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# Delineation of Groundwater Potential Zones (GWPZ) Using GIS and AHP Method for sustainable development and planning in Sapan River Watershed of district Amravati, Maharashtra, Central India

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*Abstract*— **The AHP method is widely used in management for establishing priorities in multicriteria decision problems. The study was carried out in the Sapan River watershed. Most of this study area is covered with agricultural land, leading to intensive groundwater exploitation and depleted groundwater levels. Therefore, integrating groundwater potential assessment with sustainable groundwater management practices is essential. For this integrating approach, a total of 8 thematic layers, including Lithology, Geomorphology, Lineament density, Drainage density, LULC, Rainfall, Soil, and Slope, were prepared and analyzed to delineate the groundwater potential zone. Using this method, each class in the thematic layer is assigned a weight depending on its water potential capacity and characteristics.**

**The obtained groundwater potential zones were classified into five classes, very high potential zone covers 16.94% of the area, high potential zone covers 16.68% of the area, moderate potential zone covers 20.11% of the area, low potential zone covers 17.72% of the area, and very low potential zone covers 28.52% of the area; these obtained zones were cross-checked with actual field data collected during the previous year. This methodology enables policymakers to develop more effective groundwater management strategies that enhance the region's socioeconomic status.**

***Keyword— Groundwater potential zone (GWPZ), Analytical hierarchy process (AHP), Arc-GIS, Weighted overlay analysis.***

## I. INTRODUCTION

Groundwater is a valuable natural resource and the largest source of freshwater for drinking, domestic, and agricultural use in both rural and urban parts of India. It is a renewable natural resource because meteoric precipitation is replenished annually. As surface water becomes scarce, groundwater consumption has become unavoidable. (Todd, 1980; WHO, 1984; Hem, 1991). Groundwater is a highly vulnerable and overexploited natural resource on Earth, and it is the primary source of drinking water. (Clark et al., 1997; Leduc et al., 2017). Hence, it is essential to delineate a groundwater potential zone (GWPZ) to aid the conservation and implementation of groundwater management plans. (Arivalagan et al. 2014). The study is conducted in the Sapan River watershed, where groundwater serves as the primary source of water for both domestic and agricultural use.

The groundwater potential influencing parameters, such as geomorphology, geology, drainage density, soil, land use and land cover, rainfall, and lineament density, have been mapped as thematic layers by using Arc-GIS software and weighted overlay analysis. The use of remote sensing and Geographic Information Systems (GIS) has been extremely beneficial to the study of hydrology and water resource management. For groundwater research, these technologies provide effective methods for gathering, analyzing, and combining spatial data. Numerous studies have demonstrated their effectiveness in delineating groundwater potential zones and supporting informed decision-making in water resource planning (Saravanan, 2012). The weights for the various layers were generated using the multi-criteria decision-making technique and the analytical hierarchy process (AHP), which allows pairwise comparisons of criteria influencing the groundwater potential zone (Thiyagarajan S et al., 2020). The Analytic Hierarchy Process (AHP) is a well-known multi-criteria decision-making tool that is effective for complex issues with multiple variables. The AHP method integrates both qualitative and quantitative aspects of decision-making to provide objective analysis in resource management and environmental planning. (Saaty, 2008; Srinivasa Rao & Jugran, 2003; Aggarwal et al., 2019; Agarwal et al., 2013; Hossein et al., 2016; Aneesh & Deka, 2015; Gupta et al., 2018; Thiyagarajan et al., 2020). Furthermore, the resultant groundwater potential zones were classified into five categories: very low, low, moderate, high, and very high, which were validated to some extent using data from dugwell water tables. Based on this methodology, effective management plans, including both natural and artificial recharge practices, can be developed for these areas.

## II. STUDY AREA

Sapan River is one of the watersheds of the Chandrabhaga River basin in central India. It spans 548.33 km² and is located in the districts of Amravati (MH) and Betul (MP). This watershed lies between Latitude 21o31'16 " N to 20o53'24 " N and Longitude 77°13'58" E to 77°40'45" E, and it falls on the Survey of India Toposheet nos. 55G/7, 8, 11, and 12. This area is mainly covered with basaltic rock, with Deccan Traps in the Northwestern part and Purna Alluvium in the Southern part. The area has suffered significant tectonic movement in the past, as evidenced by the varying fault and lineament associations with hills on the Northwestern side of the study area.

