussion

### Groundwater scenario

Integrated water resource management is essential for Dhaka city due to the overexploitation of groundwater. The water table beneath the city is continuously falling due to the presence of a shallow and extensive clay unit that limits the infiltration of water to form recharge; and the intense and increasing groundwater abstraction from deep tube-wells that located less than 500 m distance to meet the demands of a rapidly increasing population. From Fig. 2c, it can be seen that the rate of groundwater decline in the region varies between $-0.095$ and $-2.0294$ m/year.

### Analytic hierarchy process (AHP)

Analytic hierarchy process has been carried out on the thematic layers using the Saaty's (1980) assumption. A total of seven layers were used for this calculation. The PWCM was carried out using Eq. 1 for all thematic layers to identify the class rate. The normalized weight was calculated using Eq. 2. Finally, the consistency ratio (CR) to verify the coherence of the judgments was calculated using Eq. 4.

### Thematic layers

#### Surface lithology (SL)

Four lithological types are prominent for the proposed area: alluvia silt covering 21% area; alluvial silt and clay 42% area; Madhupur clay residue 27% area; marsh clay and peat 11% area. Below the topsoil layer, a continuous clay layer exists in the proposed area. Classes rate of lithology has been taken as alluvial silt and clay > alluvia silt > Madhupur clay residuum > marsh clay and peat. The pairwise comparison matrix has been shown in Table 3. CR value for the SL is 0.08. Figure 7a shows the SL map for the proposed area.

### Geomorphology (GM)

Five geomorphologic units for the proposed area have been identified. These are very smooth land; smooth land, moderately smooth land; uneven land, and highly uneven land (Fig. 7b). GM classes and weights with the PWCM have been given in Table 4 with a CR value of 0.04. Very smooth to smooth land is suitable for GP because of the slow movement of the water through the interconnected pore space. Therefore, a low weight value has been assigned for highly irregular landform areas.

### Drainage density (DD)

The DD is the ratio of the length of streams to the area of the watershed. DD value for the study area varies from 0 to 1.43 km per km$^2$. These values were divided into five equal interval classes. A modified DD map was produced where the settlement area kept the lowest class rate to reduce the influence of GP evaluation. As a low drainage density is suitable for groundwater recharge, a higher weight has been assigned to the higher class value (Fig. 8a). The PWCM for DD has been given in Table 4. The CR value for the DD is 0.02.

### Rainfall (RF)

The average yearly rainfall ranges from 1942 to 2059 mm per year. High intensity and short-period rainfall events cause less infiltration and more runoff. The range is classified into equal five intervals, as shown in Fig. 8b. Table 4 describes the PWCM for rainfall distribution. A high weight was assigned for a high rainfall area and low weight was assigned for low rainfall area. The CR value for rainfall calculation is 0.01.

