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Remote sensing and GIS based assessment of groundwater potential zones in AMU campus using AHP approach

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ABSTRACT

Groundwater has been a significant resource of water in many tropical countries. However, overexploitation of groundwater have raised concerns within techno-scientific community to devise sustainable development and management strategies for augmentation of the precious resource. Integration of remote sensing and GIS techniques has proved to be efficient and cost effective tool towards identification of ground water potential zones. Present study demonstrates the capability of GIS and remote sensing towards identification of ground water potential zones in AMU campus by utilizing GeoEye-2 imagery along with six thematic maps prepared in GIS framework namely, Land use land cover (LULC), rainfall, drainage density, DEM, slope and groundwater elevation. The influence of each thematic layer was evaluated on the basis of their relative significance towards groundwater recharge and the suitable weight values were assigned by employing the multi criteria decision making technique based on the Saaty's analytical hierarchical process (AHP). The groundwater potential zones were classified into five categories, i.e. excellent, very good, good, moderate, and poor. Groundwater potential zonation map revealed that, of the total study area covering 2.26 km^2, excellent zone comprised over 0.22 km^2 (9.52% of the total study area extent), whereas very good, good, moderate, and poor zones covered 0.45 km^2 (19.83%), 0.58 km^2 (25.58%), 0.60 km^2 (26.55%) and 0.42 km^2 (18.56%) respectively. Overall, the study focusses on the demarcation and assessment of groundwater potential zones so as to enable holistic insight into strategic planning, utilization, administration and management of groundwater resources within the study area.

***Key words** : Groundwater augmentation, Remote sensing and GIS, Thematic maps, Saaty's AHP.*

Introduction

Depleting groundwater resources can be enhanced by precise delineation and spatial mapping of sub-surface water potential locations by employing remote sensing and GIS techniques. Integration of remote sensing and GIS techniques having an advantage of spatial, spectral and temporal availability offers rapid, accurate and cost effective solution for accessing, monitoring and conserving groundwater resources (Saraf and Coudhary, 1998; Shahid and Nath, 1999; Jaiswal *et al.*, 2003; Shanker and Mohan 2005; Al-Amoush, 2006; Vijith *et al.*, 2007; Banai, 2010; Gitas *et al.*, 2014; Kumar and Jhariya, 2015; Nag and Kundu, 2016; Gnanachandrasamy *et al.*, 2018; Kesana and Dinesh, 2019). Aligarh district has a monsoon influenced humid subtropical climate and is categorized under the semi-arid environment

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that makes groundwater as only necessary alternative for fulfilling the water requirements (Ahmed and Umar, 2009). Depleting groundwater table within the main city area in recent years has actuated the Govt. agencies and NGO's to organize and drive water awareness campsas well as planning out effective strategies to augment the declining resource in tune with the sustainable development goals of the local administration.

The present study has been undertaken to assess groundwater potential zones within AMU campus surrounding the heart of the Aligarh city, by using remote sensing and GIS techniques in conjunction with the surveyed field data. The study furnishes a clear understanding of Saaty's AHP technique implemented for assigning ranks to the generated six thematic maps (i.e., Land use land cover (LULC), rainfall, drainage density, DEM, slope and groundwater elevation) influencing the groundwater recharge potential in the study area. The analysis of groundwater potential recharge zones in the study area facilitates implementation of appropriate and efficient groundwater recharging schemes via rain water harvesting through recharge pits assembled with direct or semi-injection bore wells etc., as sustainable remedial measures.

Study Area

Study area covers the main campus of Aligarh Muslim University (AMU), Aligarh, Uttar Pradesh, India, covering an aerial extent of 2.26 km², bounding within latitude 27.88°N and longitude 78.08°E at an elevation of approximately 178 m (587 feet) above mean sea level (Figure 1). Aligarh district lies in the middle of the doab, i.e. the land between the Ganges and the Yamuna rivers. The region is characterized by monsoon-influenced humid subtropical climate receiving an annual rainfall of 800 mm (31 in), majorly during monsoon months.

