ISSN: 0974-5823 Vol. 7 No. 2 February, 2022

International Journal of Mechanical Engineering

AHP and GIS Techniques for the Demarcation of Groundwater Potential Zones in a Part of Granitic Bundelkhand, India- A Case Study of District Jhansi

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Abstract-The district Jhansi covers a 5024 sqkm area under three tehsils and eight blocks of Bundelkhand massif on a survey of India toposheet 54K and 54O. The main source of irrigation is through groundwater and waterway. Drainage is part of the Yamuna River system. Ken- Betwa interlinking project and Rajghat canal gave relief up to some extent but still, poverty and migration are on large scale and during the premonsoon season. The area is covered with hard rock granite which makes it difficult to utilize on its optimum for agriculture. Premonsoon hits the area with water scarcity and the only option that seems that too is groundwater recharge points detection. The rivers Dhasan, Pahunj and Betwa give life in the area for all purposes. These are perennial but go without water during pre-monsoon. Lakheri and Sukhnai are the tributaries of the Dhasan and flow in the monsoon. The study is concise with pre-monsoon to demarcate the groundwater potential zones with the help of wide-ranging layers of the slope, geomorphology, geology, Landuse/land cover, soil, lineaments, and drainage using remote sensing knowledge and weighted overlay and weighted sum analysis function followed by weight-rank- score assign rule in GIS environment. The data is validated with an attribute table of groundwater levels for the past year. The groundwater potential zone map has been generated for future prospective and planning.

Keywords:*Jhansi, Bundelkhand, Ground Water Potential Mapping, Weighted Overlay analysis, Weight-Rank-score, Normalized weight*

INTRODUCTION

Water is exceptionally priceless and normally used save in nature on each surface and underground. Underground, water might be a powerful reserve since it changes transiently likewise as spatially. Groundwater is the main stock of water and is used for elective reasons. India has intense water issues, each on the domestic, availability, and agricultural requirements. Groundwater should be totally examined, and investigation of groundwater potential is an amazingly indispensable issue. it's vital to identify the zones where the groundwater can be accumulated. For this, the information of the region where the surface water is permeating down to join with the groundwater is fundamental. The regions where the accumulation of groundwater occurs are introduced as re-charge zones. Groundwater potential zones are the areas with water in spare quantity beneath submerged conditions and might be obtained efficiently. On the contrary, groundwater recharge zones are region with permeable rocks that allows surface water to go down and blends in with the groundwater. As Panda 1998 marked that the number of groundwater recharge zones might become groundwater likely zones. Human intervention can cause amendments in groundwater recharge by the change in land use/land cover and soil cover. The exploitation of groundwater or natural disaster of drought results in insufficient recharge or reduction of groundwater table can cause hydro-meteorological threats resembling drought that has become additional repeated in Bundelkhand (Bhagwat 2008).

Remote sensing and GIS comprise powerful tools that can be used for the fast valuation of natural reserves. The method is cost-effect and can be effectively used for groundwater exploration (Jha et al 2007). The present study is the integration of GIS tools and the Analytical Hierarchy Process (AHP) method using weighted overlay function after the interpretation and classification of satellite images for the final output of groundwater potential zones. AHP is an efficient method to handle complex information of the number of layers for the decision making which was introduced by Saaty in the year 1980. In the AHP method, a pairwise comparison matrix gets prepared, and analysis was done till the final output of normalized weight, weightage and score was not derived(Magesh, 2012).

Considering all the parameters here we examined the study area of district Jhansi on a part of Bundelkhand in India. The people are dependent upon groundwater in the study area for their basic needs. Because of the hard rock structure of granite and critical droughts of monsoon rainwater nonavailability of groundwater seems to be a promising solution.

STUDY AREA

The study area spans a district of 5024 sq. kilometres and its perimeter is near about 425 km. It covers the following toposheet numbers from 54K6, 7, 10, 11, 14, and 15 and 54 O on SOI toposheets. The realm range is delimited amid the meridian 78^0 10’ S and 79^0 25’ S-east longitudes and latitude 25^0 10’ N to 25 ^{0} 45’N on a georeferenced toposheet. It comprises four tehsils namely Jhansi, Moth, Garautha, and Mauranipur and eight blocks that is Baragaon, Chirgaon, Babina, Moth, Gursarai, Bamour, Ranipur and Bangra. Jhansi is the district headquarter and lies in the northern part of Bundelkhand massif. The slope direction follows the south to north direction. It is a part of the Yamuna watershed which makes the boundary of Bundelkhand in the north. The major part is covered with hard granitic rock which makes the area more difficult for groundwater availability. The identification of groundwater potential zones will make it easy to develop the area into groundwater recharge pouches followed by geology and other parameters. The climate falls under the sub-humid type with hot dry summer and cold dry winter. surplus water availability.