### Infiltration zone map (IZM)

A high groundwater infiltration rate is essential for ensuring groundwater availability. According to Faniran (1968), the infiltration rate is the product of drainage density and stream frequency of an area. The infiltration rate is inversely proportional to the runoff, and consequently, groundwater recharge is generally low in areas with a high drainage
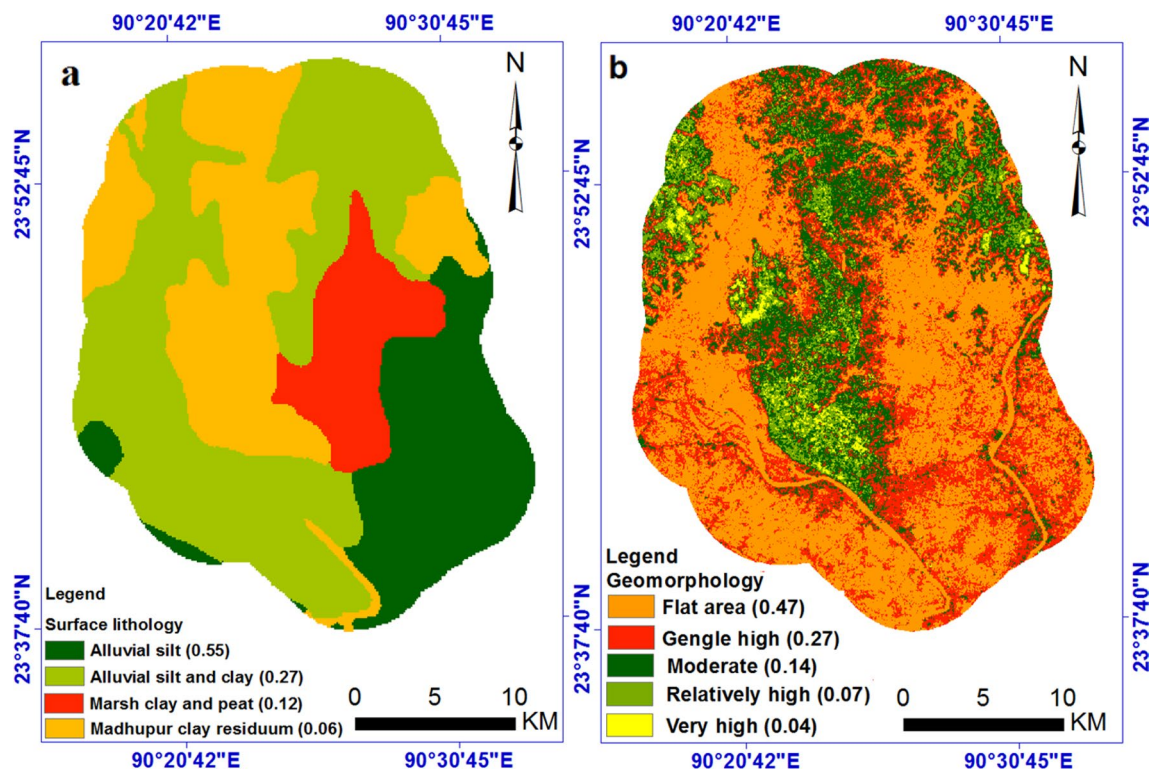
**Table 3** Pairwise comparison matrixes for lithology map

| Lithology CR = 0.08 | Alluvial silt and clay | Alluvial silt | Marsh clay and peat | Madhupur clay residuum | Rate |
|---|---|---|---|---|---|
| Alluvial silt and clay | 1 | – | – | – | 0.55 |
| Alluvial silt | 1/3 | 1 | – | – | 0.27 |
| Madhupur clay residuum | 1/5 | 1/3 | 1 | – | 0.12 |
| Marsh clay and peat | 1/6 | 1/5 | 1/3 | 1 | 0.06 |

**Fig. 7** **a** Surface lithology and **b** geomorphology map

density. A modified IZM was produced to reduce the influence of recharge on the settlement area for GP calculation. The infiltration map was divided into five classes, namely very low < low < moderate < high < very high. Figure 9a shows the infiltration zone map. Table 4 shows the pairwise comparison matrix for the IZM. The CR value for the IZM is 0.08.

### Groundwater abstraction (GWA)

Three groundwater abstraction zones were identified high, medium, and low for the study area (Fig. 9b). The city area has fallen under a high abstraction zone and the area outside of the Dhaka city has fallen into a low groundwater abstraction zone. The lowest class rate (0.17) was taken for a high groundwater abstraction zone and a high-class rate (0.54) was taken for a low abstraction zone. Table 5 shows the pairwise comparison matrix. CR value was obtained 0.01 for GWA. Where the high groundwater abstraction zone is occupying 75% area, medium abstraction zone is occupying 8% area and low abstraction zone is occupying 18% area.

