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# Evaluation of Groundwater Potential Zones and Recharge Potentiality in Hanumana Block, Rewa District, Madhya Pradesh, India Using Multi-Criteria Decision Analysis

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## Abstract

The area chosen for the research is a hard rock terrain of Central India. Despites having sufficient rainfall, the area faces water crisis for drinking and irrigation during the summer months. To cope up with this problem, the area has been undertaken for the study. Groundwater potential zones (GWPZ) are delineated and interpreted according to appropriate assigned weights. The zones are characterized into high (35.04 %), moderate (51.60 %) and low (13.36 %) groundwater potential zones. The findings have also been validated by choosing selected wells yield in the field randomly. The groundwater recharge potentiality of the area is calculated using relevant parameters which indicates that 20% of the total surface water collected through rain fall recharges the groundwater. In the study, measures have been suggested to increase recharge potentiality and management of water resources. It is concluded that RS and GIS are very useful and powerful techniques to evaluate the groundwater resources as well as recharge potentiality.

*Keywords:* Groundwater Potential Zones, Recharge Potentiality, Remote Sensing, GIS, Overlay Analysis, Central India

## Introduction

The groundwater is most valuable resource which fulfils substantial part of domestic and agricultural needs of the country. Its indiscriminate use is causing precipitous fall in the groundwater levels, in major parts of our country. Due to exponential population growth, urbanization, industrialization and erratic behaviour of monsoon, India is facing serious challenges in groundwater resource management. The groundwater quantity and quality of the area are adversely affected due to various anthropogenic activities (Tiwari *et al.,* 2010; Tiwari and Mishra, 2011). Recent study (Bhanja and Mukherjee, 2019) shows acute shortage of water in different parts of the country due to various reasons. Judicious use of this vital resource is urgently needed in areas dominated by hard rocks having insignificant porosity. The key factor for a sustainable development of groundwater resources is its scientific management, especially in the context of the exponential growth in the population of the country and its increasing water needs (Singhal, 2017). Due to insufficient surface water availability, groundwater is extensively used for various purposes (Tiwari 2017; Tiwari and Kushwaha, 2018). Groundwater overexploitation has led to falling groundwater levels, drying of wells, acute paucity of drinking water, drying of wetlands and base flows and declines of well irrigated agriculture production (Das, 2020). Depleted monsoon rains and wanton use of groundwater have made planners to think in the direction of proper management of this vital, life sustainable natural resource.

The utility of RS and GIS in different aspects of groundwater studies have been discussed by various researchers (Gupta and Srivastava, 2010; Narendra *et al.*, 2013; Ahirwar *et al.,* 2020; Tiwari and Kushwaha, 2020). The RS and GIS studies give comparatively more precise results, less time taking as well as cost effective; hence very useful in natural resource studies With the help of RS and GIS, various weightage of different parameters are decided which ultimately determines the different zones of groundwater recharge potential (Javed and Wani, 2009; Rao and Jugran, 2010; Sunganthi *et al.,* 2013, Ghimire *et al.,* 2019; Roy *et al.,* 2019, Kadam, 2020). From last one decade, the geospatial techniques are used in water resources studies by various agencies as well as geoscientists. Earlier workers have carried out groundwater resource potential studies using RS and GIS

