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Research Article

Identifying Prospective Areas for Groundwater Potential in Allahabad City

Mukesh Kumar[1], Keshav Kumar Sharma[2], Deepak Lal[1], Atul[3], Ashhad Imam[3], Shakti Suryavanshi[3*]

[1]Center for Geospatial Technologies, SIET, SHUATS, Allahabad, UP, India
[2]Department of Civil Engineering, NIT Jamshedpur, Jamshedpur, UP, India
[3]Department of Civil Engineering, SIET, SHUATS, Allahabad, UP, India
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*suryavanshi.shakti@gmail.com

ABSTRACT

Groundwater is an important resource, contributing significantly to the total annual supply. However, over-exploitation has depleted groundwater availability considerably. Assessing the potential zone of groundwater recharge is extremely important for the protection of water quality and the management of groundwater systems. Integration of Remote Sensing data and the Geographical Information System (GIS) for the exploration of groundwater resources has become a breakthrough in the field of groundwater research, which can assist in assessing, monitoring and conserving groundwater resources. The accurate information to obtain the parameters that can be considered for identifying the groundwater potential zone were found to be geomorphology, slope, land use/land cover and lithology. In this study weighted overlay method has been utilized in the ArcGIS environment. Suitable ranks were assigned for each category of the parameters; the procedure was repeated for all other layers and the resultant layers were reclassified. About 43.44 sq. km of the total study area was falling under the ‘very poor’ groundwater potential zone, 21.56 sq. km under the 'poor' zone, 18.89 sq. km under the moderate zone and 12.61 sq. km under the 'very good' zone. The excellent groundwater potential zone was concentrated in the northeast region of the study area due to the distribution of alluvial plains and agricultural land with high infiltration ability. This potential groundwater information will be useful for the effective identification of suitable locations for the extraction of water. The study will be useful in conserving natural resources which are depleting at high rates due to the pressure and demand of the increasing population.

Keywords: Groundwater potential; Remote Sensing; GIS; Weighted Overlay Technique.

1. INTRODUCTION

Groundwater represents the second-most abundantly available freshwater resources and constitutes about 30% of global freshwater resources (Subramanya, 2008). Groundwater contributes to about 80% of the drinking water requirements in rural areas, 50% of the urban water requirements and more than 50% of the irrigation requirements of the nation. Hence it plays a fundamental role in human well-being, as well as that of aquatic and terrestrial ecosystems. Because of its several inherent qualities, it has become an immensely important and dependable source of water supply in all climatic regions, including both urban and rural areas of developed and developing countries.

Currently, groundwater exploration is gaining more attention due to the uneven and untimely distribution of rainfall, which ultimately leads to regular drought events, less availability of rural and urban water supply, poor irrigation management, etc. Over the years, the growing importance of groundwater based on an increasing need has led to unscientific exploitation of groundwater, creating a water stress condition. This alarming situation calls for a cost-effective and time-saving technique for proper evaluation of groundwater resources, planning and management.

Remote sensing data, with their advantages of spatial, spectral and temporal availability and manipulation of data covering large and inaccessible areas within a short time, have become very handy tools in accessing, monitoring and conserving groundwater resources. GIS and remote sensing tools are widely used for the management of various natural resources (Magesh *et al.* 2012). Delineating the potential groundwater zones using remote sensing and GIS is an effective tool. In recent years, extensive use of satellite data along with conventional maps and rectified ground truth data has made it easier to establish baseline information for groundwater potential zones (Chowdhury *et al.* 2009). Remote sensing not only provides a wide-range scale of the space-time distribution of observations but also saves time and money (Murthy, 1996). In addition, it is widely used to characterize the earth's surface (such as lineaments, drainage patterns and lithology) as well as to examine the groundwater recharge zones.

Allahabad, a major city of Uttar Pradesh state, is situated at the confluence of River Ganga and Yamuna. The increasing population of Allahabad is heavily dependent on groundwater resources. Over-exploitation of groundwater could prove catastrophic in the future, if corrective measures are not taken in the region. Therefore, the present study was focuses on the explicit objective to identify potential groundwater zones in Allahabad city using the advanced technology of remote sensing and GIS for the planning, utilization, administration and management of groundwater resources.

2. MATERIALS AND METHODS

2.1 Study Area Characteristics

Allahabad is located at 25^0 27' N, 81^0 50' E; 25.45^0 N, 81.84^0 E in the southern part of Uttar Pradesh at an elevation of 98 m. To its southwest, east and southwest is the Bundelkhand region, to its north and northeast is the Awadh region and to its west is lower Doab.