### Land use/land cover (LULC)

Six LULC classes were identified in the study area, namely: vegetation, sand bars, open water, non-urban land; urbanized

land; and roads (Fig. 10). In 2014, vegetation-covered 13% (100 km$^2$) of the area, sand bars covered 2% (14 km$^2$) of the area; open water covered 5% (39 km$^2$) of the area, non-urban land covered 60% (463 km$^2$) of the area, urbanized land covered 17% (131 km$^2$) of the area; and roads covered 3% (25 km$^2$) of the area. Land use type provides information about infiltration, soil moisture, groundwater, and surface water (Ibrahim-Bathis and Ahmed 2016). Class rates for LULC are taken as water > land > sand bar > vegetation > building > road. Table 6 shows the pairwise comparison matrix for the LULC. CR value for LULC is 0.09. In Dhaka city, runoff water after rainfall store in some lakes that are larger water reservoirs in this area.

### Groundwater potential zone identification using WCL

For seven thematic layers, weightings were applied and a PWCM analysis was carried out (Table 7). The thematic layers were assessed in the GP calculation in the order: lithology > geomorphology > drainage density > rainfall > infiltration zone > groundwater abstraction > land use/land cover. The GP calculation was carried out as follows:

**Table 4** Pairwise comparison matrixes for geomorphology, drainage density, rainfall, and infiltration zone

| Geomorphology CR = 0.04 | Flat | Gentle high | Moderate | Relatively high | Very high | Rate |
|---|---|---|---|---|---|---|
| Flat | 1 | – | – | – | – | 0.47 |
| Gentle high | 1/2 | 1 | – | – | – | 0.27 |
| Moderate | 1/5 | 1/2 | 1 | – | – | 0.14 |
| Relatively high | 1/6 | 1/5 | 1/2 | 1 | – | 0.07 |
| Very high | 1/8 | 1/6 | 1/5 | 1/2 | 1 | 0.04 |
| Drainage density CR = 0.02 | 0–0.286 | > 0.286–0.572 | > 0.572–0.858 | > 0.858–1.144 | > 1.144–1.43 | Rate |
| 0–0.286 | 1 | – | – | – | – | 0.5 |
| > 0.286–0.572 | 1/3 | 1 | – | – | – | 0.26 |
| > 0.572–0.858 | 1/5 | 1/3 | 1 | – | – | 0.13 |
| > 0.858–1.144 | 1/7 | 1/5 | 1/3 | 1 | – | 0.07 |
| > 1.144–1.43 | 1/9 | 1/7 | 1/5 | 1/3 | 1 | 0.04 |
| Rainfall CR = 0.01 | > 2.027–2.059 | > 2.008–2.027 | > 1.993–2.008 | > 1.976–1.993 | 1.942–1.976 | Rate |
| > 2.027–2.059 | 1 | – | – | – | – | 0.47 |
| > 2.008–2.027 | 1/2 | 1 | – | – | – | 0.27 |
| > 1.993–2.008 | 1/4 | 1/2 | 1 | – | – | 0.14 |
| > 1.976–1.993 | 1/6 | 1/4 | 1/2 | 1 | – | 0.08 |
| 1.942–1.976 | 1/8 | 1/6 | 1/4 | 1/2 | 1 | 0.04 |
| Infiltration zone CR = 0.02 | Very high | High | Moderate | Low | Very low | Rate |
| Very high | 1 | – | – | – | – | 0.52 |
| High | 1/3 | 1 | – | – | – | 0.27 |
| Moderate | 1/6 | 1/3 | 1 | – | – | 0.12 |
| Low | 1/8 | 1/6 | 1/3 | 1 | – | 0.06 |
| Very low | 1/9 | 1/8 | 1/6 | 1/3 | 1 | 0.03 |

$$GP = 0.37 \times SL + 0.24 \times GM + 0.16 \times DD + 0.10 \times RF$$
$$+ 0.06 \times IZM + 0.04 \times GWA + 0.03 \times LULC.$$
$$(10)$$

The GP map was classified into five zones: 'very low', 'low', 'moderate', 'high', and 'very high' GP values Fig. 11a. The GP calculations indicated that 188 km$^2$ (24%) of the area had a 'very low' classification; 150 km$^2$ (19%) had a 'low' classification; 138 km$^2$ (18%) of the area had a 'moderate' classification; 143 km$^2$ (19%) of the area had a 'high' classification and 154 km$^2$ (20%) of the area had a 'very high' classification. The CR value for the thematic layer was 0.06. The highest potentiality values occurred in areas underlain alluvial silts and clay-to-silt-dominated areas because river bottom moves through these layers, which may facilitate water to percolate into the aquifer; on the other hand, low to moderate roughness, the limited number of deep tube-well and open land surface also support more groundwater potentiality in this area.