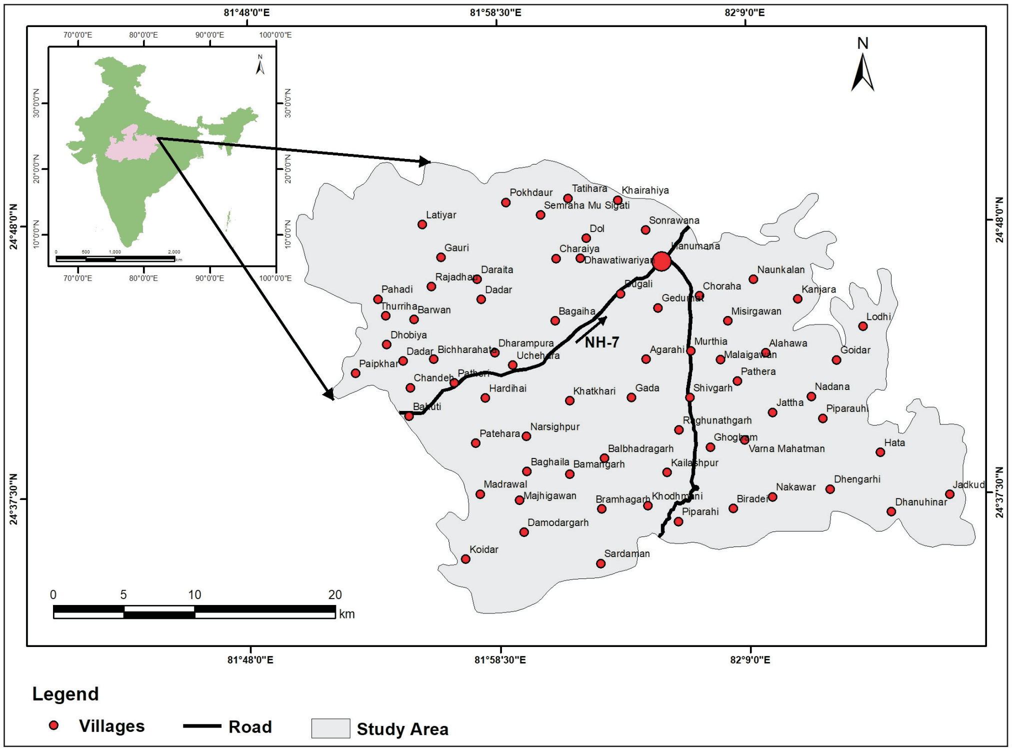

**Fig.1.** Location map of the study area

techniques in different parts of the world (Jothiprakash *et al.,* 2003; Jha *et al.*, 2007; Jasrotia *et al.*, 2009; Manap *et al.*, 2011; Chaudhary and Kumar, 2018, Serele *et al.*, 2020). The occurrence and movements of groundwater is controlled by various geological and geomorphological factors (Nag and Kundu, 2018). Adham *et al.* (2010) have been discussed the recharge potentiality of Bangladesh using geospatial technique. Some of the researchers have studies the delineation of GWPZ in Central India using RS and GIS techniques. Roy *et al.* (2019) have carried out groundwater potential zonation in Sonepur district, Odisha. Ahirwar *et al.* (2020) have carried out similar study in upper Betwa watershed, Madhya Pradesh. Tiwari and Kushwaha (2020) have carried out groundwater potential zonation studies using RS and GIS in Sidhi area, Madhya Pradesh. The objective of the present study is to (i) identification of groundwater potential zone; and (ii) estimation of recharge potentiality of the lithounits in the study area. This study would be very helpful to mitigate the problem of water scarcity as well as better planning in watershed management.

## Study Area

The Hanumana Watershed is located in the Rewa district of Madhya Pradesh and falls in latitude 24°33'59.34" N to 24°50'58.473" N and longitude 81°50'3.479" E to 82°18'5.269" E covering a total geographical area of 948.73 km$^2$ (Fig. 1). It lies in the part of the Survey of India Toposheets 63H/14, 63H/13, 63L/2 and 63L/6 at 1:50,000 scales. The Gorma River flows in the northern part from southeast to northwest and meets the major river Belan, a tributary of Tons in the study area. The road network, village information etc. are delineated from toposheets and satellite imagery data and it is part of the Gorma River Catchment. It mainly comprises rocks of the Vindhyan Supergroup. In general, the area constitutes a plateau having restricted plains along the course of rivers. The annual rainfall of Hanumana watershed is about 975 mm in which about 89% annual rainfall is received during monsoon season. Rainfall is the most important recharge sources of groundwater in the area whereas other sources of recharge are ponds, check dams, canals etc.

## Methodology

All relevant thematic layers such as geology, lineament density, drainage density, geomorphology, soil, slope and land use/land cover (LULC) are processed and overlaid to generate the groundwater potential map. Several methods are being widely used for the multi-criteria decision analysis (MCDA). Among various methods, the Analytic Hierarchy Process (AHP) technique has been widely applied for MCDA, where a hierarchical structure is maintained for decision-making (Saaty, 1980). In this study, remote sensing, GIS and AHP are integrated to delineate the Groundwater Potential Zone (GWPZ) of the widely accepted score index based method for groundwater potential zone is used for the preparation of GWPZ map. The multiplication of ranks and weight of each thematic layer is carried out to calculate Groundwater

Potential Index (GWPI) (Malczewski, 1999) and which is expressed as below:

GWPI = ∑ {(Geomorphology (Weight*Rank) + Lineament density (Weight*Rank) + Geology (Weight*Rank) + Slope (Weight*Rank) + Soil type (Weight*Rank) +Land Use/Land Cover (Weight*Rank) + Drainage density (Weight*Rank)}

The Survey of India (SOI) Toposheets, Aster DEM 30m spatial resolution and the Landsat 8 OLI (Operational Land Imager) image data having 30 m multispectral and 15m panchromatic spatial resolution (17th November, 2019) have been used for the present study.