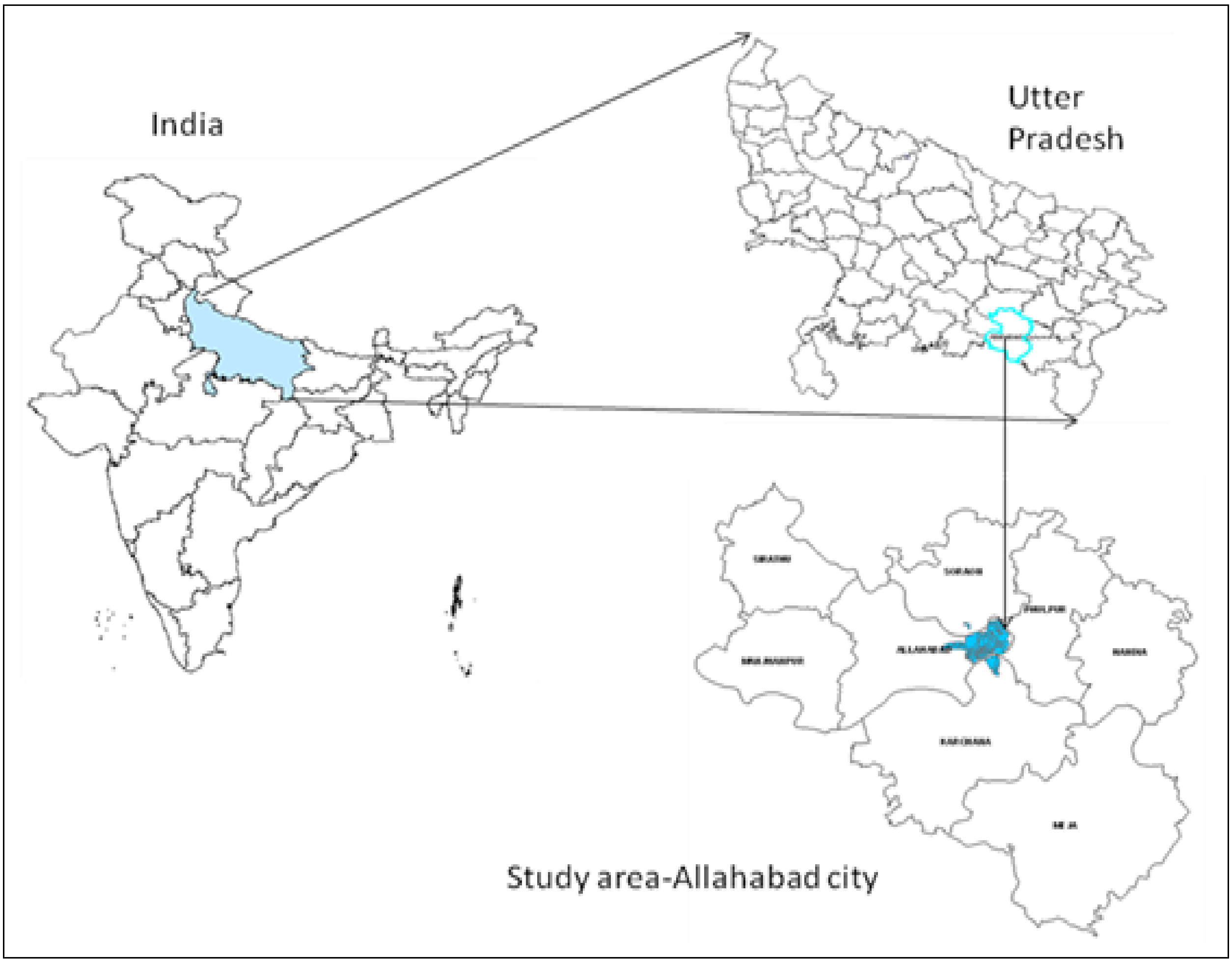

Fig. 1: Location map of the study area

2.1.1 Soil

The soil of Allahabad is dominant with alluvial (entisols) soil, which is fertile but not too moist. The non-doabi parts of the district, the southern part and the eastern part of the district are somewhat dry and rocky (similar to the adjoining Bundelkhand and Bagelkhand region).

2.1.2 Demography

Allahabad city has a population of 1,042,229 as per the 2001 census. It is the 32nd most populous city in India and 3rd fastest growing city of Uttar Pradesh after Lucknow and Agra, with area of about 7000 sq. km.