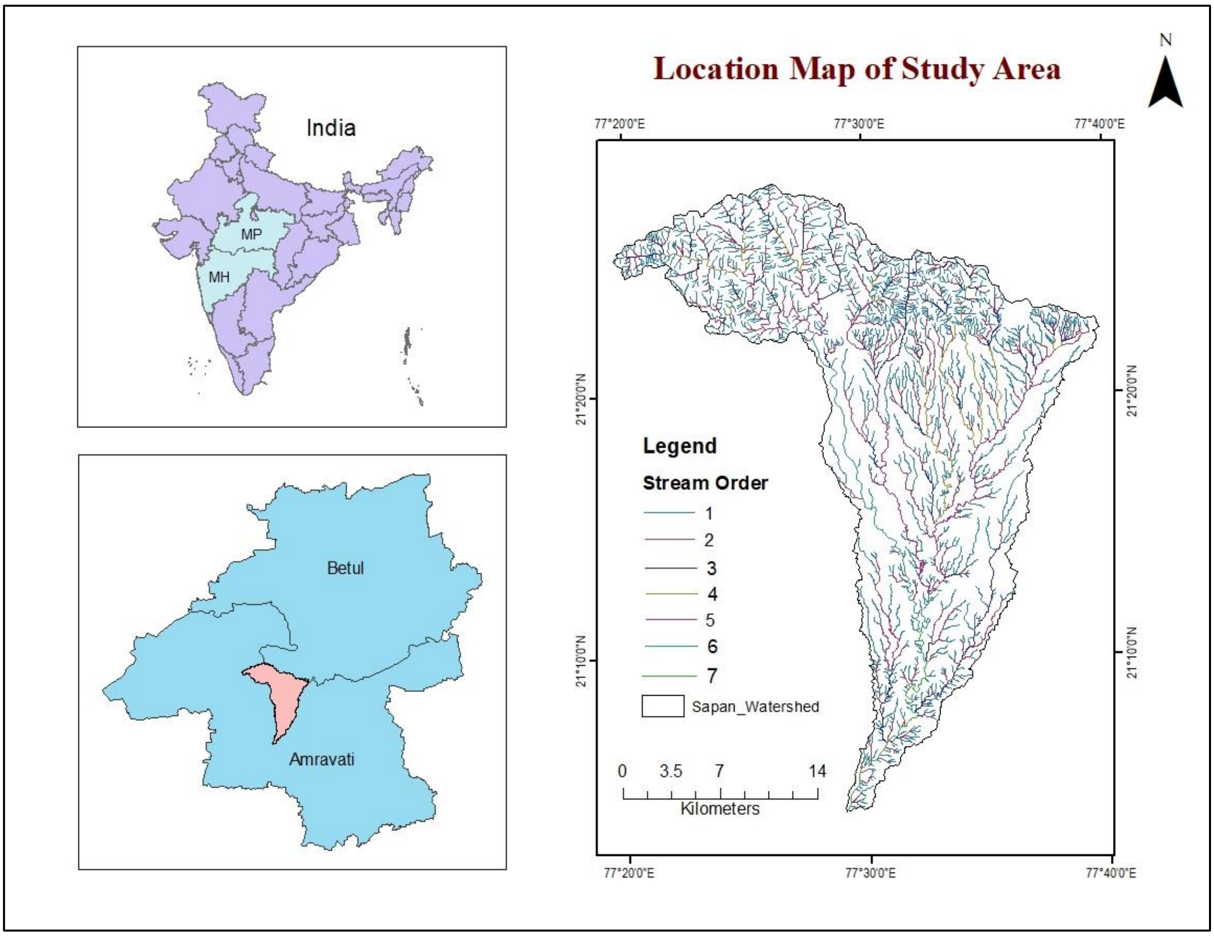


Fig. 1. Location Map of study area

## III. DATA COLLECTION & METHODOLOGY

The GWPZ map of the Sapan Watershed was developed by systematically integrating several thematic layers essential for groundwater assessment. The process began with the lithology map, which used the district resource map from the Geological Survey of India (GSI) and was validated through field surveys. Next, geomorphology was derived by visually interpreting Sentinel-2 data, further supported by Bhuvan/NRSC data. Slope and drainage density maps followed, generated from ALOS PALSAR DEM data (12.5 m resolution), utilizing the DEM to provide the drainage network. Additionally, the soil map was sourced from the FAO/UNESCO site. Lineament density maps were created by identifying lineaments on hillshade maps via a GIS platform. Bhuvan/NRSC data also supported LULC mapping. Average rainfall data from 2008–2018 were obtained from the office of the Joint Director of Agriculture, Amravati, and spatially distributed using the IDW interpolation method in ArcGIS. All these thematic layers were collectively analyzed with the GIS-AHP multicriteria evaluation technique. This method is widely used for groundwater management (Razandi et al. 2015). The AHP evaluates several datasets in a pairwise comparison matrix and assigns weights to each criterion based on priority (Saaty, 1980).

Table 1. Satty's scale of relative importance:

| Scale | Definition | Explanation |
|---|---|---|
| 1 | Equal importance | Two activities contribute equally to the objective |
| 3 | Moderate Importance | Experience and judgment slightly favor one activity over another |
| 5 | Strong Importance | Experience and judgment strongly favor one activity over another |
| 7 | Very Strong Importance | An activity is strongly favored and its dominance demonstrated in practice |
| 9 | Extremely Importance | The evidence favoring one activity over another is of the highest possible order of affirmation |
| 2,4.6.8 | Intermediate values between two adjacent Judgments | compromise is needed |

Table 2. AHP Pairwise Matrix comparison

| Matrix | LD | G | SL | DD | LI | S | LL | R | Normalizes Eigenvector Values |
|---|---|---|---|---|---|---|---|---|---|
| LD | 1 | 2 | 3 | 2 | 3 | 4 | 5 | 6 | 27.78 |
| G | 1/2 | 1 | 2 | 1 | 2 | 3 | 4 | 5 | 17.58 |
| SL | 1/3 | 1/2 | 1 | 2 | 2 | 2 | 3 | 3 | 14.30 |
| DD | 1/2 | 1 | 2 | 1 | 2 | 3 | 4 | 4 | 17.18 |
| LI | 1/3 | 1/2 | 1/2 | 1/2 | 1 | 2 | 3 | 3 | 9.30 |
| S | 1/4 | 1/3 | 1/2 | 1/3 | 1/2 | 1 | 2 | 2 | 6.14 |
| LL | 1/5 | 1/4 | 1/3 | 1/4 | 1/3 | 1/2 | 1 | 2 | 4.30 |
| RF | 1/6 | 1/5 | 1/3 | 1/4 | 1/3 | 1/2 | 1/2 | 1 | 3.42 |

The normalized weights for the layers were obtained by satisfying the consistency index and consistency ratio value of the constructed pairwise matrix. The matrix thus created is said to be consistent if its CR value falls below 0.1. The layers were subjected to weighted overlay analysis after assigning the determined weights. In this analysis, various parameters were assigned normalized weights and ranks to delineate the groundwater potential index (GWPI) zone using eq.1. The multiple thematic layers, assigned weights and ranks, were subjected to a weighted overlay analysis in the ArcGIS environment to delineate the (GWPI) Zone of the study area.