## Results and Discussion

Groundwater occurrences depend on relevant aspects/ parameters like geology, lineament density, soil type, drainage density, geomorphology, slope and LULC *etc*. These aspects/ thematic layers have been delineated and discussed below:

### *Geomorphology*

In the study area, the main delineated geomorphic features are Pediplain, Plateau, Escarpment and water bodies. The recognition of geomorphologic features is essential element and relevant factor for GWPZ mapping. The surface water bodies play an essential role as good recharge zones and thus enhancing the potentiality of groundwater. The more existing recharge sources and their surrounding areas are reflected as good potential areas for development and exploration of groundwater. The geomorphological map can be easily generated with the help of remote sensing even in diverse and inaccessible terrain (Maitra, 1999). Geomorphological map is prepared from Landsat 8 imagery data (17th November, 2019) based on visual interpretation (Fig. 2).

### *Lineament Density*

A lineament, i.e. linear feature, is associated with a drainage course, ridge topography, linear vegetation pattern, etc. Geologic lineament mapping is considered as a very important key for the groundwater studies (Tiwari and Kushwaha, 2018). The significant amount of lineaments indicates high groundwater potential area because it facilitates the groundwater movement. Lineaments appear in presence of alignment of vegetation, presence of moisture, straight stream/river courses etc., as a linear imprint on the imagery data. It controls groundwater occurrences and movement. Lineaments have been delineated from Landsat 8 imagery data (17th November, 2019) and prepared the lineament density map and categories as: 0-0.19, 0.19-0.39, 0.39-0.66, 0.66-1.02 and 1.02-1.94 (Fig. 3).

### *Geology*

The area is a part of the Pre-Cambrian sedimentary groundwater province in Central India and comprises Kaimur Sandstone, Rewa Shale and Rewa Sandstone of the Vindhyan Supergroup (Fig. 4). Kaimur Sandstone is quartzitic in nature, medium to fine grained, varying in colour from yellowish red to white, it is mostly horizontal. Rewa Shale is grey, brown and chocolaty in colour. It is thinly bedded and shows mud cracks and other sedimentary structures. Most of the area is covered by Rewa sandstone. It is reddish to purple in colour as well as hard and compact in nature. Ripple marks and cross bedding are very common in this formation.

In the absence of primary porosity, the groundwater recharge from the monsoon rains is mostly through secondary opening such as joints, fractures, enlarged bedding planes *etc.* (Tiwari, 2017).The geology of the area has been identified and demarcated from Landsat 8 OLI imagery incorporated with District resource map (DRM).