2.1.3 Climate

Allahabad experiences all four seasons. The summer seasons are from April to June, with the maximum temperatures varying from 35 to 45 ˚C. Monsoon begins in early July and lasts till September. The winter seasons fall in the month of December, January and February. Temperatures in the cold weather could drop to freezing, with a maximum of almost 12 to 14 ˚C. The lowest temperature recorded was 1 ˚C.

2.1.4 Population

In the 2001 census, Allahabad had a population of 4,936,105 of which males were 2,626,448 and females were 2,309,657. Allahabad district density was at 901 people per sq. km. The initial provisional data released by Census India 2014 had shown that the density of Allahabad district for 2014 is 1087 people per sq. km.

2.1.5 Hydrogeology

Groundwater in the district occurs both in alluvium and in the weathered and jointed sandstone areas, which are underlain by hard rocks. In the un-consolidated or alluvial formation, groundwater occurs under un-confined to confined conditions in the shallow and deeper aquifers, respectively, and depth to water ranges between 2 m and 20 m during the pre-monsoon period while in the post-monsoon period, it falls between 1 m and 18 m.

2.2 Data Used

2.2.1 Remote Sensing Data

In this study, ETM+ sensor data was utilized. Since the study area was covered in many paths of Landsat satellite data acquisition (each path was covered separately on a different day as per the orbital calendar), cloud-free data was acquired in different time windows depending upon the overpass of the satellite. Each scene was ortho-corrected; geo-referenced and suitable image enhancements were applied to facilitate the delineation and interpretation of different thematic information; after the processing of data, land use map was prepared for the study area.

2.2.2 Software Used

ERDAS Imagine 9.4 software was utilized in various steps of satellite image processing, and Arc GIS 9.4 software was used for analysis, database creation, composition and generation of maps.

2.3 Methodology

In the present study, a hierarchical methodology was used. The potential sites were selected based on a range of criteria such as land use/land cover, geomorphology, lithology and slope. The groundwater potential zones were obtained by overlaying all the thematic maps in terms of the weighted overlay method using the spatial analysis tool in the ArcGIS interface. During the weighted overlay analysis, the ranks have been given for each individual parameter of each thematic map and the weight is assigned according to the influence of the different parameters. The weights and rank have been taken as suggested by Krishnamurthy *et al.* 1996. The logical combination of these created layers was utilized in assessing potential groundwater sites. The maximum value was given to the feature with the highest groundwater potentiality and the minimum to the lowest potential feature. As far as the slope was concerned, the highest rank value was assigned for a gentle slope and a low-rank value was assigned to a higher slope. In LULC, high rank was assigned to cropland and low value was assigned to barren land.

3. RESULTS AND DISCUSSION

3.1 Land use / Landcover

The satellite data was transformed into a thematic land use/land cover map of Allahabad for the year 2014 using on-screen visual interpretation. The land use land cover map of the study area is shown in Fig. 2. Statistics of land use/cover are depicted in Table 1. The different classes of land use/land cover were: built-up land (urban/rural), fallow land, agricultural cropland, gullied / ravines, wasteland, plantation orchards, scrubland and waterbodies. The total area of Allahabad city was found to be 96.201 sq. km (Table 1). The study area was dominated by built-up land (urban / rural) area, which contributed about 63.42% of the total area (61.21 sq. km). About 3.01 sq. km (3.12%) of the area was covered by fallow land. The area covered by cropland was 18 sq. km (18.65%). The area covered by Gullies/Ravines was 0.70 sq. km (0.72 %). The area covered by other wastelands was 1.09 sq. km (1.15%). The area covered by plantation/orchards was 0.76 sq. km (0.79%). The scrubland covered about 1.13 sq. km (1.16%). The area covered by water bodies was 10.69 sq. km (10.99%). The area coverage of the water body is high due to the fact that Allahabad city is situated at the confluence of two mighty rivers, the Ganga and the Yamuna.

3.2 Lithology Mapping

Fig. 3 depicts the lithology and Table 2 exhibits the area statistics of the lithology of the study area. The clay with sand/silt parting area was found to be 16.31 sq. km (16.9%) of the total area (96.51 sq. km). The area of clayey sand was 2.45 sq. km (2.54%). The area of gravel/sandy silt was 5.93 sq. km (6.14%). The settlement area was 63.43% of the study area. The area covered by the water body was 10.61 sq. km (10.99%).