Groundwater potential index (GWPI) = LDrLDw + GErGEw + SLrSLw + DrDw + LIrLIw + SrSw + LUrLUw+ RrRw (Eq.1)

Whereas:

LD is Lineament density, GE is Geomorphology, SL is Slope, DD is Drainage density, LI is Lithology, S is Soil, LU is LULC and R is Rainfall.

Table 3. AHP Weight and rank assigned as per the influence of parameters.

| FACTORS | RANK | WEIGHT |
|---|---|---|
| | | |
| LINEAMENT DENSITY | | |
| Very High | 5 | 27.78 |
| High | 4 | |
| Moderate | 3 | |
| Low | 2 | |
| Very Low | 1 | |
| | | |
| GEOMORPHOLOGY | | |
| Older Alluvial Plain | 4 | 17.58 |
| Younger Alluvial Plain | 5 | |
| Pediment Pediplain Complex | 4 | |
| Waterbody - River | 5 | |
| Highly Dissected Plateaus | 1 | |
| Moderately Dissected Plateaus | 2 | |
| Piedmont Slope | 3 | |
| | | |
| SLOPE | | |
| 0-4 Very Low | 5 | 14.30 |
| 4-12 Low | 4 | |
| 12-20 Moderate | 3 | |
| 20-28 High | 2 | |
| >28 Very High | 1 | |
| | | |
| DRAINAGE DENSITY | | |
| Very High | 1 | 17.18 |
| High | 2 | |
| Moderate | 3 | |
| Low | 4 | |
| Very Low | 5 | |
| | | |
| LITHOLOGY | | |
| Basalt | 3 | 9.3 |
| Alluvium | 5 | |
| Clay | 2 | |
| Boulder Bed | 4 | |
| Cherty Limestone | 2 | |
| | | |
| SOIL | | |
| Chromic Vertisols | 3 | 6.14 |
| Vertic Cambisols | 4 | |
| | | |
| LULC | | |
| Waterbody | 5 | 4.3 |
| Agriculture | 5 | |

| | | |
|---|---|---|
| Rangeland | 2 | |
| Built Up Area | 1 | |
| Vegetation | 5 | |
| | | |
| RAINFALL | | |
| Very High | 5 | 3.42 |
| High | 4 | |
| Moderate | 3 | |
| Low | 2 | |
| Very Low | 1 | |

## IV. RESULT & DISCUSSION

The delineation of groundwater potential zones within the Sapan watershed using multiple thematic layers, including lineament density, geomorphology, slope, drainage density, lithology, land use/land cover (LULC), rainfall distribution, and soil characteristics, as detailed in the following sections.

### 4.1 Lineament Density

Lineaments are the surface expressions of geological features, such as joints, faults, and fractures, and are not just physical formations. They are indirect indicators of groundwater potential zones (Thiyagarajan S. et al., 2020; Pinto et al., 2017). Furthermore, the density of lineaments in an area is a key indicator of groundwater availability (Warghat et al, 2023; Chepchumba et al., 2019). In this region, the northern part of the Sapan Watershed, with its higher lineament density, is more structurally favorable for groundwater. Conversely, the southern parts, with their lower lineament density, are less suitable for groundwater potential. Therefore, this map is a critical tool that supports groundwater resource planning in the region.