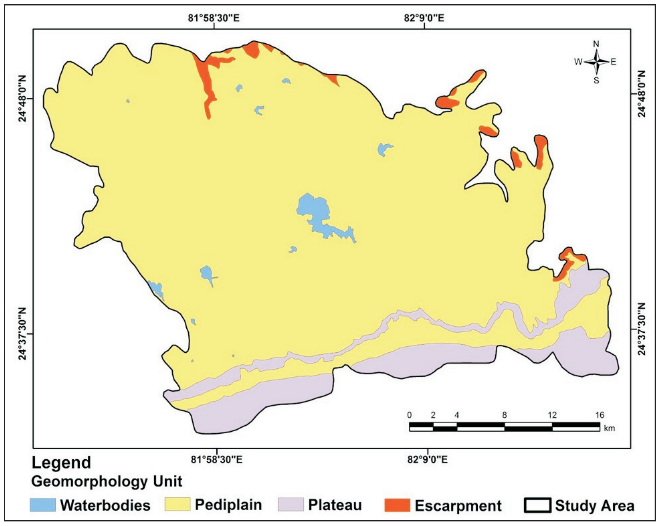

**Fig.2.** Geomorphology map of the study area

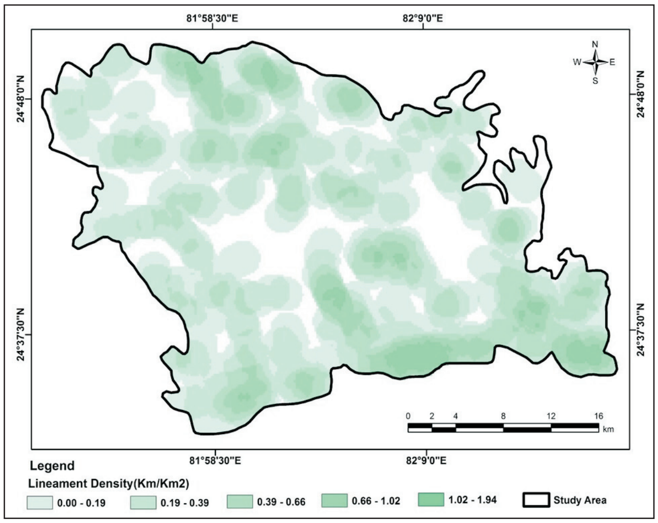

**Fig.3.** Lineament density map of the study area

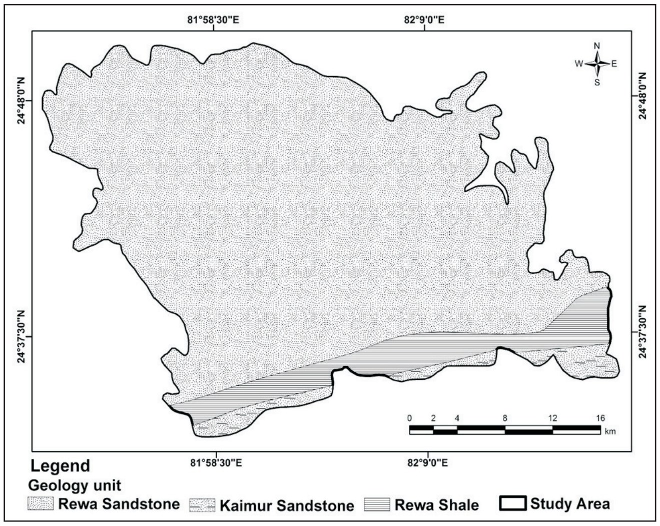

**Fig.4.** Geology map of the study area

### *Slope*

The Slope map extracted from Digital Elevation Model and which provides essential and significant information of groundwater for controlling the infiltration into the subsurface in potential zone mapping. The slope of area influences the extent of runoff and intensity contribution to the stream flow and to the groundwater reservoir. It also controls the duration of overland flow, infiltration depth to the water table, pattern of land use and land cover, erosion intensity and feasibility of the construction for storage and artificial recharge (Reddy *et al.,* 2011). Higher amount of the slope will promote more run off which will reduce the infiltration and ultimately will reduce the groundwater potential. Digital elevation model is extensively used and the slope map prepared from Aster Dem using GIS techniques, analysed as degree-based for hydrogeological analysis. The slope map have been categorised as: 0-1.63°, 1.63-7.18°, 7.18-17.95°, 17.95-43.42° and 43.42-70.84° (Fig. 5).

### *Soil*

Satellite remote sensing data has emerged significant tool in soil resource survey and generation of soil information (Velmurgan and Guillen, 2009). The soil has developed mainly from the weathering of sandstones and shale of Vindhyan Supergroup in study area. Major part of study area is covered with sandy loam, red and yellow mixed soil and red soil. A soil map is generated on the basis of visual interpretation of Landsat 8 imagery data (17th November, 2019) (Fig. 6).

### *Land Use and Land Cover*

Spatial distribution of LULC classes assists to decipher the possible groundwater potentiality and groundwater recharge in the study area. The change in LULC strongly affects the groundwater condition in a particular area (Shah and Lone, 2019). The various land use / land cover classes are delineated from landsat 8 imagery data an interpreted from different spectral signatures. The LULC class helps to quantify the water resources which are interpretable from imagery data using the geospatial software. Classification of LULC delineated and interpreted based on their characteristics to hold and to infiltrate water into the ground. LULC map is prepared using unsupervised image classification of Landsat 8 imagery data (17th November, 2019) based on visual interpretation for the study area (Fig.7). In the study area, Major land use/ land cover classes are covered by agriculture land/plantation, scrub forest, deciduous forest and built-up.