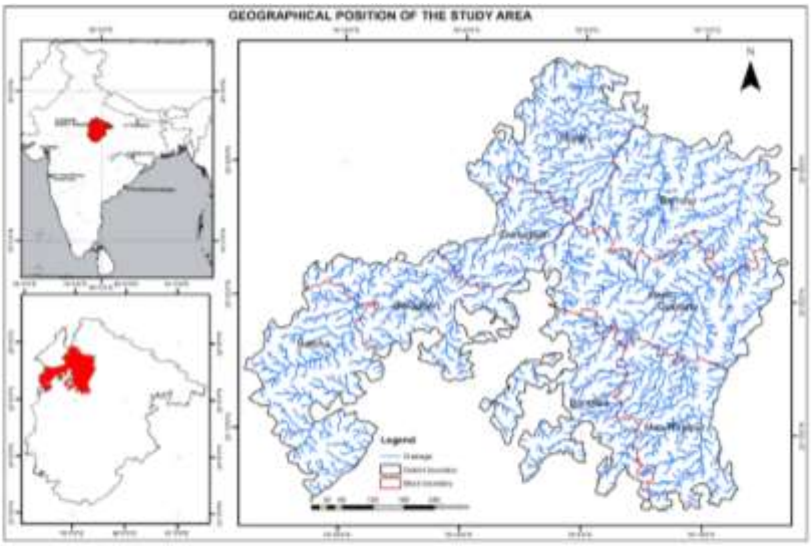
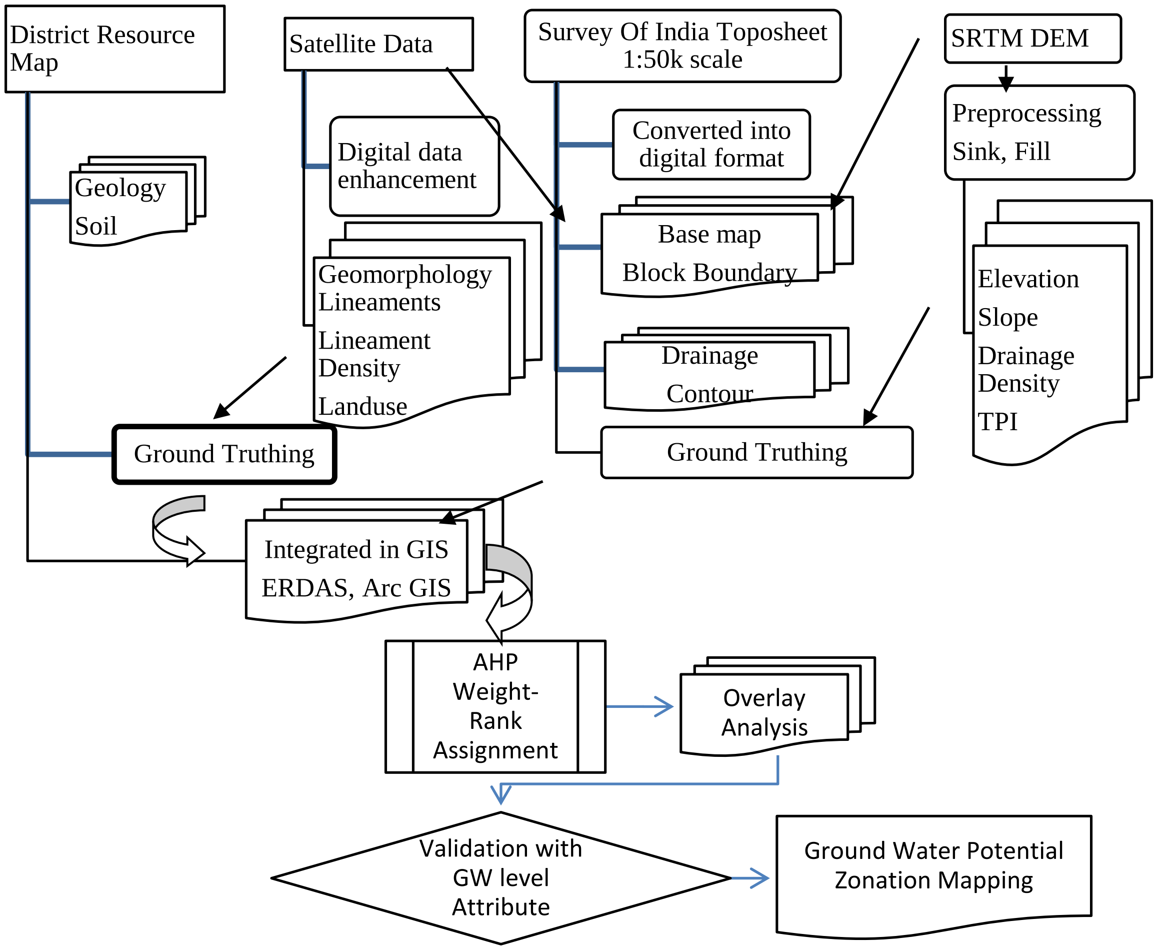