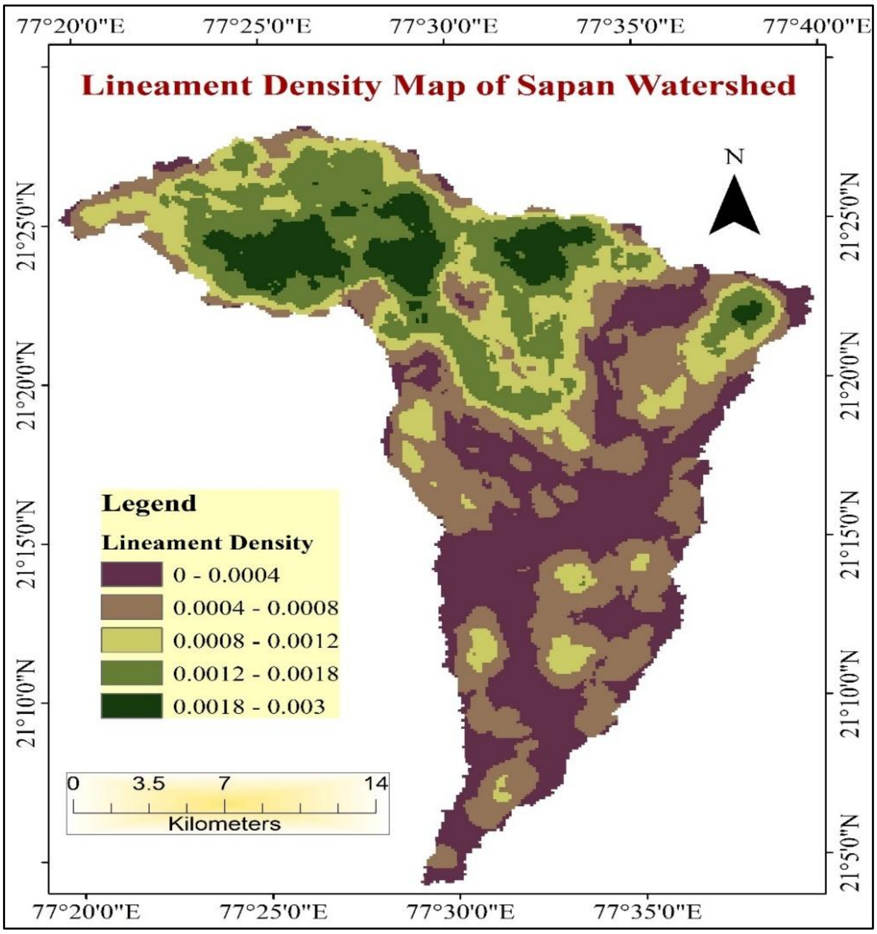


Fig. 2. Lineament Map of study area

4.2 Drainage Density

The inverse relationship between drainage density and permeability (Marweshi, M. J., 2022) has significant practical implications. It is essential to acknowledge the regional variations within the Sapan Watershed. For example, the northern region, with its high to very high drainage density, experiences high runoff and erosion, as well as very low infiltration, resulting in poor groundwater recharge. By contrast, the Central & Southern Region, with its low to medium drainage density, presents a favorable condition for groundwater potential. Furthermore, the southwestern and southeastern edges, characterized by their low drainage density, exhibit minimal surface streams.

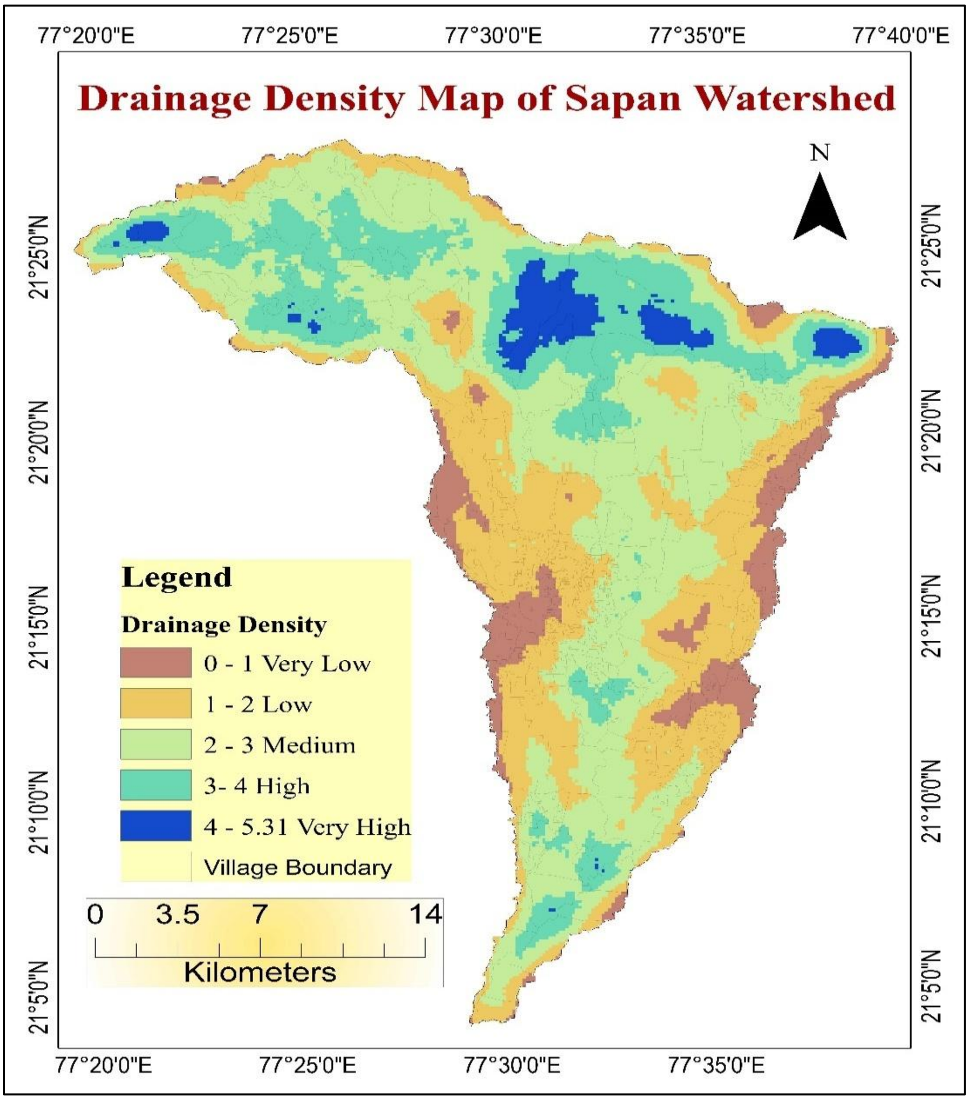


Fig. 3. Drainage density Map of study area

4.3 Geomorphology

Water percolation and recharging in the subsurface are significantly impacted by geomorphology (Donselaar et al.). In the northern and northwestern parts, the Highly Dissected Structural Upper Plateau represents rugged terrain with high relief and steep slopes. Surrounding the upper plateau region, the Moderately Dissected Structural Lower Plateau shows less ruggedness than the upper plateau. In the northern central part of the watershed, just below the dissected plateau, the Pediment Pediplain Complex is dominant. The Piedmont Slope, as the transitional zone between plateaus and plains, plays a crucial role in the watershed's hydrology. In the central and southern regions, the older alluvial plain flat areas have old river deposits. A river denotes its drainage pattern and main channels. Sapan River and its tributaries are crucial for surface water flow and recharge to nearby aquifers. Adjacent to river channels, the Younger Alluvial Plain is found.