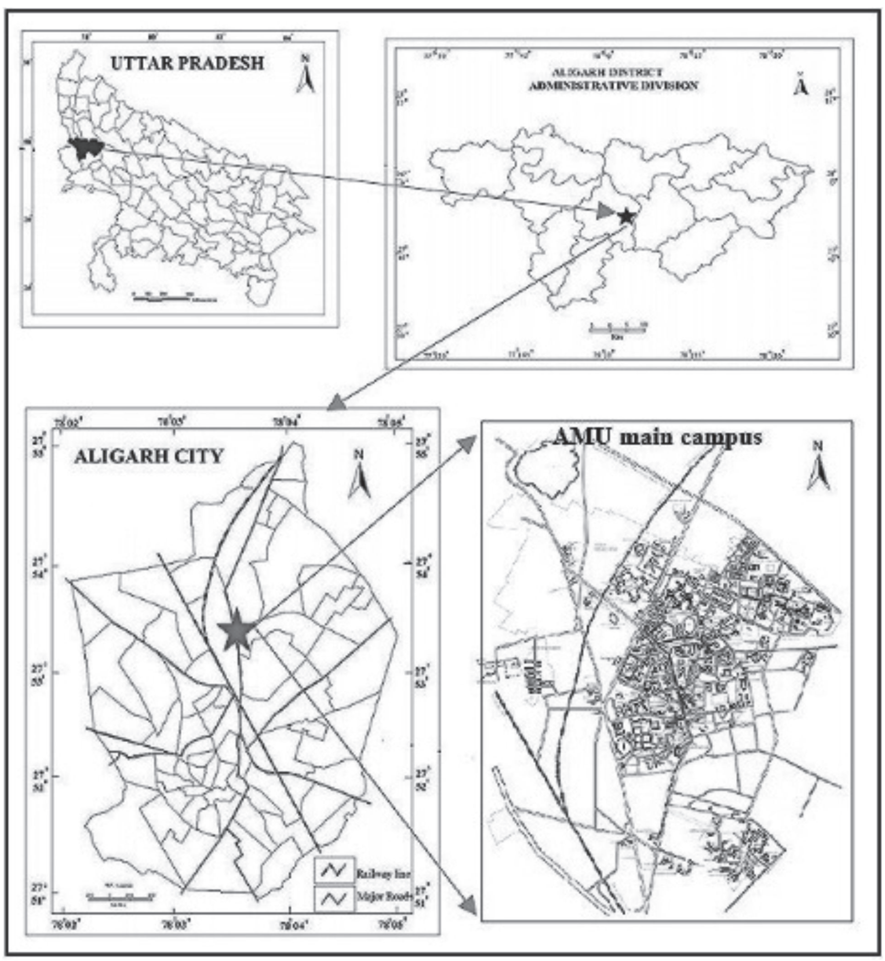

Fig. 1. Location map of study area (Map not to scale).

Materials and Method

Data and software used

GeoEye-2 image of year 2018, operated by Digital Globe having spatial resolution at 0.41 m was utilized for the preparation of LULC map of the study area by employing supervised classification with maximum likelihood training algorithm in Erdas Imagine 9.2 software. Image was geo-referenced by considering Geographic (Lat/Lon) projection system and World Geodatic System; WGS84 Spheroid and datum respectively. Subset image bounding the study region (Figure 2a) was extracted before performing the supervised classification. The major land use of the study region were grouped into five categories or classes, i.e. barren land, grassland, tree cover, impervious (includes buildings, parking lots) and roads, classified LULC map of the study area is shown in Figure 2b. Remaining five thematic layers i.e. rainfall, drainage density (D_d), DEM, slope and groundwater elevation were prepared in GIS framework using ArcGIS 9.3 software.

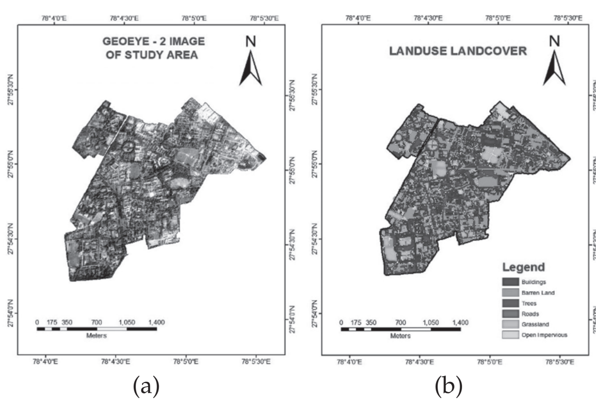

Fig. 2. (a) Geo-referenced subset image (b) classified image of the study area.