### *Drainage Density*

The drainage density is defined as the total stream length per unit area in a given basin. The value of drainage density indicates coarse density due to high resistance rocks, dense vegetation, little permeable subsurface formation in the basin

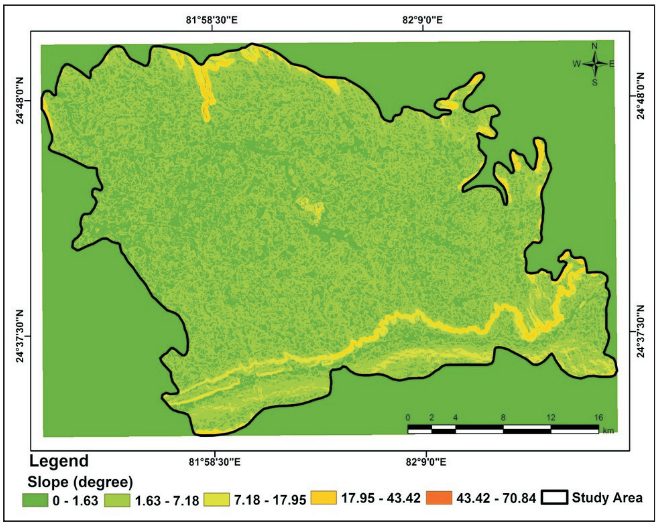

**Fig.5.** Slope map of the study area

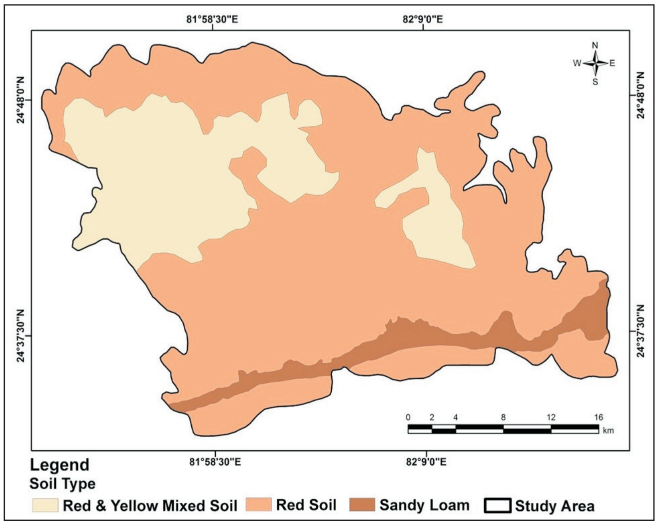

**Fig.6.** Soil map of the study area

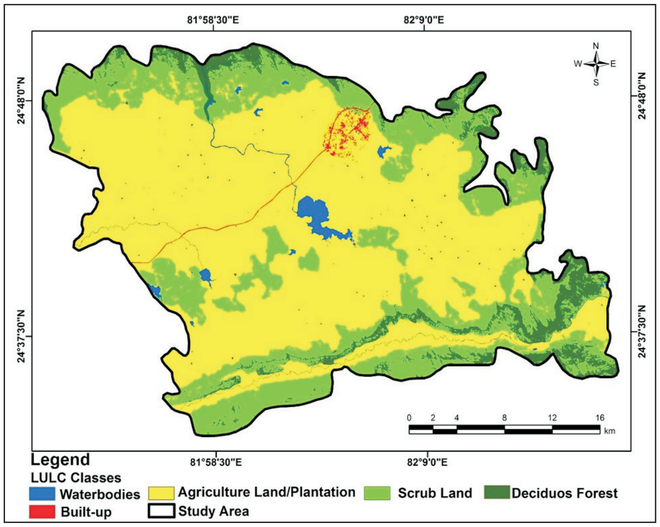

**Fig.7.** LULC map of the study area

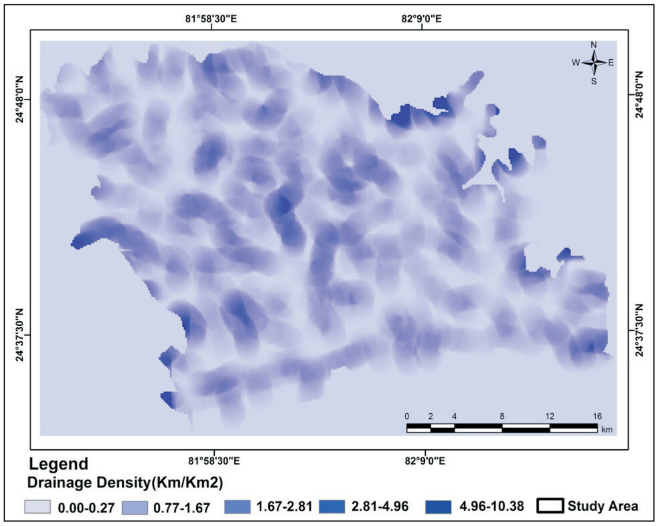

**Fig.8.** Drainage density map of the study area

(Smith, 1950). An Area with higher runoff and low infiltration suggests higher drainage density whereas lower runoff and high infiltration indicates low drainage density (Prasad *et al.,* 2008). Drainage pattern of study area indicates the characteristics of surface and subsurface geological formations. Drainage pattern supports to understand the runoff and groundwater infiltration characteristics. In the drainage density map, the values have been delineated depending on the density of the drainage pattern (Fig. 8). The study regions it is classified as 0-0.77, 0.77-1.67, 1.67-2.81, 2.81-4.96 and 4.96-10.38 km/km$^2$.