## Sensitivity analyses

A sensitivity analysis of the final GP map was carried out using a map removal sensitivity analysis (MRSA) and a single parameter sensitivity analysis (SPSA).

### Map removal sensitivity analysis (MRSA)

The MRSA result is shown in Table 8. The result shows that the most sensitive layer for the GP map is surface lithology. This layer had a mean variation index and standard deviation (SD) values of 4.18% and 2.71%, respectively, and the assigned empirical layer weight was 37%, as shown in Table 6. The second- and third-most sensitive layers are geomorphology and lineament, with mean values of 2.42 and 1.98, respectively. The least sensitive MRSA result was 4% for groundwater abstraction, which had mean and SD values of 1.22 and 0.45, respectively. The result shows that GP values are not only dependent on class rate but are also reliant on thematic layer weight.
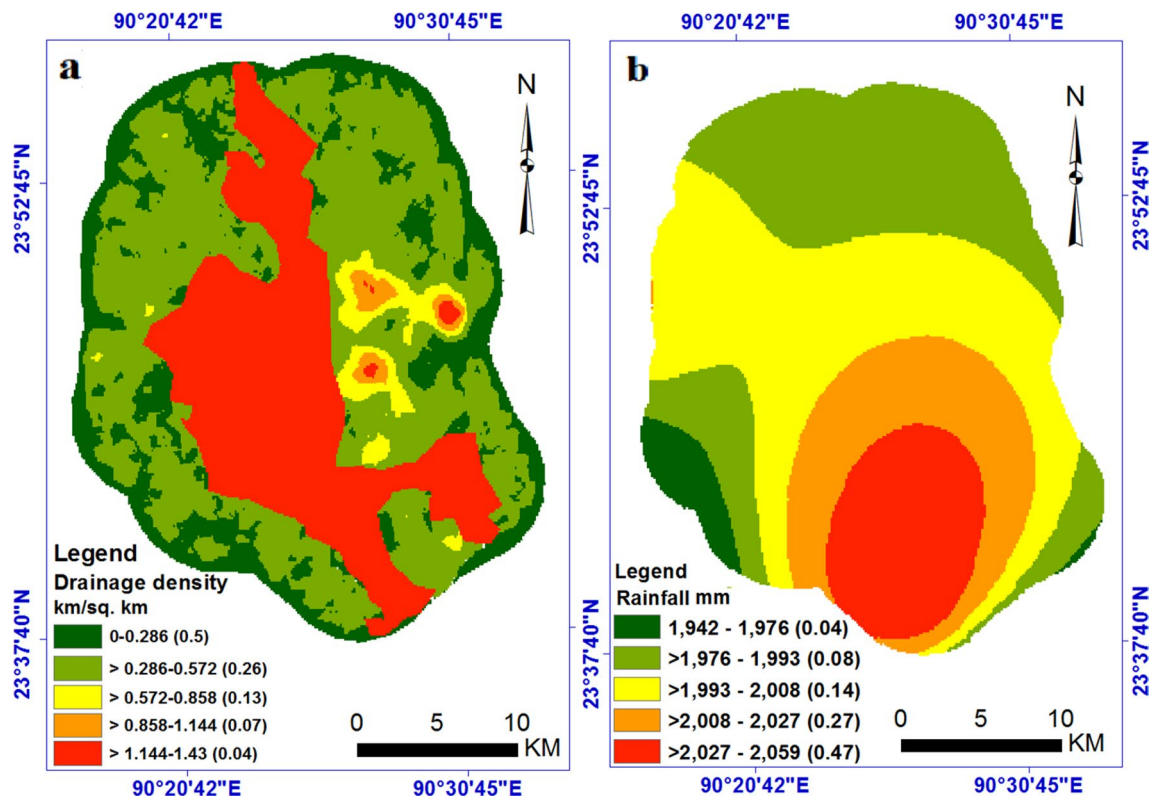
**Fig. 8** **a** Drainage density and **b** rainfall map
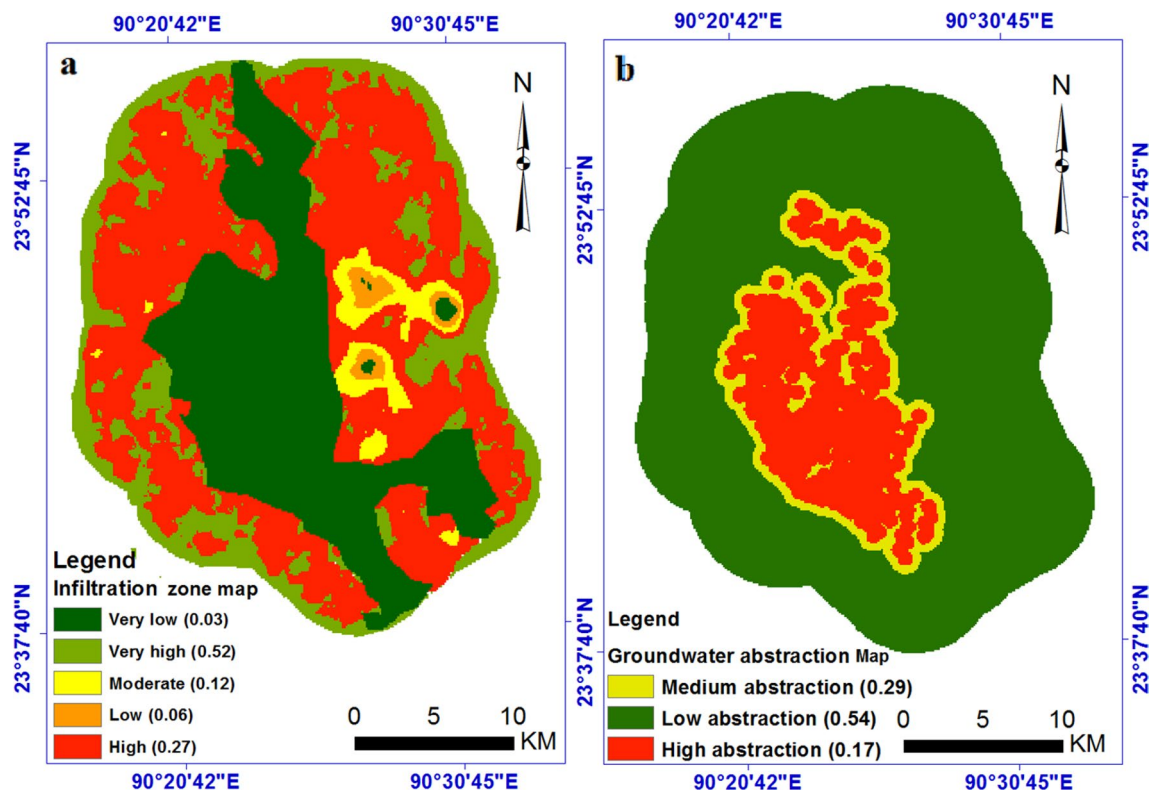