Methodology

Broad overview of methodology adopted to delineate the groundwater potential zones in the study area is illustrated in Figure 3 as flow chart.

DEM was generated from the contour map using Kriging interpolation technique in spatial modular tool of ArcGIS10.3. Contour map of the study area was generated with 250 ground control points (GCP's) collected at random locations with handheld GPS device. Contour interval was kept as 0.5m owing to the relatively flat and small study area (i.e. < 2.5 km^2). Slope map and drainage density map were generated from DEM as input. Higher rainfall is favorable for the presence of more groundwater. Rainfall distribution map was prepared with 10 year average annual rainfall data (January 2007 to January 2016) by interpolating the output grid pixel using Inverse Distance Weight method (IDW) technique in ArcGIS. The eastern and north eastern parts of study area receives marginally more rainfall of the order of 75.76 mm, than the rest of the parts receiving 75.69 mm. Groundwater elevation (GWE) data from over 154 tube wells and bore wells was obtained to prepare groundwater elevation map using IDW method. The variation of groundwater levels in the study area ranges from 185 feet to 210 feet. The groundwater levels are sensitive to the monsoon rainfall and any irregularity in rainfall directly influences the groundwater levels. The various spatial data set utilized for generation of groundwater potential map are shown in Figure 4.

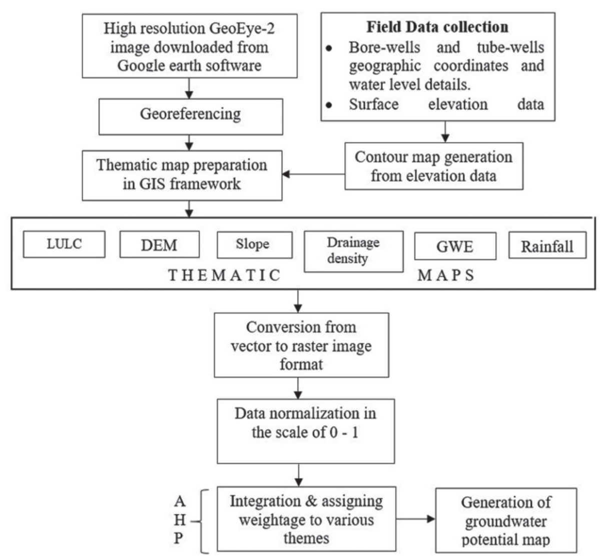

Fig. 3. Methodology adopted for delineating groundwater potential zones in study area.

Multi-criteria evaluation allows map layers to be weighted to reflect their relative importance (Voogd, 1983; Eastman *et al.*, 1995). Saaty's (1980), analytic hierarchy process scales the weight of parameters whose entries indicate the strength with which one element dominates over the other in relation to the relative criterion. Saaty'snine points scale values were assigned to each prepared thematic