FIGURE 1: GEOGRAPHICAL POSITION AND DRAINAGE PATTERN MAP OF THE STUDY AREA

The average annual rainfall is 850.1 mm during the monsoon and is completely uncertain in every fourth consecutive year of drought. Bundelkhand comes under awater scarcity region and monsoon is the only option to accumulate the surplus water for charging to groundwater. The total number of 16 dug wells for groundwater monitoring of Jhansi was excavated by Central Ground Water Board. All over the study of Jhansi district shows maximum depth in groundwater in the year 2000 (16.24 mt.) for Premonsoon and minimum in the year 2004 for monsoon season which was 3.2 meters. The maximum average monthly temperature goes 32.59 ^{0}C and the average minimum temperature falls 19.21 C. More than 91% of rainfall takes place during the monsoon from June to September. There is a major drought evident almost every four years. Recharge of groundwater is possible only during monsoon

DATA USED AND METHODOLOGY



FLOW CHART 1 METHODOLOGY USED FOR THE GWPZ MAPPING

Geospatial tools were applied to get the output layer of groundwater potential zones using knowledge-based factor analysis of a total of seven thematic layers. All toposheets were converted into digital format and digital satellite data was purchased. All datasets were georeferenced and resampled. IRS images of March 20016 (pre-monsoon), Oct 20018 (post-monsoon) and Bhuvan images were used for the study. The satellite images have multispectral bands with LISS 3 (24m spatial resolution) sensor in visible & near infra-red spectrum. Various standard digital image pre-processing techniques have been applied to enhance and extract information from the visual interpretation using Arc GIS and ERDAS software. Preprocessing of images has been done to achieve the desired result and supervised classification was for the generation of LULC thematic layers. An elevation profile map was extracted from DEM and high points database generated through Arc GIS digitization tool from the SOI topographic sheet. Contour layer generated at 20 m interval. Surface drainage layer generated with the help of SOI toposheet and satellite image as well as for the cross verification. Stream Order, slope, drainage density, lineaments layers were generated from SRTM DEM 30m resolution. Hydrology tools were applied for the delineation of drainage layers viz, flow direction, flow accumulation, stream order, watershed. Geology based on Bhukosh classification and Geomorphology, and soil layers are generated, followed by groundwater report and Bhukosh database. To generate thematic layers such as Landuse/landcover (LULC), water body and drainage, geology, slope, geomorphology, lineament density, drainage density and soil (Figure) visual interpretation techniques were applied and followed the National Remote Sensing Centre India (NRSC) classification. Ultimately groundwater zonation mapping was finalized. The groundwater level table and graphs were generated for the previous year for validation purposes. Point locations of wells were digitized, and groundwater data were interpolated.

Multicriteria decision analysis using AHP and GIS techniques:

A well popular and accurate method of AHP was used and integrated into GIS for the groundwater delineation using a Pairwise comparison matrix in multicriteria decision analysis. This method is very accurate for multiple layer integration. Total 7 layers are considered as controlling factors of flow and storage of water in the area. The integration of these layers is weighted with expert opinions and groundwater occurrence. The highest weight is assigned to the layer assumed to be more influential and the lowest weight is assigned to the low impact layer for groundwater potential.

Saaty's scale of relative importance was the base for the weight assignment. All thematic layers were compared in a pairwise comparison matrix (Table 1). In table 4 subclassification of thematic layers to assign the Rank (r) followed by past research and natural brake system in GIS environment. Subclass assigned with rank (r) from 1 to 4 scale as per groundwater influence limit and finally score calculated for each subclass. To calculate the CR principal eigenvalue (λ) and consistency Index (CI) was derived from given formulae.

	Assigned weightage	**Soil**	**G.**	**LU/ LC**	**LD**	**DD**	**SL**	**GM.**	**Geometric Mean**	**Normalized weight**	**Weighted sum**	**Row Average**	**λ**
Soil	6	1.00	1.00	0.86	1.20	1.20	1.20	0.75	1.02	0.14	1.00	0.14	7.14
Geology	6	1.00	1.00	0.86	1.20	1.20	1.20	0.75	1.02	0.14	1.00	0.14	7.14
LU/LC	7	1.17	1.17	1.00	1.40	1.40	1.40	0.88	1.18	0.17	1.17	0.17	6.86
Lineaments Density	5	0.83	0.83	0.71	1.00	1.00	1.00	0.63	0.85	0.12	0.83	0.12	6.94
Drainage Density	5	0.83	0.83	0.71	1.00	1.00	1.00	0.63	0.85	0.12	0.83	0.12	6.94
Slope Degree	5	0.83	0.83	0.71	1.00	1.00	1.00	0.63	0.85	0.12	0.83	0.12	6.94
GM	8	1.33	1.33	1.14	1.60	1.60	1.60	1.00	1.35	0.19	1.33	0.19	7.02
Total									7.1059	1	7		49

TABLE1: PAIR-WISE COMPARISON MATRICES AND NORMALIZED WEIGHT INCLUDING THE RESULT OF CONSISTENCY RATIO

$$\lambda_{max} = 49 / 7 = 7$$

$$CI = \frac{\lambda\, max - n}{n - 1},$$

Where n=7 is the number of layers used in the matrix

$$CI = (7 - 7) / (7 - 1) = 0$$

Consistency Ratio derived with the help of Saaty's standard Random Consistency Index table

$$CR = CI / RCI$$

$$CR = 0/1 \cdot 32 = 0$$

Saaty has decided if the CR value is 0 it means it is a perfect consistency in the pairwise comparison matrix.