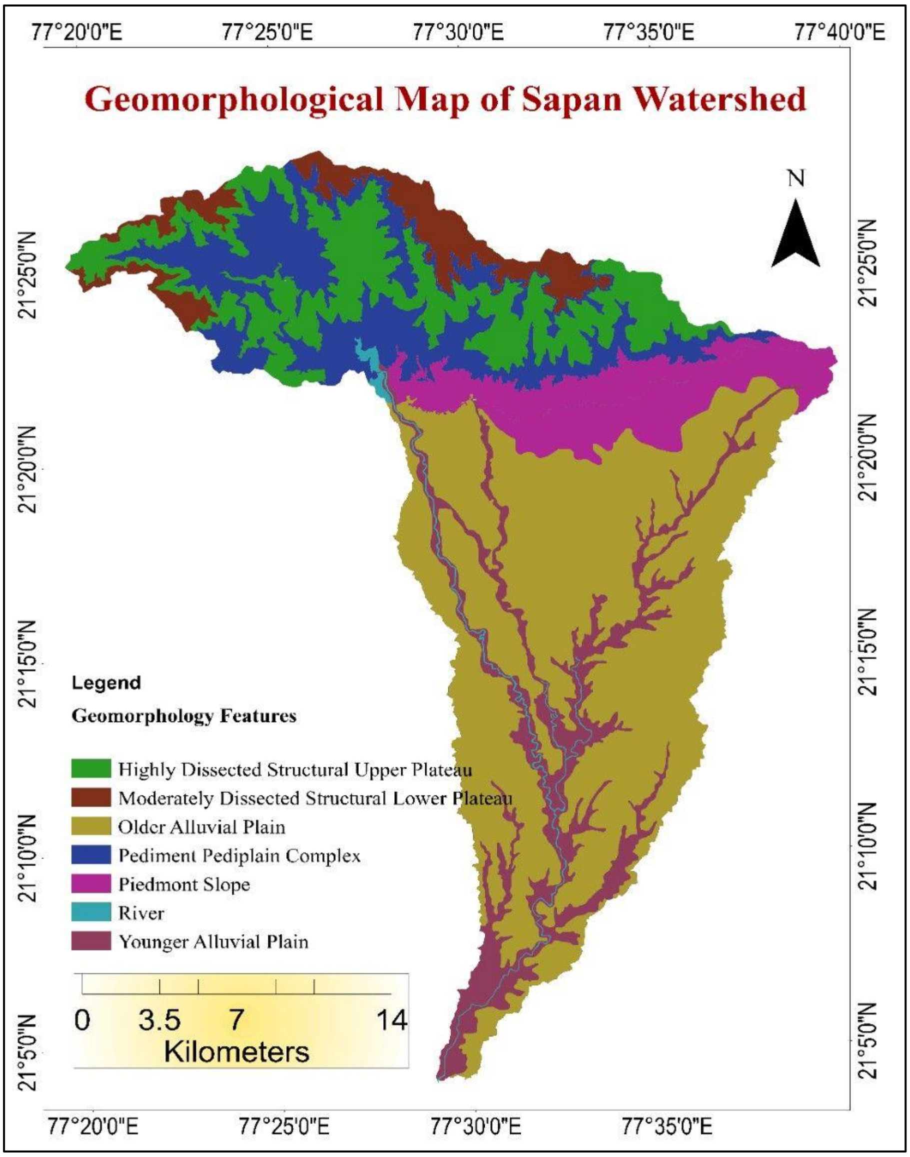


Fig. 4. Geomorphological Map of study area

4.4 LULC

Another crucial element in determining the groundwater potential zone is LULC. For instance, in the Sapan watershed region, information on infiltration, soil moisture, groundwater requirements, and surface water dependency was inferred using a LULC map. The dominant crops are found in the southern and central parts of agricultural fields, which predominate in the lower and central watershed. Built areas are concentrated centrally and in the south, corresponding to urban or semi-urban settlements. Rangeland is predominantly in the northern zone. Open lands, possibly grassland or areas with fallow trees, are also present. Forested or densely vegetated areas are mainly located in the northern and northwestern areas and are associated with high infiltration and natural recharge. Water bodies, such as small patches, are primarily found in the central areas, with lakes, reservoirs, or rivers playing a crucial role in local recharge through direct seepage.