### *Evaluation of Groundwater Potential Zones*

In this study, all relevant thematic layers are assigned an appropriate rank and weight depending on its influence on groundwater occurrence as well as recharge potentiality. The weightage of thematic layer, therefore, signifies the relative importance for developing groundwater resources. Based on these groundwater parameters, the GWPZ were identified, evaluated and mapped. The study area is categorised as high, moderate and low GWPZ (Fig. 9). The weights have been assigned through pair wise comparisons matrix based on Analytic Hierarchy Process (AHP) (Table 1) and the weightage and rank of relevant thematic layers and their calculated score values of ground water potential zonation are presented (Table 2).

The entire study area falls in the Kaimur and Rewa Group of rocks of the Vindhyan Supergroup. The major rock types in study area are sandstone and shale. The sandstones are assigned highest weightage due to the availability of significant secondary porosity and their weathered, jointed and fractured nature. Likewise for geomorphic units, water bodies and pediplain are assigned high value and escarpment is assigned the lowest weightage. The lineament density (km$^2$) values (1.94 to 0.66) are assigned the highest weightage on account of the highest number of lineament per unit area that act as conduits for groundwater flow. The ranges between 0.66-0.39 are assigned moderate weightage and < 0.39 are assigned the lowest weight. The slope (0-7.18°) was assigned the highest weightage on account of lower slope and lower run off whereas the 7.18-17.95° slope was assigned moderate weightage and >17.95° slope was assigned he lowest weightage. The drainage density value of 0-1.67 are assigned the highest weightage on account of the lower number of drainages per unit area, range 1.67-4.96 was assigned moderate weight and > 4.96 was assigned the lowest weightage. The high potential zone of groundwater occurred in patches mostly in western part of the study area.

### *Validation*

For the validation of the findings of the study, 30 dug wells have been selected randomly in different locations from

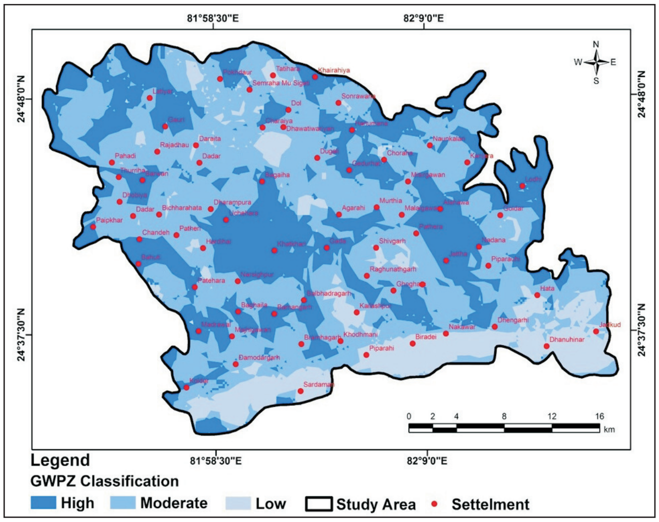

**Fig.9.** Ground water potential zone classification of the study area

**Table 1:** Normalized Pair wise comparison matrix developed for AHP based groundwater potential zones

| Factors | Geomorphology | LD | Geology | Slope | Soil | LULC | DD | Weightage |
|---|---|---|---|---|---|---|---|---|
| Geomorphology | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0.38 |
| Lineament Density | 7/2 | 6/2 | 5//2 | 4/2 | 3/2 | 2/2 | 1/2 | 0.19 |
| Geology | 7/3 | 6/3 | 5/3 | 4/3 | 3/3 | 2/3 | 1/3 | 0.12 |
| Slope | 7/4 | 6/4 | 5/4 | 4/4 | 3/4 | 2/4 | 1/4 | 0.10 |
| Soil | 7/5 | 6/5 | 5/5 | 4/5 | 3/5 | 2/5 | 1/5 | 0.08 |
| LULC | 7/6 | 6/6 | 5/6 | 4/6 | 3/6 | 2/6 | 1/6 | 0.066 |
| Drainage Density | 7/7 | 6/7 | 5/7 | 4/7 | 3/7 | 2/7 | 1/7 | 0.064 |

the study area for the determination of the yield. It is found that the yield varies from 4500 -5000 litre per hour (lph) in High potential zone, 2000-3000 lph in moderate potential zone whereas 600-1200 lph in low potential zone (Table 3). Thus, it can be concluded that the field observations corroborate the findings of the study.