N	1	2	3	4	5	6	7	8	9	10	11	12
RCI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48

TABLE 2: SAATY'S RANDOM CONSISTENCY INDICES FOR DIFFERENT VALUES OF N

Less influential				Equally influential Equally important	More influential			
Extreme importance	Very strong importance	Strong importance	Moderate importance		Moderate importance	Strong importance	Very strong importance	Extreme importance
1/9	1/7	1/5	1/3	1	3	5	7	9

TABLE 3: CONSTANT RATING SCALE OF SAATY'S AHP (1990)

Sl. No.	Criteria	Weightage (w) = Normalized W.*100	Classes	Rank(r)	Score=Weightage*Rank
1	Geomorphology	19	Floodplain, Alluvial plain, Waterbody, Wash plain, Valley fill, Channel bar, Meanders, Point bar etc.	3	57
			Pedi plain,	2	38
			Hill, Ravines, Pediment, Inselberg, Drainage	1	19
2	Landuse/Landcover	17	Water body	4	68
			Agriculture	3	51
			Fallow land, Scrubland, Forest, Fresh sediments	2	34
			Wasteland, Barren land, Settlement, Rock surface	1	17
3	Lineaments Density	12	0-.36	1	12
			.36-.54	2	24
4	Soil	14	Mix Red Black Soil	3	42
			Red Desert Soil	2	28
5	Drainage Density	12	0-4.7	4	48
			4.77-8.2	3	36
			8.23-11.6	2	24
			11.69-15.16	1	12
6	Slope	12	0-2	4	48
			2-8	3	36
			8-15	2	24
			15-31	1	12
7	Geology	14	Fluvial deposit	4	56
			Bundelkhand Granite complex	1	14

TABLE 4: NORMALIZED WEIGHTAGE, ALLOCATED RANK AND TOTAL SCORE OF EACH LAYER FOR GROUNDWATER POTENTIAL

To generate the groundwater potential zone map of the study area all the seven layers were integrated using the weighted overlay analysis method in GIS environment using the equation:

$$GWPZ = Geomorphology(GM) + Geology(G) + Landuse(LU) + Soil(S) + Slope(SL) + Drainage\ Density + Lineament\ Density$$

Abbreviation used in the research paper

$$GWPZ = GMw * GMr + Gw * Gr + LUw * LUr + Sw * Sr + SLw * SLr + DDw * DDr + LDw * LDr$$

$$\mathrm{GWPZ} = \sum_{\mathrm{i}-1}^{\mathrm{n}} \mathrm{w_i} \times \mathrm{r_i}$$

The ‘w’ represents the weight of the theme and ‘r’ stands for a featuring rank for all feature layers.

PREPARATION OF THEMATIC MAPS

Knowledge of remote sensing interpretation during GIS integration with alternative ancillary data is beneficial to demarcate groundwater potential zones. wide-ranging layers of information like geomorphology, geology, lineaments, soil, land use/land cover, drainage map and slope maps were obtained from SOI topographical sheets. Elevation and slope data were generated from the shuttle radar topography mission (SRTM) digital elevation model (DEM). These themes were weighted overlaid in spatial analyst function to get a ground-water potential zonation (GWPZ) map of the study area. The final map of the study area shows ground-water prospects, viz., excellent, very good, good, moderate, poor which cannot be believed without modern tools.

Drainage Density

Drainage density is inversely related to the groundwater (Shao et al. 2020), higher drainage density means a well-developed drainage system or a higher runoff rate and caused by lower permeability of rocks or soil. Though it is considered as one of the parameters in groundwater potential mapping. The area belongs to the hot arid and semi-arid conditions on Bundelkhand granitic plateau. Jhansi comes under the drought prone Bundelkhand region so that every 4 years all the tributaries become dry. The drainage belongs to the river Yamuna watershed. The major and minor river network was delineated with the help of a survey of India toposheets on a scale of 1:50k and finalised with the help of satellite imagery and SRTM DEM to delineate the changes. Several res water in the offseason, but they won't meet the irrigation, drinking and livelihood requirements. The major rivers of the Jhansi district are Pahuj, Betwa and Dhasan. All three main rivers are perennial (Fig 2 C). Drainage density depends upon lithology and geology and provides the infiltration index. The total length of all the rivers in the area was divided by the study area and obtained the drainage density. The drainage map of the study area has four subclasses based on density (Fig 2 C) which shows from 4.7 to 15.16 per km.

$$DD = \sum_{i-1}^{n} \frac{RL}{A}$$

Where RL stands for a total length of entire streams in km in the study area and A represents the total study area

Geology

Geology controls groundwater occurrence through percolation and penetration limitation. That's why geology is a vital parameter in groundwater studies (Aju et al. 2021). The area was classified into two subclasses based on lithology and determined rank and calculated score after achieving weightage followed by a given method. The area is covered with Bundelkhand granite and Alluvium. Alluvium of quaternary has been identified in the northern part. The alluvium comprising of main silt, clay, pebble, kankar, fine to coarse sand accomplishes a maximum thickness of about 60 meters. The weathered zone comprises of Bundelkhand granite-gneissic complex of Archean age and residual soils spreads over the surface all over largely forms the aquifer system in a coherent part of the district. Outcrops, hillocks, and linear quartz reefs are comprised of impervious rock which reflects in the aquifer system. groundwater occurs in fine intersections and fractures of the weathered rock material in the granitic terrain. (Fig 2B).