Table 1. Area statistics of Land use / Land cover map

Class	Area (sq. km)	Area (%)
Built-up land / Settlement	61.21	63.42
Fallow land	3.01	3.12
Cropland	18	18.65
Gullied / Ravine	0.70	0.72
Other wastelands	1.09	1.15
Plantation / Orchards	0.76	0.79
Scrubland	1.13	1.16
Water bodies	10.61	10.99
Total	**96.51**	**100**

Table 2. Area statistics of the Lithology of Allahabad city

Class	Area (sq. km)	Area (%)
Clay with sand/Silt parting	16.31	16.90
Clayey sand	2.45	2.54
Gravel/Sandy, silt	5.93	6.14
Settlement	61.21	63.43
Waterbody	10.61	10.99
Total	**96.51**	**100**

Table 3. Area statistics of the Geomorphology of Allahabad city

Class	Area (sq. km)	Area (%)
Alluvial plain	17.03	17.65
Flood plain	7.66	7.93
Settlement	61.21	63.43
Waterbody	10.61	10.99
Total	**96.51**	**100**

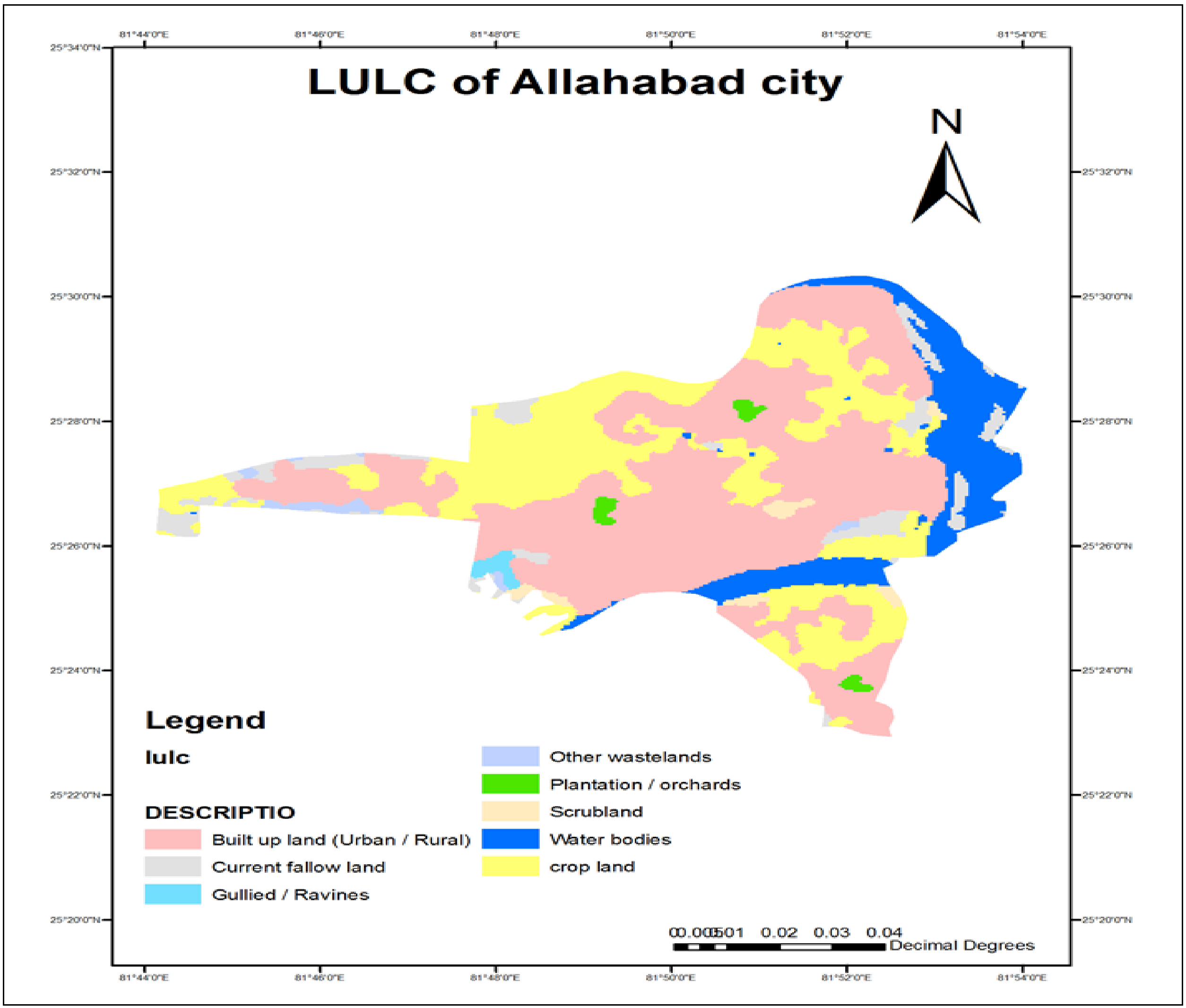

Fig. 2: Land use / Land cover map of Allahabad city

3.3 Geomorphology Mapping

According to the geomorphology, Allahabad city is classified into alluvial plain, flood plain settlement and water body (Table 3 and Fig. 4). The area of the alluvial plain was 17.03 sq. km (17.65% of the total area). The area of the flood plain was 7.66 sq. km (7.93%) and the settlement area was 61.21 sq. km (63.43%). The area covered by the water body was 10.61 sq. km (10.99% of the total area).