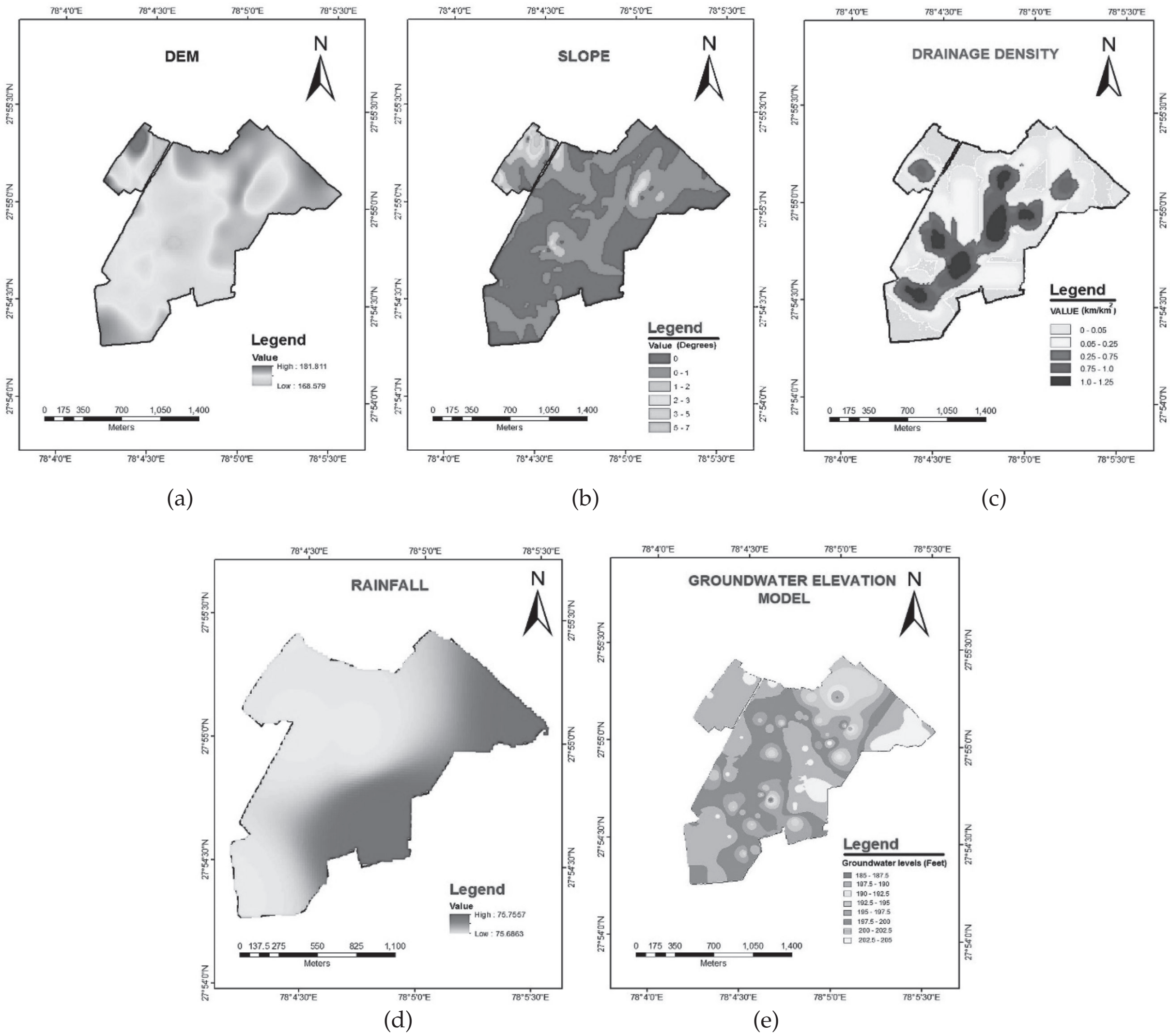

Fig. 4. (a) DEM (b) slope map (c) drainage density map (d) rainfall map and (e) GWE map of the study area used for identification of groundwater potential zones.

map on the basis of their influence towards groundwater potential by constructing pair wise comparison matrix of *n* parameters and of the order ($n \times n$). Criteria weight w_i (*m*-dimensional column vector) is obtained by averaging the sum of all the criterion values in each row of the standardized comparison matrix. The measure of consistency called the Consistency Index (CI) as a deviation or degree of consistency was calculated using the Equation 1. To control the consistency analysis and scale judgment, the Consistency Ratio (CR) which is a measure of consistency pairwise comparison matrix is calculated by Equation 2; the value of CR must be less than 10%.

$$CI = \frac{\lambda MAX - N}{N - 1} \quad .. (1)$$

Where N is the total number of criterion, λ_{MAX} is the largest eigenvalue of the pairwise comparison matrix. Consistency Ratio (CR) is a measure of precision and acceptability of AHP.

$$R = \frac{CI}{RI} \quad .. (2)$$

Where RI is the Ratio Index for the number of criteria involved and is predefined by Saaty. The groundwater potential zones map of the study area was produced by overlaying all thematic layers using the weighted index overlay procedure. The following formula shown as Equation 3, was used to estimate the groundwater potential map (Prasad *et al.*, 2008; Kumar *et al.*, 2014). Equation 3 can further be written as Equation 4.