Soil

The porosity of the soil is responsible for the water percolation and transport into the ground. Ferrosol has poor and lithosols have good groundwater potential (Ifediegwu et al. 2019). Broadly Jhansi has been classified into two categories that are mixed red and black soil and red desert soil. A large area has low infiltration properties and countable places are having medium and high infiltration rates in the district which makes it vulnerable to drought. Data analysis shows very thin layers of weathered rock with fine sand and clay /sand in the whole Jhansi district. The term basin of Jhansi has obtained a good fertile alluvial soil because of the erosion process in the region (Fig 2A).

Lineament Density

Lineaments are generally referred to as linear features on the surface in the analysis of remote sensing. The study area has very limited lineament coverage and has been classified into four categories good, moderate, low, and very low between .36 to .54 sqkm. Geomorphology and geology feature controls most for the lineament detection. In Jhansi geomorphology and geology both regulate the direction and flow of drainage. Erosional processes work on these lineaments and rivers intersected lineaments in very few places which show that the origins of these hills are very new in the Bundelkhand. The feature map was prepared using satellite images and geological maps. Features are the manifestation of linear features that can play an important role in identifying suitable sites, (Leary et al. 1976) has defined those lineaments as simple and complex linear features such as faults, fractures, cleavages, and various surfaces of discontinuity, that are settled in a straight line or a minor curve, as detected by remote sensing. Many non-geological structures, such as roads, railway lines and channels may cause errors in the analysis of lineaments. Therefore, geologic maps and on-site investigations are compulsory for the analysis. Linear features may be used to conclude groundwater movement, direction, and storage. Lattman and Parizek (1964) were the first to implement a lineaments map to identify groundwater. Thereafter, scientists and researchers started to apply this method in complicated geological regions (Solomon and Quiel2006). Lineaments are necessary for groundwater recharge in hard rock terrains. Lineament-length density (Ld) is the total length of all depicted lineaments divided by the entire area into account (Greenbaun 1985, Chowdary et al. 2008).

$$Ld = \sum_{i-1}^{n} \frac{L_i}{A}$$

Low lineament density signifies low infiltration and high lineament density indicated high infiltration in the area. All are denudational structural hills have residual dykes and ridges which doesn't seem like a barrier in groundwater recharge.

Geomorphology

Geological formations and structure are controlling factors in Geomorphological features. The geomorphology layer has the highest weightage with a normalized weight of .190 in the study area. Bundelkhand region geomorphology has been classified into two broad regions viz., the hill ranges and the intermountain fertile valleys. The hill ranges are made up of hard compact and resistant granite masses intruded by quartz reef. The thickness of alluvial fill varies from 10-16 meters towards the south. As per groundwater availability, the study area has been classified into major geomorphic classes. The broad area has been classified into the water body, river, wash plain, pediplain, pediment, linear ridges, alluvium, and ravine or badland landforms. The general geomorphology of the Jhansi is undulating with eroded hills of hard rocks. After the study of Toposheet(s) and satellite image, it is depicted Jhansi comes under the northern part of the Bundelkhand which is a highly upland plateau and towards the south, the region is undulating with small hillocks which are denudation part of Vindhyan range. Mainly Jhansi can be classified into two types denudational and fluvial geomorphology and water bodies with limited structural geomorphic features.