3.4 Slope

The slope is one of the important terrain parameters, which is explained by the horizontal spacing of the contours. In general, in the vector form, closely spaced contours represent steeper slopes and sparse contours exhibit a gentle slope; whereas, in the elevation output raster, every cell has a slope value. Here, the lower slope values indicate flatter terrains (gentle slopes) and higher slope values correspond to steeper slopes of the terrain (Fig. 5).

Based on the thematic maps of different parameters (land use/land cover, geomorphology, lithology and slope) and by using the weighted overlay method, different weights were given to individual parameters and scores were calculated. It can be observed from Table 4 that geomorphology is very sensitive to groundwater potential. The groundwater potential map (Fig. 6) has revealed that the excellent groundwater potential zone is concentrated in the north-east regions of the study area due to the distribution of alluvial plains and agricultural land with high infiltration ability. About 43.44 sq. km of the total area was falling under the 'very poor' zone, 21.56 sq. km under the 'poor' zone, 18.89 sq. km under the moderate zone and 12.61 sq. km under the 'very good' groundwater potential zone. Finally, the cumulative effect of the weighted multi-influencing factors through overlay analysis in the GIS platform has revealed the mapping of potential groundwater zones in the study area.

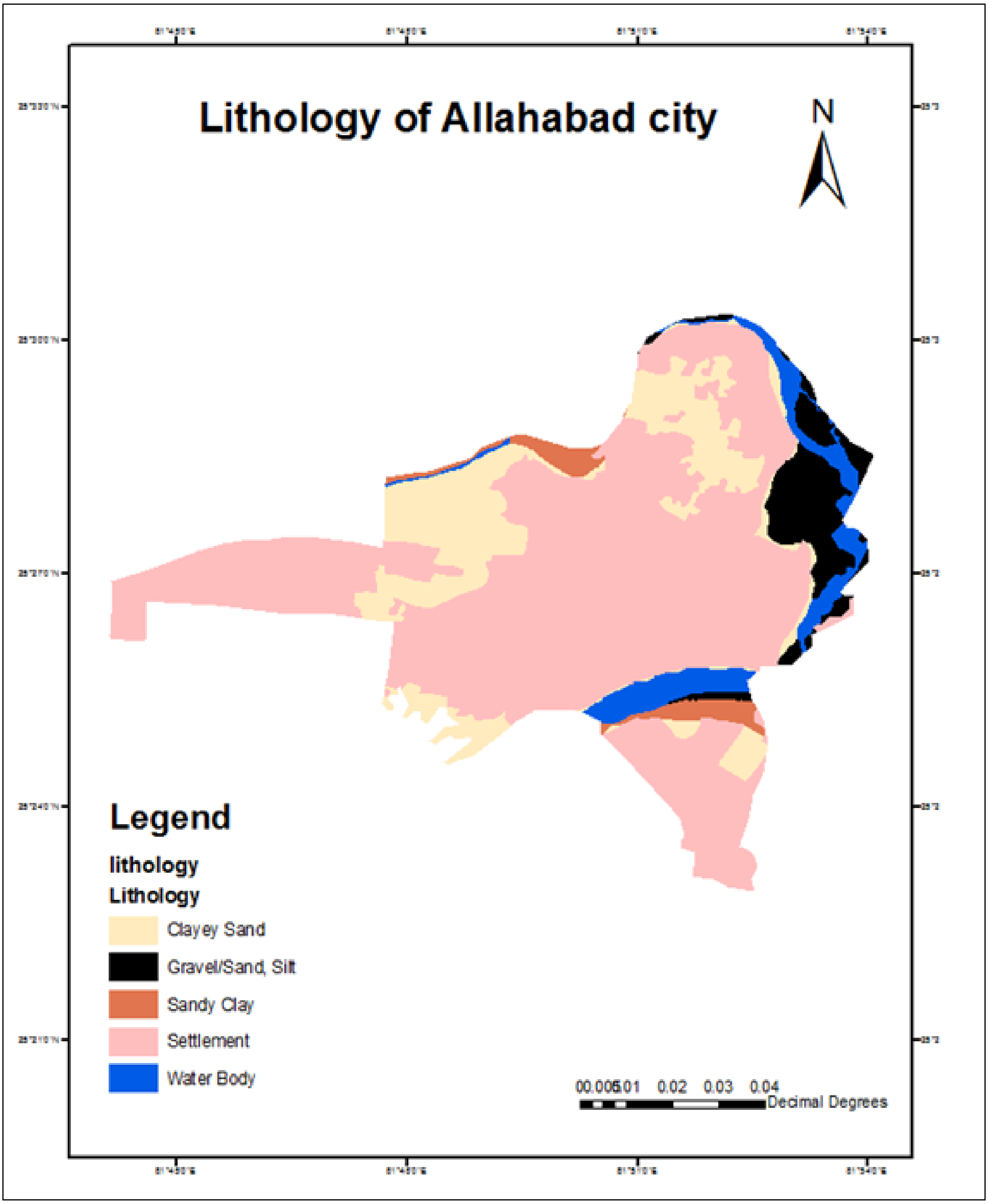

Fig. 3: Lithology map of Allahabad city

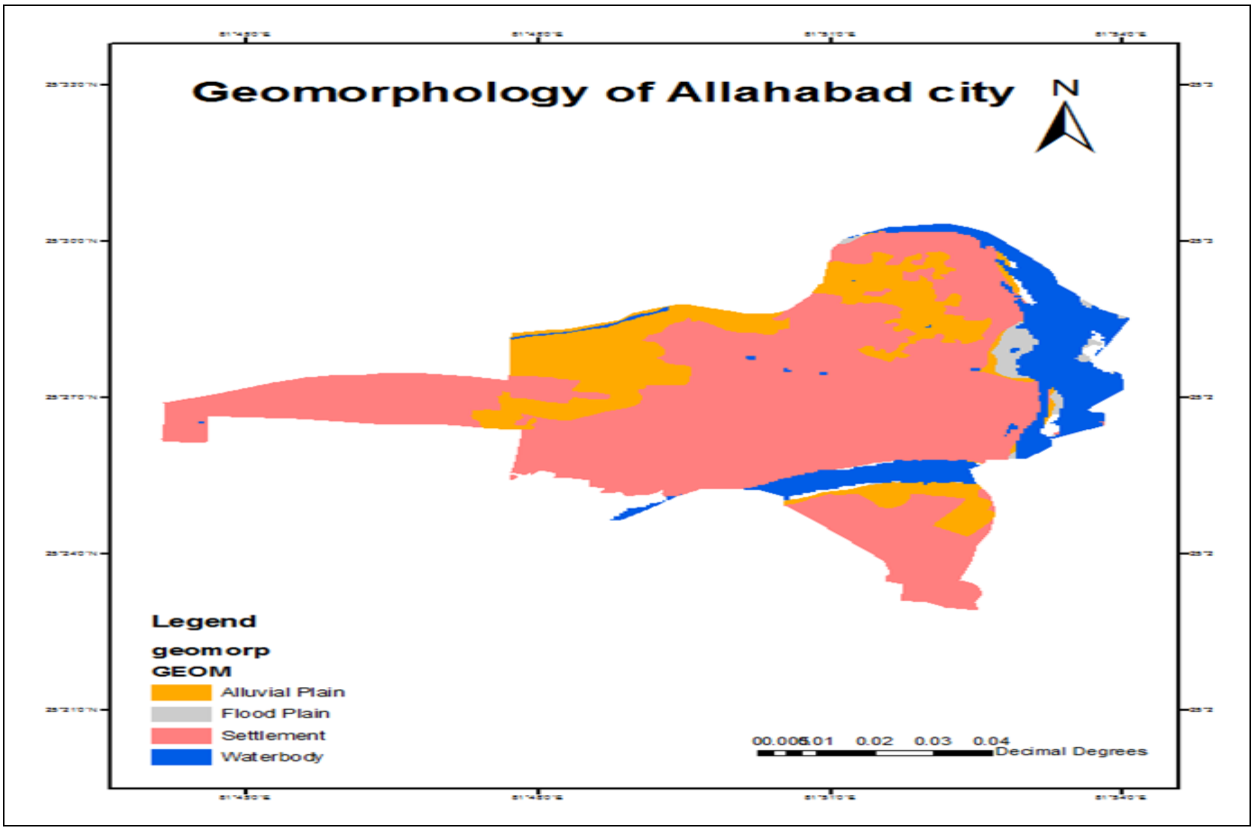

Fig. 4: Geomorphology of Allahabad city

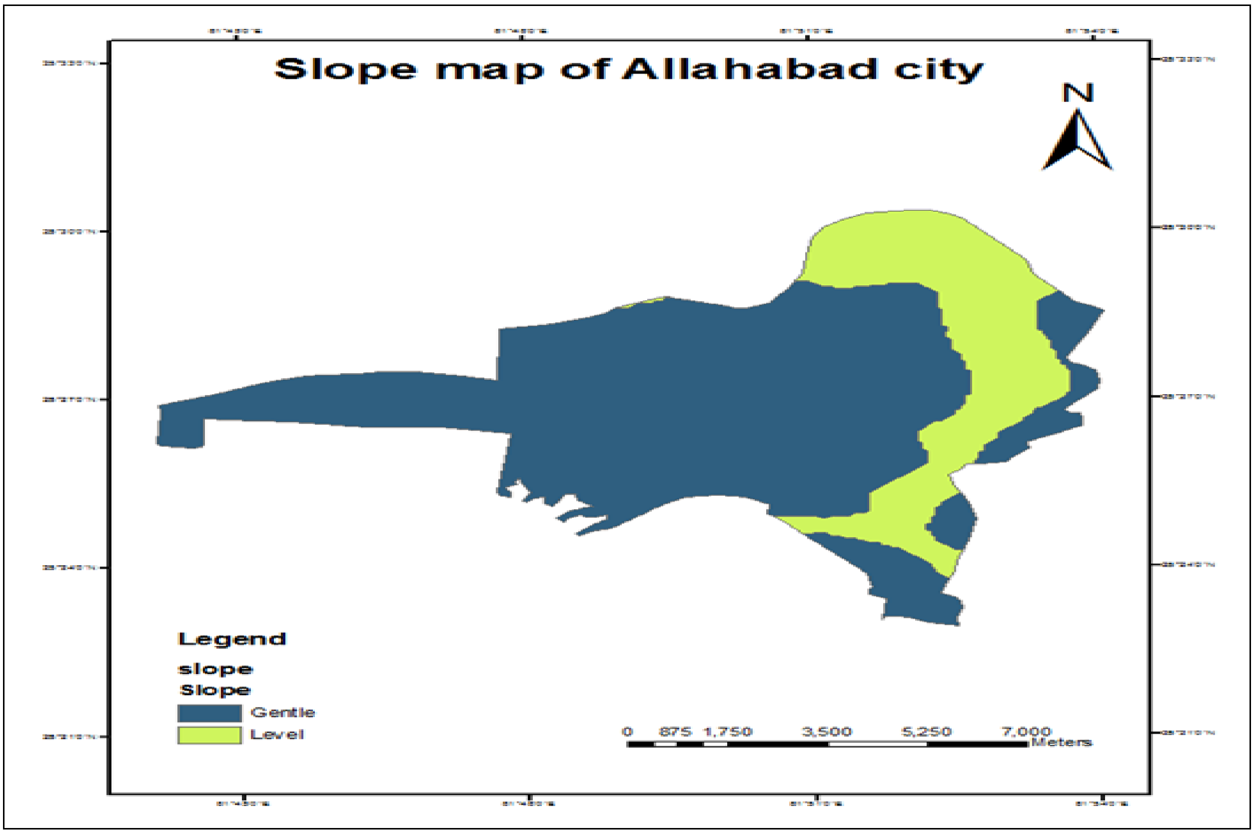

Fig. 5: Slope map of Allahabad city

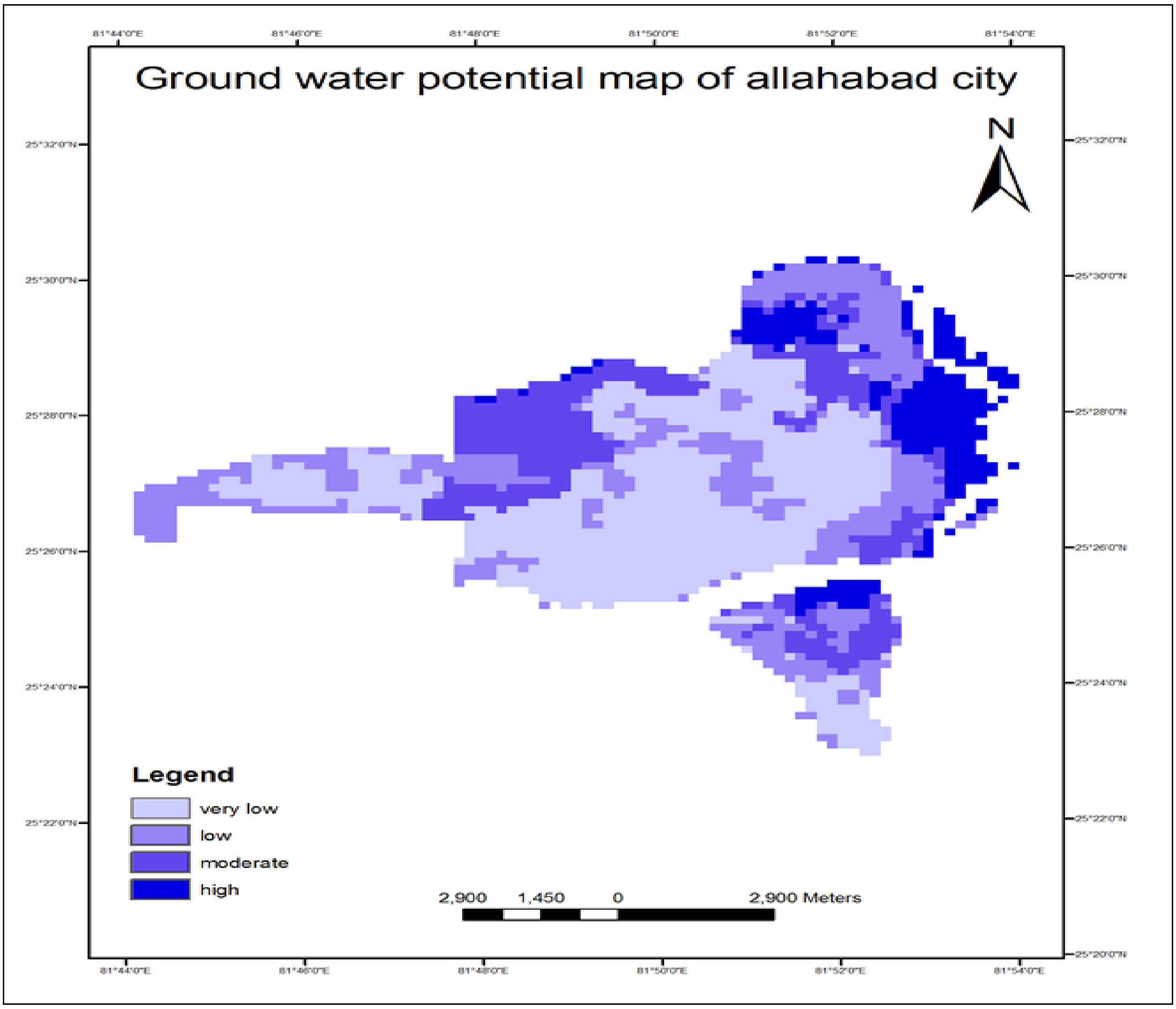

Fig. 6: Groundwater potential map of Allahabad city

Table 4. Rank for different parameters of potential groundwater zone

Parameters	Class	Rank	Weight	Score