Groundwater Potential Zone Map (GWP)

$$= \Sigma^{6}_{i,j=1} W_i X_j \times R_i \quad .. (3)$$

$$GWP = (W1 \times DEM) \times R1 + (W2 \times LULC)) \times R2 + (W3 \times rainfall)) \times R3 + (W4 \times slope)) \times R4 + (W5 \times Dd)) \times R5 + (W6 \times GWE) \times R6 \quad .. (4)$$

Where, W_i is the percent weight of each thematic map, R_i is the rank assigned to each theme and X_i is the corresponding pixel value of the thematic map prepared for integrated overlay analysis.The cumulative weight values of the main themes and sub themes were evaluated and brief illustration of main theme results is provided in Table 1, to prepare the raster map of groundwater potential zone in GIS framework. The groundwater potential (GWP) map produced from Equation 3, was categorized into five classes, i.e. excellent, very good, good, moderate and poor.

Results and Discussion

The GWP map generated is shown in Figure 5 and the extent of various zones in terms of percentage of area is provided in Table 2, reveals that around 29% of the total area is under excellent and very good potential zone whereas 45% of the total area falls under moderate and poor potential zone and the rest 26 % falls under good potential zone. It is observed that poor and moderate potential zones in the study area covers built up areas viz. residential block, hostels, impervious parking lots and up to certain extent, barren lands. Grasslands and tree covered areas constitute good to moderate potential zones that is clearly ascertained in GWP map, i.e. comprising tree covered areas, university graveyard and grassland/parks etc.

It is therefore imperative to say that groundwater prospects are good to very good in more than half of the study area whereas poor to moderate potential areas should be taken up on priority basis for water conservation measures through construction of efficient water harvesting structures. Based on the composite GWP map of the study area, vulnerable locations can be identified for setting up of different rain water recharge structures with and without semi injection bore wells.

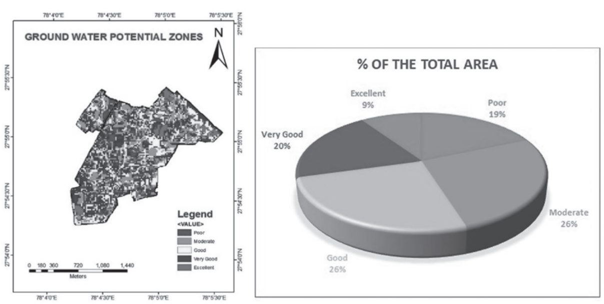

Fig. 5. Groundwater potential zone map of the study area and percent of total area covered as pie chart.

Table 1. Final rank, priority and weights assigned to thematic layers

S No.	Thematic layers	Weight	Priority (%)	Rank	Consistency ratio (CR)
1	Slope	0.1024	10.2	4	9.5 %
2	LULC	0.2913	29.1	2	
3	D_d	0.0621	6.2	5	
4	Rainfall	0.1752	17.5	3	
5	DEM	0.3342	33.4	1	
6	GWE	0.0363	3.6	6	

Table 2. Area distribution of groundwater potential zones

S. No.	GWPZ categories	Area (sqm)	Area (Ha)	% of the area
1	Poor	419974.800	41.997	18.563
2	Moderate	600620.400	60.062	26.547
3	Good	577995.600	57.800	25.547
4	Very Good	448609.400	44.861	19.828
5	Excellent	215290.100	21.529	9.516
	Total	226.249	100	

Conclusion

The application of geospatial technique and the AHP approach have been demonstrated as appropriate tools for the identification of groundwater potential zones in the study area. The present study delineates the potential zones for groundwater occurrences by preparing and analyzing six thematic maps as influencing factors. Results indicate that out of the total aerial extent of the study area (i.e. 2.26 km^2; 54.89%), 1.24 km^2 is characterized under excellent, very good and good potential areas, whereas, 1.02 km^2 (45.11% of the total area) covers moderate to poor potential groundwater zones. It is evident from the results that almost half of the study area falls under moderate to poor potential and therefore necessitates immediate remedial measures through awareness drive to conserve the available groundwater resource and initiate efficient schemes of rainwater harvesting such as recharge wells in conjunction with direct or semi-injection bore wells covering all major buildings and open areas within the study area. Percolation/Di-siltation tanks are recommended in areas with moderate to poor groundwater potential.

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