### *Recharge Potentiality*

A quantitative estimation of recharge water volume (W) to subsurface media in recharge potential of study area is calculated as per the formula:

$$W = P \times \text{recharge ratio} \times \text{Area} (\%)$$

Where P = precipitated volume

$P = 1386.88 \times 10^6\ m^3$ /year (Calculation of Recharge Ratio and Area considered, be mentioned clearly, as follows:

$\text{Recharge Ratio} = 0.475 \times 0 + 0.325 \times 0.35 + 0.15 \times 0.52 + 0.075 \times 0.13 + 0.02 \times 0$

P was calculated as per rainfall recharge method suggested by GWREC (1997).

$W = 1386.88 \times 10^6 (0.475 \times 0 + 0.325 \times 0.35 + 0.15 \times 0.52 + 0.075 \times 0.13 + 0.02 \times 0)$

$W = 1386.88 \times 10^6 (0 + 0.113 + 0.078 + 0.009 + 0)$

**Table 2:** Thematic layers with classes assigned Weightage and Rank

| Sr. No. | Thematic Layer | Classes | Weight | Influence Weightage (%) | Rank | Overall Weightage |
|---|---|---|---|---|---|---|
| 1. | Geomorphology | Waterbodies | 0.38 | 38 | 5 | 190 |
| | | Pediplain | | | 3 | 114 |
| | | Plateau | | | 2 | 76 |
| | | Escarpment | | | 1 | 38 |
| 2. | Lineament density (km/km2) | 1.02-0.94 | 0.19 | 19 | 5 | 95 |
| | | 0.66-1.02 | | | 4 | 76 |
| | | 0.39-0.66 | | | 3 | 57 |
| | | 0.19-0.39 | | | 2 | 38 |
| | | 0.00-0.19 | | | 1 | 19 |
| 3. | Geology | Rewa Sandstone | 0.12 | 12 | 4 | 48 |
| | | Kaimur Sandstone | | | 3 | 36 |
| | | Rewa Shale | | | 2 | 24 |
| 4. | Slope (Degree) | 0-1.63 | 0.10 | 10 | 5 | 50 |
| | | 1.63-7.18 | | | 4 | 40 |
| | | 7.18-17.95 | | | 3 | 30 |
| | | 17.95-43.42 | | | 2 | 20 |
| | | 43.42-70.84 | | | 1 | 10 |
| 5. | Soil Type | Red soil and Yellow Soil | 0.08 | 8 | 4 | 32 |
| | | Sandy Loam | | | 3 | 24 |
| | | Red Soil | | | 2 | 16 |
| 6. | Land Use and Land Cover | Waterbodies | 0.066 | 6.6 | 5 | 33 |
| | | Agriculture Land/Plantation | | | 4 | 26.4 |
| | | Scrub Land | | | 3 | 19.8 |
| | | Deciduous Forest | | | 2 | 13.2 |
| | | Built-up | | | 1 | 6.6 |
| 7. | Drainage density (km/km$^2$) | 0.00-0.77 | 0.064 | 6.4 | 5 | 32 |
| | | 0.77-1.67 | | | 4 | 25.6 |
| | | 1.67-2.81 | | | 3 | 19.2 |
| | | 2.81-4.96 | | | 2 | 12.8 |
| | | 4.96-10.38 | | | 1 | 6.4 |