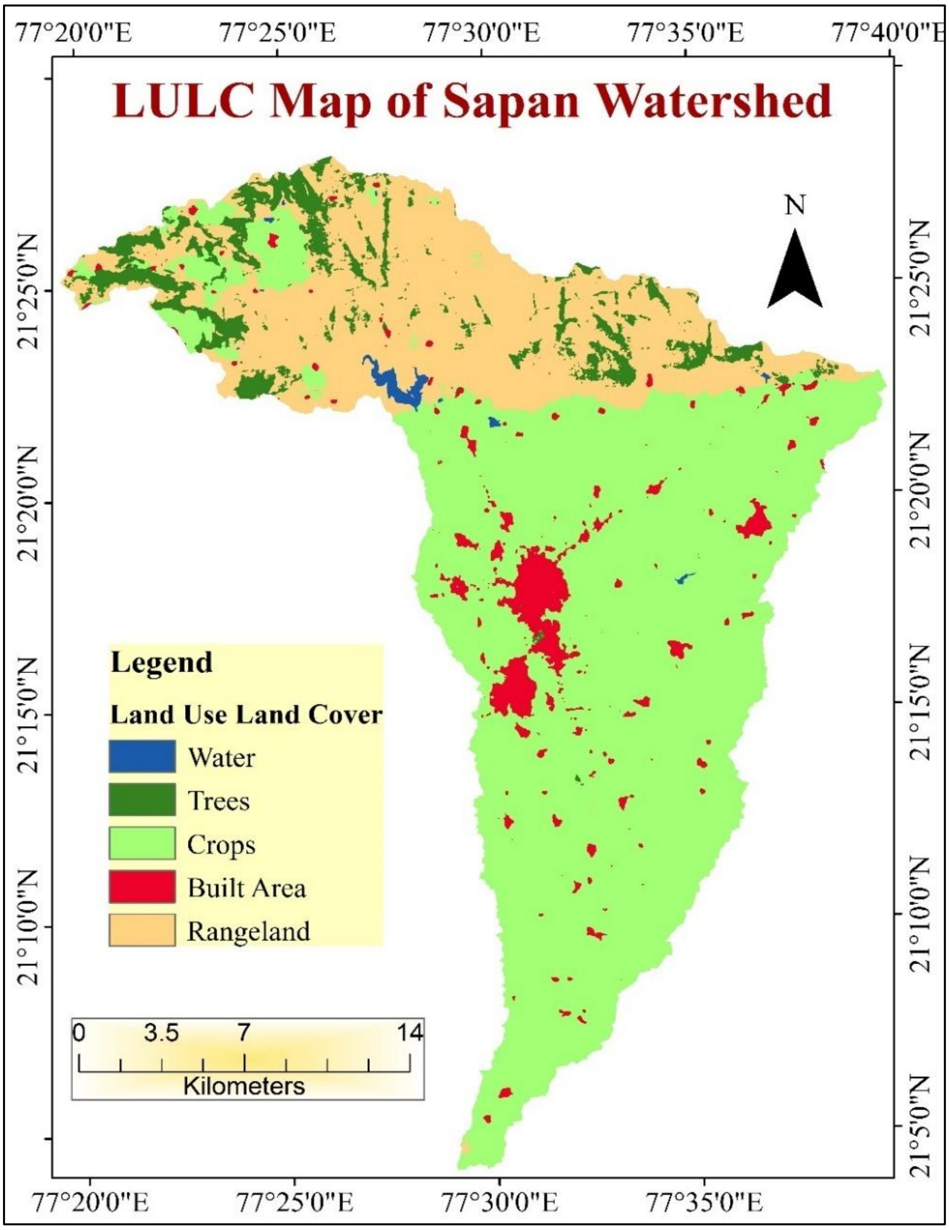

Fig. 5. LULC Map of study area

4.5 Lithology

Alluvium is predominantly found in the southern and central parts of the watershed. Basalt covers the entire northern part. Boulder Bed lies in a narrow belt between the basalt and alluvium zones. Cherty Limestone is a very small patch within the Boulder Bed zone. A tiny clay patch, also within the Boulder Bed zone.