**Fig. 9** **a** Infiltration zone map and **b** groundwater abstraction map

**Table 5**  Pairwise comparison matrix for groundwater abstraction map

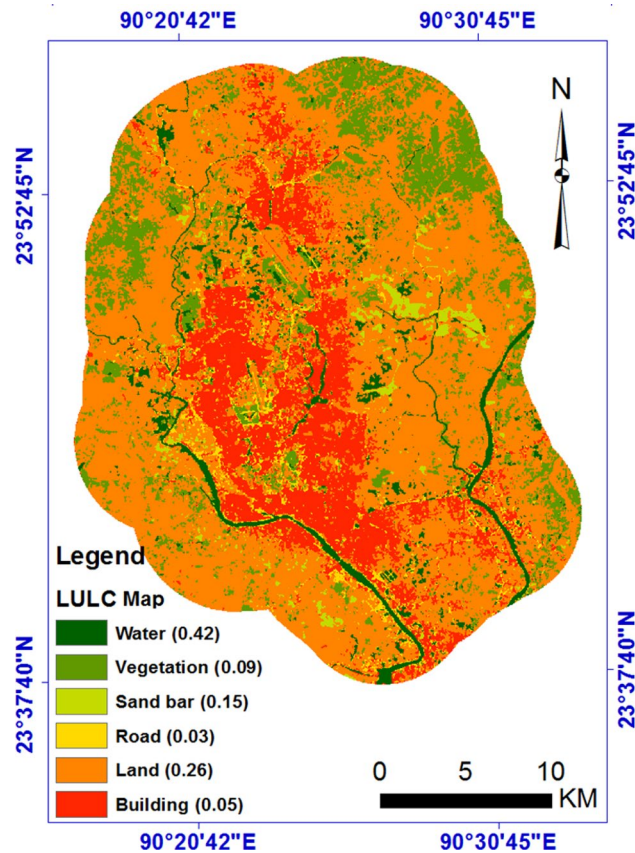| Groundwater abstraction CR = 0.01 | Low | Medium | High | Rate |
|---|---|---|---|---|
| Low | 1 | – | – | 0.54 |
| Medium | 1/2 | 1 | – | 0.29 |
| High | 1/3 | 1/2 | 1 | 0.17 |



**Fig. 10  a** Land use/land cover map

### Single parameter sensitivity analysis (SPSA)

Table 9 shows the SPSA result. This analysis indicated that, like MRSA, lithology is the most sensitive parameter (mean and SD values of 36.39% and 17.91%, respectively). The empirical weight of lithology is 37%, which is also higher than the other six thematic layers (Table 7). The least sensitive parameter is the LULC with mean and SD values 2.35 and 1.66, respectively (Table 9).

### Validation of GP zone with the groundwater table depth (GWTD)

The groundwater table depth depends on many factors, including recharge and groundwater abstraction. The groundwater table depth map was prepared from the data obtained from the Bangladesh Water Development Board (BWDB). The GWTD was calculated concerning the surface topography. The GWTD varies from 6 to 47 m in the study area. The map was divided into four classes in the ranges 6–22 m; > 22–30 m; > 30–38 m; and > 38–47 m. The largest depth (47 m) of the groundwater table is the result of pumping groundwater of a 563-m deep tube-well in the city area. Figure 11b shows the GWTD map. The high groundwater potential zone most fell (93%) in the 6–22-m GWTD zone area.

### Conclusion

Dhaka is the capital city of Bangladesh and is also the center of economic development and rapid urbanization. Groundwater beneath the city area is being depleted because of intense pumping for potable, commercial, and industrial water supply. Most groundwater (2.0 Mm$^3$ per day) is extracted from the upper Dupi-Tilpa aquifer by 563-m tube-wells, causing a progressive decrease in the elevation of the water table. Additionally, a drought analysis shows that there is a risk that groundwater recharge will decrease in the region due to an increased frequency of droughts.

An assessment of groundwater potential was undertaken to assess the factors that influence groundwater availability in the region. The evaluation was undertaken using a weighted linear combination (WLC) technique. The assessment was undertaken in the following way.