**Table 3:** Depth and yield of the selected dug wells

| Sr. no. | Locations | Depth (meter) | Yield (lph) | Evaluated Groundwater potential zone |
|---|---|---|---|---|
| 1. | Khatkhari | 10.5 | 5000 | High |
| 2. | Barwan | 6.0 | 4600 | High |
| 3. | Gada | 5.6 | 4500 | High |
| 4. | Chandel | 8.0 | 4700 | High |
| 5. | Paipkhar | 13.0 | 4600 | High |
| 6. | Jatha | 8.0 | 4500 | High |
| 7. | Murthia | 8.6 | 4700 | High |
| 8. | Baghaila | 9.0 | 5000 | High |
| 9. | Deora | 5.6 | 4500 | High |
| 10. | Rajdhau | 7.0 | 2100 | Moderate |
| 11. | Hardihai | 9.0 | 2300 | Moderate |
| 12. | Mishrgawan | 8.0 | 2000 | Moderate |
| 13. | Pathera | 9.0 | 2300 | Moderate |
| 14. | Pahadi | 15 | 2500 | Moderate |
| 15. | Charaiya | 7.0 | 2600 | Moderate |
| 16. | Majhgawan | 14 | 3000 | Moderate |
| 17. | Dol | 12 | 2400 | Moderate |
| 18. | Gaur | 10.8 | 3000 | Moderate |
| 19. | Dadar | 7.8 | 2700 | Moderate |
| 20. | Shahpur | 12.5 | 2900 | Moderate |
| 21. | Hardihal | 9.0 | 2400 | Moderate |
| 22. | Bichharhata | 10.0 | 3000 | Moderate |
| 23. | Naunkala | 12.0 | 2300 | Moderate |
| 24. | Lodhi | 11.5 | 2500 | Moderate |
| 25. | Kailashhpur | 10.0 | 1000 | Low |
| 26. | Piprahi | 9.0 | 600 | Low |
| 27. | Jadkud | 9.0 | 1200 | Low |
| 28. | Sardman | 15 | 1100 | Low |
| 29. | Khonta | 10 | 700 | Low |
| 30. | Hata | 12 | 900 | Low |

$$W = 1386.88 \times 10^{6}(0.2)$$

$W = 277.38 \times 10^{6}\ m^{3}$ /year (20% of the precipitated surface water), It means that about 20% of the precipitated volume of water percolating downward to recharge the groundwater in the study area, whereas rest of the water is lost as runoff or evaporation.

Based on various parameters, the GWPZ of the area are evaluated and categorized into high (35.04 %), moderate (51.60 %) and low (13.36 %) potential zones (Fig. 9). The recharge potential zones are categorized and their estimation is calculated and presented (Table 4).

**Table 4:** Recharge potential categories and their qualitative estimation of the study area

| Recharge potential categories | Estimation according to FAO (1969) (%) | Average (%) | Area, $Km^2$ (%) |
|---|---|---|---|
| Very high | 45-50 | 47.5 | 0.0 (0) |
| High | 30-35 | 32.5 | 332.3 (35.04) |
| Moderate | 10-20 | 15 | 488.93 (51.60) |
| Low | 5-10 | 7.5 | 126.59 (13.36) |
| Very Low | <5 | 2.5 | 0.0 (0) |

## Conclusions

The study reveals that the integrated approach of RS and GIS helps and emphasize for preparation and application of various relevant thematic layers for evaluation of GWPZ. The interpretations of different thematic layers are carried out using ArcGIS platform. By assigning weightage and assigning ranks based on relevant importance for various thematic layers are generated. The three groundwater potential zones (High, Moderate and Low) are evaluated based on weightage and rank of various thematic layers. The result of the study indicates that 35.04 % (332.03 $km^2$) of the area is falling in the high potential zone, 51.60 % (488.93 $km^2$) is in the moderate zone whereas 13.36 % (126.59 $km^2$) area is falling in the category of low potential zone. The field observations of Well yield also support the finding of the study.

Despite having sufficient amount of rainfall, the study area faces water crisis in the summer season. The study may be very useful for planning and management to cope up with this problem. The calculated recharge potential indicates that the 20% of total precipitated water is going downward and recharges the groundwater of the area. The rest of the amount of water is lost as runoff or evaporation. Various recharge structures such as contour trenches, check dam, percolation tanks etc. will be helpful to increase the recharge potential. There are many hilly areas where overgrazing has nearly destroyed native grasses. Such overgrazed areas have decreased infiltration rates, reduced soil water saturation and soil porosity. Hence, the planners and community will see water/vegetation as an interactive system. To decrease the evapotranspiration, afforestation is needed in hilly areas. In the study area, precaution must be taken to select only those species of trees, bushes and grasses for afforestation which have comparatively low evapotranspiration. So, it is concluded that the identified zones of groundwater potential and recharge potentiality may be very useful for improving the groundwater resources and groundwater quality condition in research area.

## Authors' Contributions

**Rabindra Nath Tiwari:** Supervision, Conceptualization, Methodology, Data Intepretation, Reviewing and Editing. **Vikash Kumar Kushwaha:** Software, Visualization, Methodology, Writing- Reviewing and Editing, Writing-Original Draft Preparation. **Vidyakant Tiwari:** Investigation, Formal Analysis, Editing.

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