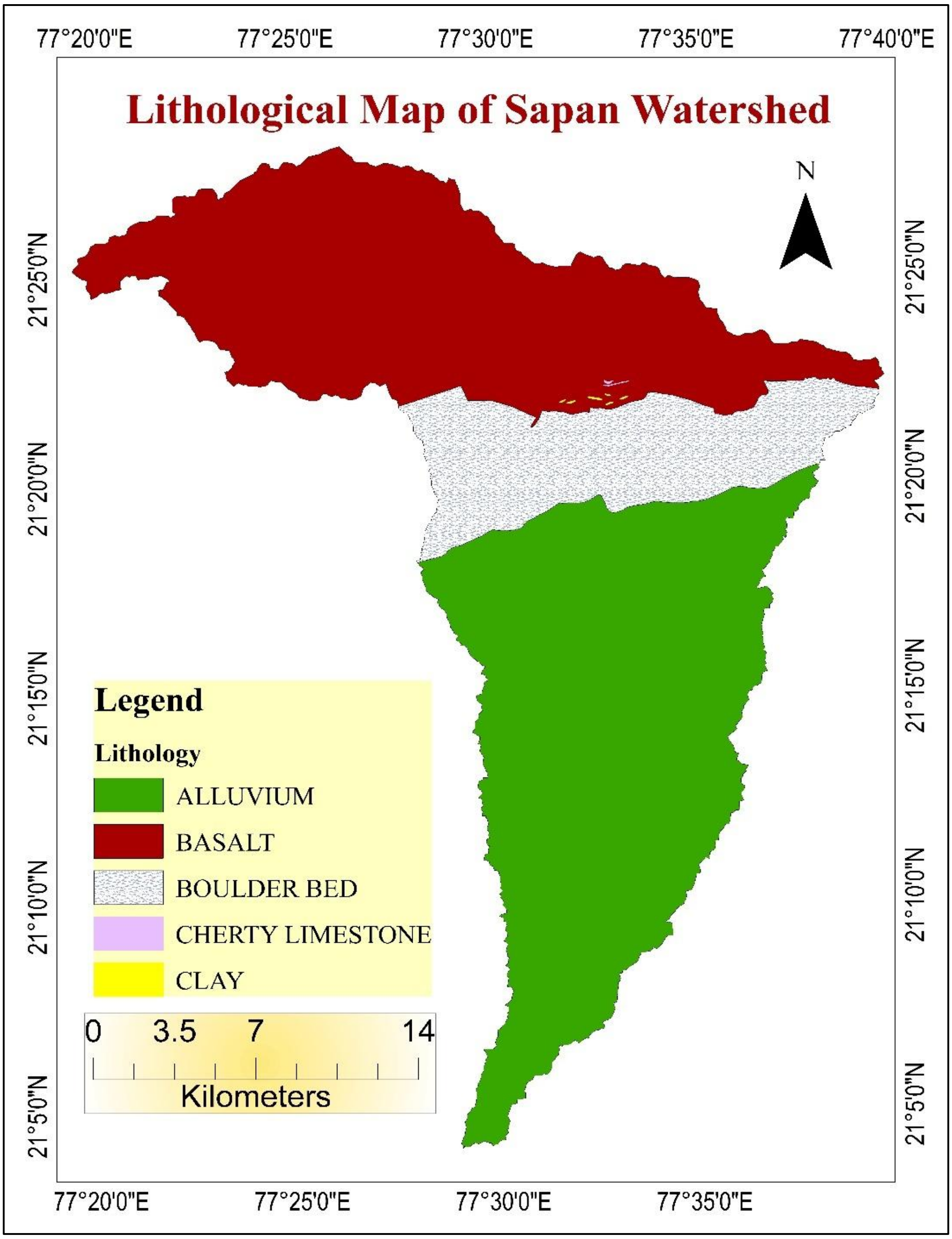


Fig. 6. Lithological Map of study area

4.6 Soil

Across the Sapan Watershed, the soil map shows the spatial distribution of two main soil types in the region. The northern and central parts of the watershed are characterized by Vertic Cambisols, while Chromic Vertisols predominate in the southern and southeastern parts.