Land use / Land cover	Built-up land (Urban/Rural)	1	25	25
	Current fallow land	3		75
	Cropland	4		100
	Gullied/Ravine	3		75
	Other wastelands	2		50
	Plantation / Orchards	4		100
	Scrubland	2		50
	Water bodies	5		125

Lithology	Clay with sand/Silt parting	3	20	60
	Clayey sand	2		40
	Gravel/Sandy, silt	3		60
	Settlement	1		20
	Waterbody	5		100
Geomorphology	Alluvial plain	4	30	120
	Flood plain	5		150
	Settlement	1		30
	Waterbody	5		150
Slope	Gentle	3	25	75
	Level	5		125

4. SUMMARY AND CONCLUSION

Satellite imageries and conventional data were used to prepare the thematic layers of lithology, slope, geomorphology and land use. The various thematic layers were assigned proper weightage through the weighted overlay technique and then integrated into the GIS environment to prepare the groundwater potential zone map of the study area. According to the groundwater potential zone map, Allahabad city has been categorized into four different zones, namely 'very low', 'low', 'moderate' and 'high, which cover 43.44 sq. km, 21.56 sq. km, 18.89 sq. km and 12.61 sq. km, respectively. The results of the present study can serve as guidelines for planning future artificial recharge projects in the study area in order to ensure sustainable groundwater utilization. This is an empirical method for the exploration of groundwater potential zones using remote sensing and GIS, and it succeeds in proposing potential groundwater sites/zones. This method can be widely applied to a vast area with rugged topography for the exploration of suitable sites. Delineating the potential groundwater zones in Allahabad city, India, using remote sensing, GIS and Weighted overlay techniques was found to be efficient to minimize time, labor and money, thereby enabling quick decision-making for sustainable water resource management.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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