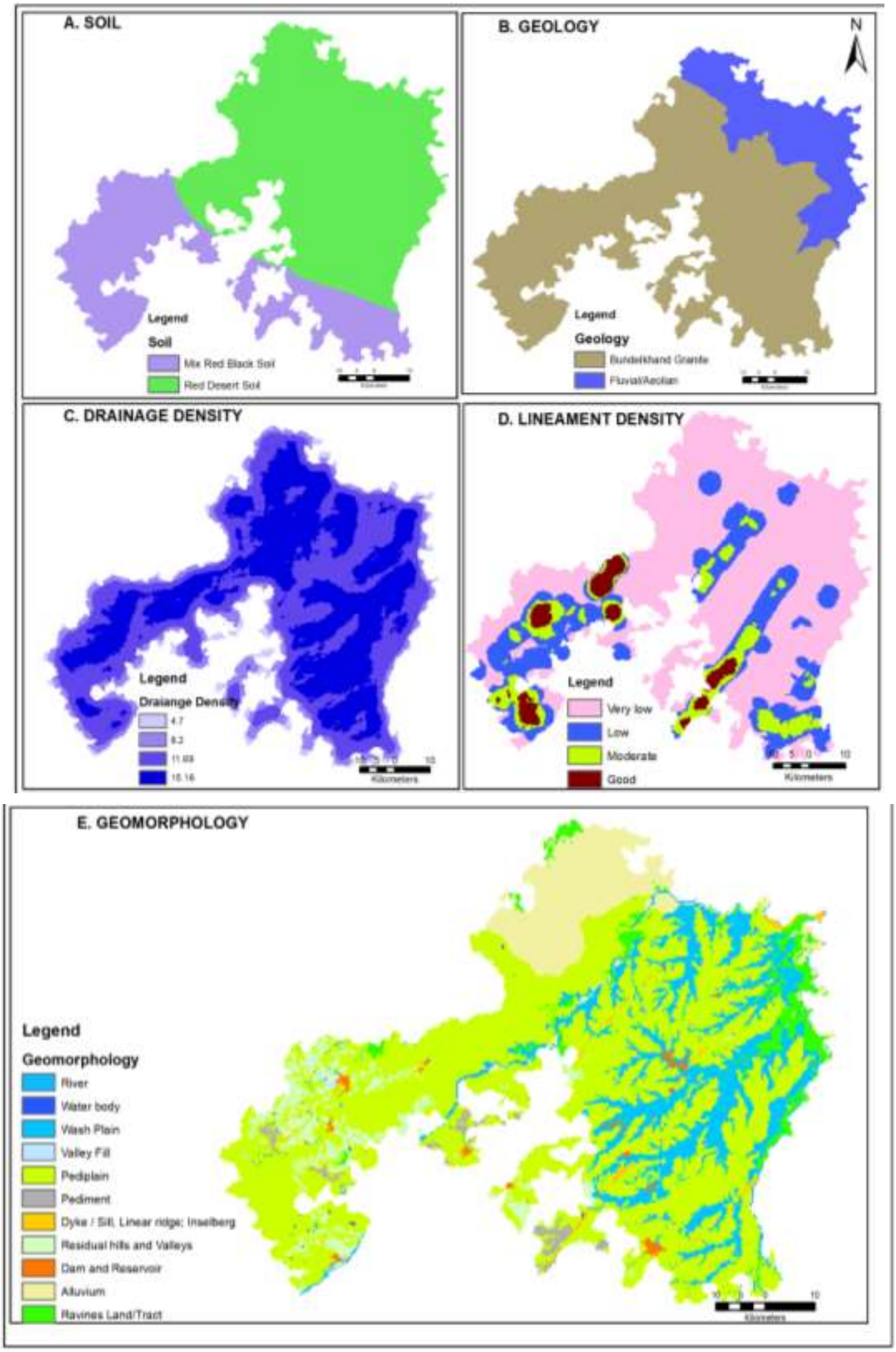


FIGURE 2: THEMATIC LAYERS, A. SOIL, B. GEOLOGY, C. DRAINAGE DENSITY, D. LINEAMENT DENSITY, E. GEOMORPHOLOGY

LANDUSE/LANDCOVER

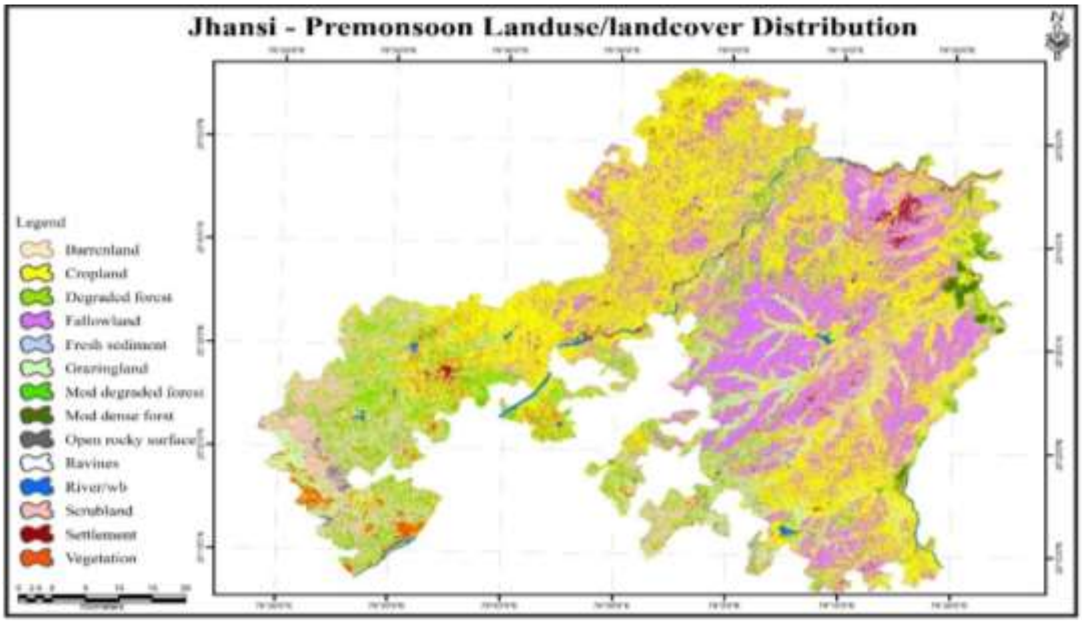
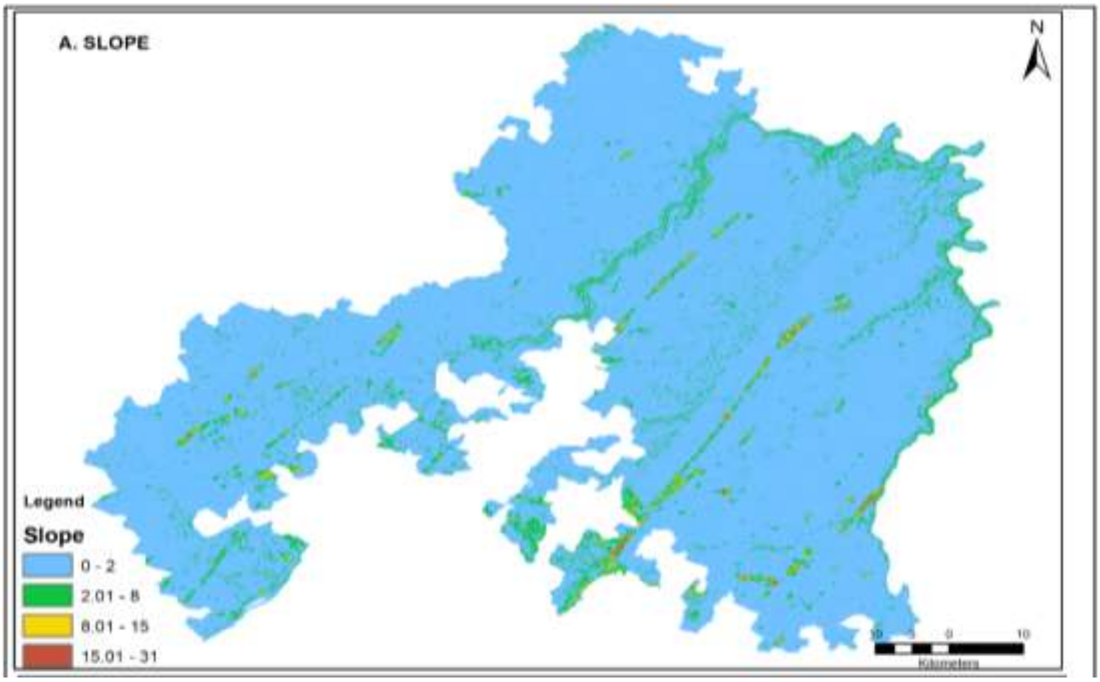


FIGURE 3: JHANSI PRE-MONSOON LULC

Pre-monsoon landcover-land use (LULC) has shown in figure 3 in the thematic layer. LULC have the second-highest weightage with 17 in the study and is the most important feature among all the layers. LULC is classified into fourteen subclasses based on groundwater potential. Highest Rank assigned to water body followed by agriculture and fallow land, forest, scrub, and grazing land and the lowest given to construction, barren land, query and ridges due to less permeable structure for groundwater with poor potentiality.

SLOPE

The slope is an important factor for groundwater delineation. Jhansi district shows a general northeasterly slope direction. The southern plateau shows a 200m height range in general above mean sea level and about 345 m. above mean sea level on the south. Viz (a) southern Bundelkhand pediplain, province and (b) northern highly eroding composite plain province. A slope map with the help of a survey of India Toposheet(s) and SRTM data was generated using spatial analyst tools. The degree of slope in the area varies from 0 to 31 degrees. Based on the slope, the study area can be divided into six slope subclasses. The area with a 0–2-degree slope falls under the 'good water potential' category due to the nearly 'Flat' terrain and relatively high infiltration rate. The maximum area comes under this category. The area with a 2–5-degree slope is considered good for groundwater storage due to 'gently undulating' topography with some runoff. Mostly gentle undulating slope found along the river and in patches. Apart from this, a small portion comes under the 'Undulating' and 'Rolling' slope category which covers 5–15-degree slope and high runoff and low infiltration. A small portion of the whole area comes under the moderately steep and steep category (15-31 degrees).