- Seven thematic layers were used in the analysis: surface lithology (four classes); geomorphology (five

**Table 6**  Pairwise comparison matrix for LULC map

| Land use CR = 0.09 | Water | Land | Sand bar | Vegetation | Building | Road | Rate |
|---|---|---|---|---|---|---|---|
| Water | 1 | – | – | – | – | – | 0.42 |
| Land | 1/2 | 1 | – | – | – | – | 0.26 |
| Sand bar | 1/5 | 1/2 | 1 | – | – | – | 0.15 |
| Vegetation | 1/6 | 1/5 | 1/2 | 1 | – | – | 0.09 |
| Building | 1/7 | 1/6 | 1/5 | 1/2 | 1 | – | 0.05 |
| Road | 1/8 | 1/7 | 1/6 | 1/5 | 1/2 | 1 | 0.03 |

**Table 7** Pairwise comparison matrix for all thematic layers

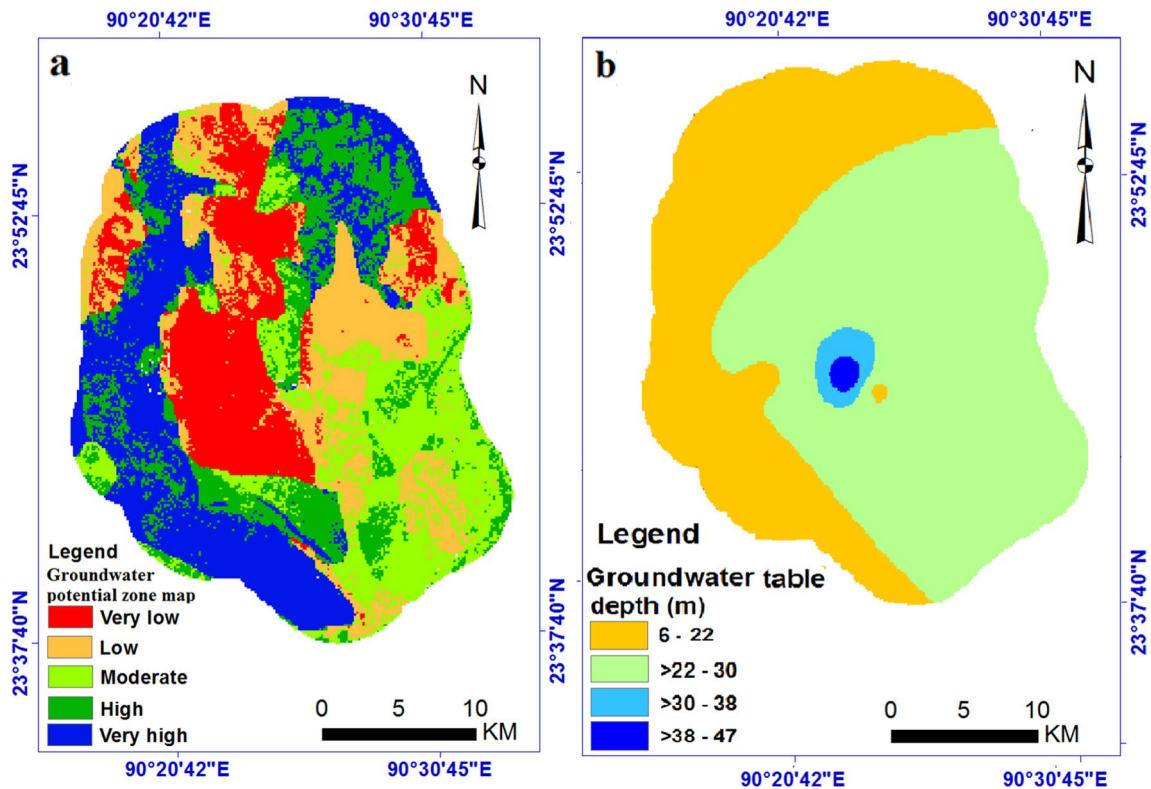| GP layers CR = 0.08 | SL | GM | DD | RF | IZM | GWA | LULC | Weight |
|---|---|---|---|---|---|---|---|---|
| SL | 1 | – | – | – | – | – | – | 0.37 |
| GM | 1/2 | 1 | – | – | – | – | – | 0.24 |
| DD | 1/4 | 1/2 | 1 | – | – | – | – | 0.16 |
| RF | 1/5 | 1/4 | 1/2 | 1 | – | – | – | 0.10 |
| IZM | 1/6 | 1/5 | 1/4 | 1/2 | 1 | – | – | 0.06 |
| GWA | 1/7 | 1/6 | 1/5 | 1/4 | 1/2 | 1 | – | 0.04 |
| LULC | 1/8 | 1/7 | 1/6 | 1/5 | 1/4 | 1/2 | 1 | 0.03 |