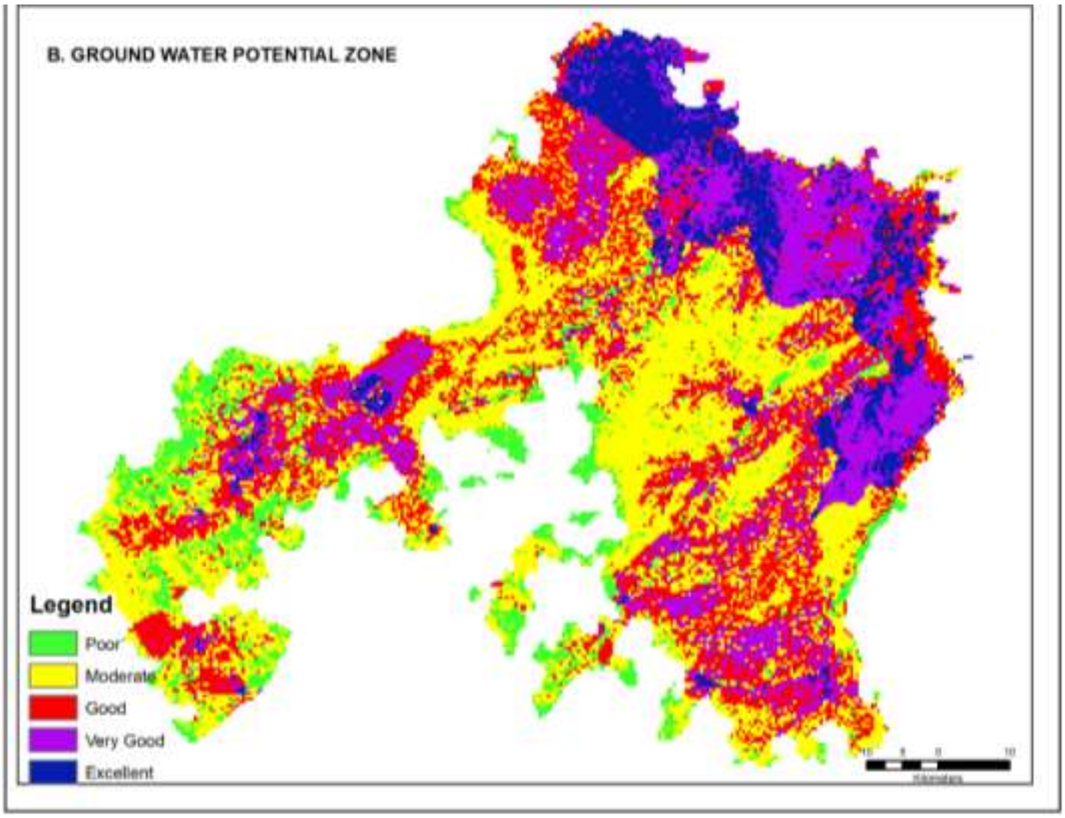


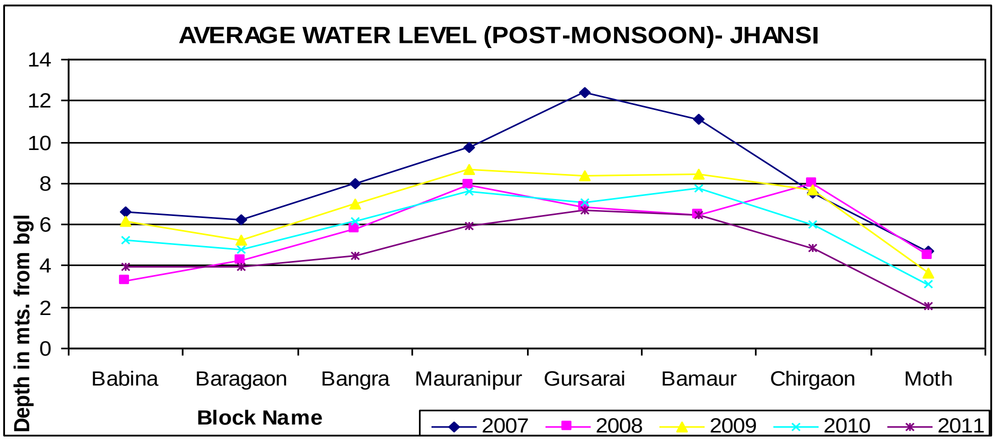
FIGURE 4: THEMATIC LAYERS A. SLOPE, B. GROUNDWATER POTENTIAL ZONES MAP

VALIDATION USING GROUNDWATER LEVEL ATTRIBUTE

There are 89 government tube wells through which a 38 sqkm area is irrigated. Irrigation by private tube wells is 86.78 sqkm. Hence 54 area is irrigated by groundwater. The net sown area is 3267.67 sqkm and the net irrigated area is 1960.78 sqkm. Total 1236 km canal serves 75235 ha area for irrigation. Water level data for the past years has been used for the validation which shows that the area comes under a safe zone (graph 2). The classified groundwater potential map is verified with a water level table and shows the result of two major categories that are good and moderate and minor locations located in poor groundwater potential. Jhansi have medium water availability and most of the water is acquired during the monsoon.

CONCLUSION

Delineation of GWPZ integrated with GIS using weighted overlay function and AHP multicriteria pairwise comparison index proved to be promising and efficient with cost-effective and less time taking method. All the primary and secondary datasets are useful for efficient thematic layers creation and analysis. The prior knowledge and expert reviews are milestones in the study and multicriteria analysis. The district has been classified into five classes based on groundwater occurrence for potential zones mapping viz: excellent, very good, good, moderate, poor. The reservoir location can be decided with the help of GWPZ mapping as a future project by various departments and this method can be widely functional for the exploration.



GRAPH 2: AVERAGE WATER LEVEL DEPTH

ACKNOWLEDGEMENT

The study was sponsored by the University Grant commission as a fellowship grant. The authors are very grateful for lab support to the Bundelkhand University, Department of Geology. We would like to thank the Groundwater board Jhansi and NIC Jhansi for data support.

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