**Fig. 11** **a** Final groundwater potential zone map and **b** groundwater table depth map

**Table 8** Map removal sensitivity analysis (MRSA) result

| Class | Map removal sensitivity analyses | | | |
|---|---|---|---|---|
| | Min | Max | Mean | SD |
| Groundwater abstraction | 0 | 2.68 | 1.22 | 0.45 |
| Drainage density | 0 | 44.15 | 1.47 | 1.68 |
| Geomorphology | 0 | 9.45 | 2.42 | 1.82 |
| Land use | 0.03 | 2.35 | 1.98 | 0.28 |
| Lithology | 0 | 23.84 | 4.18 | 2.71 |
| Rainfall | 0 | 43.09 | 1.63 | 1.73 |
| Infiltration zone | 0.35 | 2.31 | 1.59 | 0.58 |

**Table 9** Single parameter sensitivity analysis (SPSA) result

| Class | Single parameter sensitivity analyses | | | |
|---|---|---|---|---|
| | Min | Max | Mean | SD |
| Groundwater abstraction | 1.49 | 30.37 | 7.16 | 3.41 |
| Drainage density | 1.27 | 13.15 | 12.72 | 9.19 |
| Geomorphology | 2.41 | 164.43 | 27.90 | 14.29 |
| Land use | 0.18 | 17.17 | 2.35 | 1.66 |
| Lithology | 4.59 | 255.97 | 36.39 | 17.91 |
| Rainfall | 0.86 | 49.63 | 7.96 | 6.95 |
| Infiltration zone | 0.34 | 44.13 | 4.77 | 3.72 |

classes); drainage density (five classes); rainfall (five classes); infiltration zone characteristics (five classes); groundwater abstraction (three classes); and LULC (six classes) have been used.

- CR values were determined and were found to range from 0.01 to 0.09.
- A WLC for the seven thematic layers was carried out.

The GP assessment indicated that

- An area of 188 km$^2$ (24% of the study area) had a 'very low' potential; 150 km$^2$ (19% of the study area) had a 'low' potential; 138 km$^2$ (18% of the study area) had a 'moderate' potential; 143 km$^2$ (19% of the study area) had 'high' potential, and 154 km$^2$ (20% of the study area) had a 'very high' potential.
- Most of the areas with high potential are underlain by alluvial silts and clays and other silty areas that have a gentle slope near open water bodies. These areas have relatively moderate drainage density.
- Sensitivity analysis using MRSA and SPSA techniques show that surface lithology is the most important parameter influencing groundwater potential. These analyses indicate that mean deviation and SD values for surface lithology are 4.18% and 2.71% (for MRSA), respectively, and 36.39% and 17.91% (for SPSA), respectively.
- 93% area of the area with a high groundwater potential zone occurs in the area where the depth to groundwater is in the range of 6–22 m below the land surface.

The current study will helpful for hydrogeologists/hydrologists or planners as an indicator of areas that warrant further investigation. GIS and RS based studies reduce time consumption and costs.

## Compliance with ethical standards

**Conflict of interest** The research work is not associated with any government or private organization so there is no conflict of interest.

**Ethical approval** The data sets used for the research are publicly available so there is no need for ethical approval. The manuscript was not submitted to any other journal before or after submission to this journal.

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