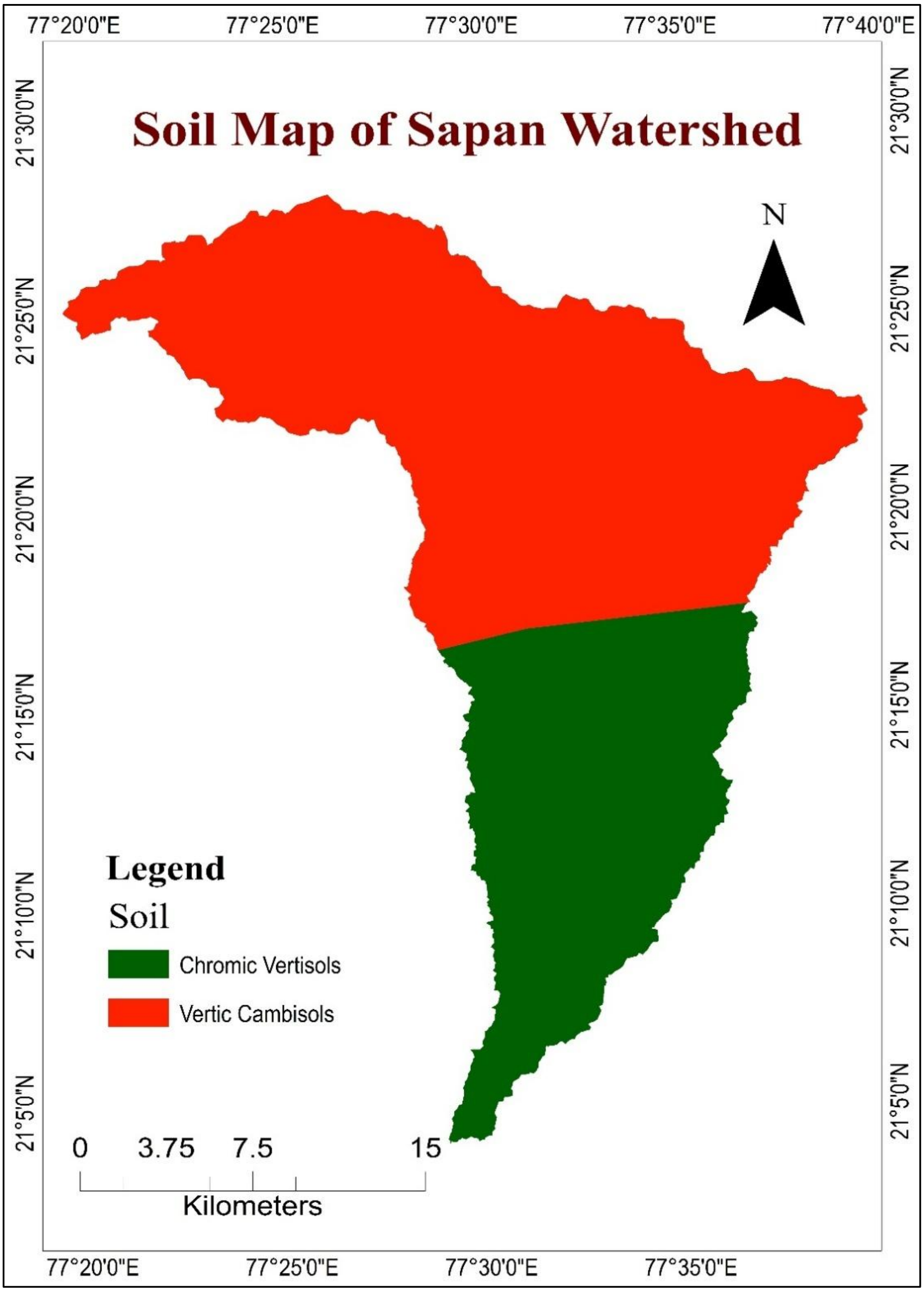


Fig. 7. Soil Map of study area

4.7 Rainfall

Displaying the spatial distribution of annual rainfall, the rainfall map of the Sapan Watershed highlights increasing values from southeast to northwest. In the northwestern part, the highest rainfall (216–249 cm) occurs, while the southeastern region records the lowest (137–150 cm).

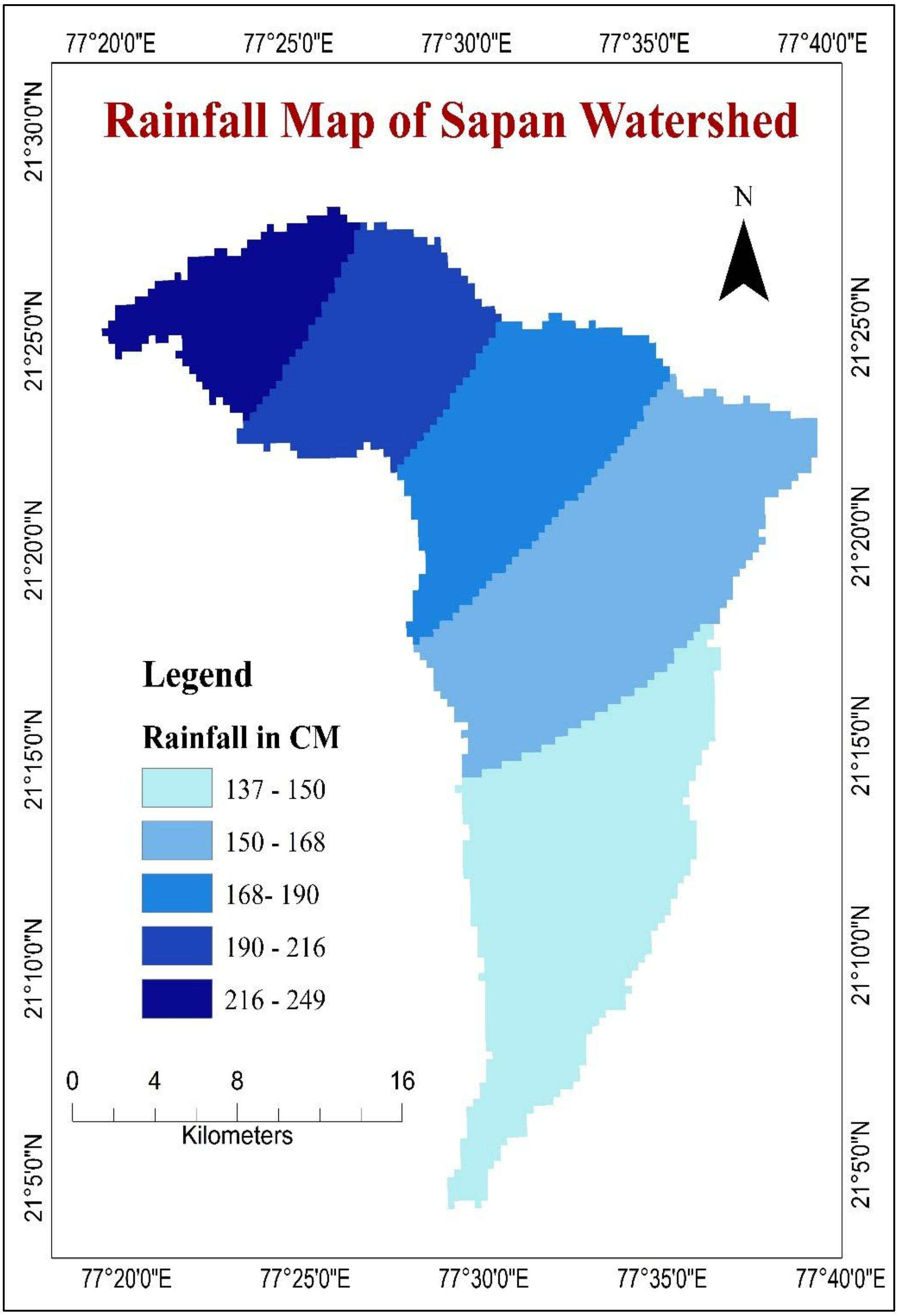


Fig. 8. Rainfall Map of study area

4.8 Slope

The recharge of aquifers on slopes influences the recharge of aquifers, affecting surface water infiltration and runoff as one of the primary factors. Degrees serve as units of measurement for slope. The degree of slope determines whether a zone favors infiltration or runoff (Njumbe, L.J.N., et al., 2023; Ishola, K.S., et al., 2023). Higher runoff and reduced infiltration of surface water result from steeper slopes (Dixon et al., 2001). In the north-northwestern part, the steepest slopes occur at the highest elevation. Slope classes on the map include: very gentle (0–4°), gentle (4–11°), moderate (11–19°), steep (19–28°), and very steep (28–70°).

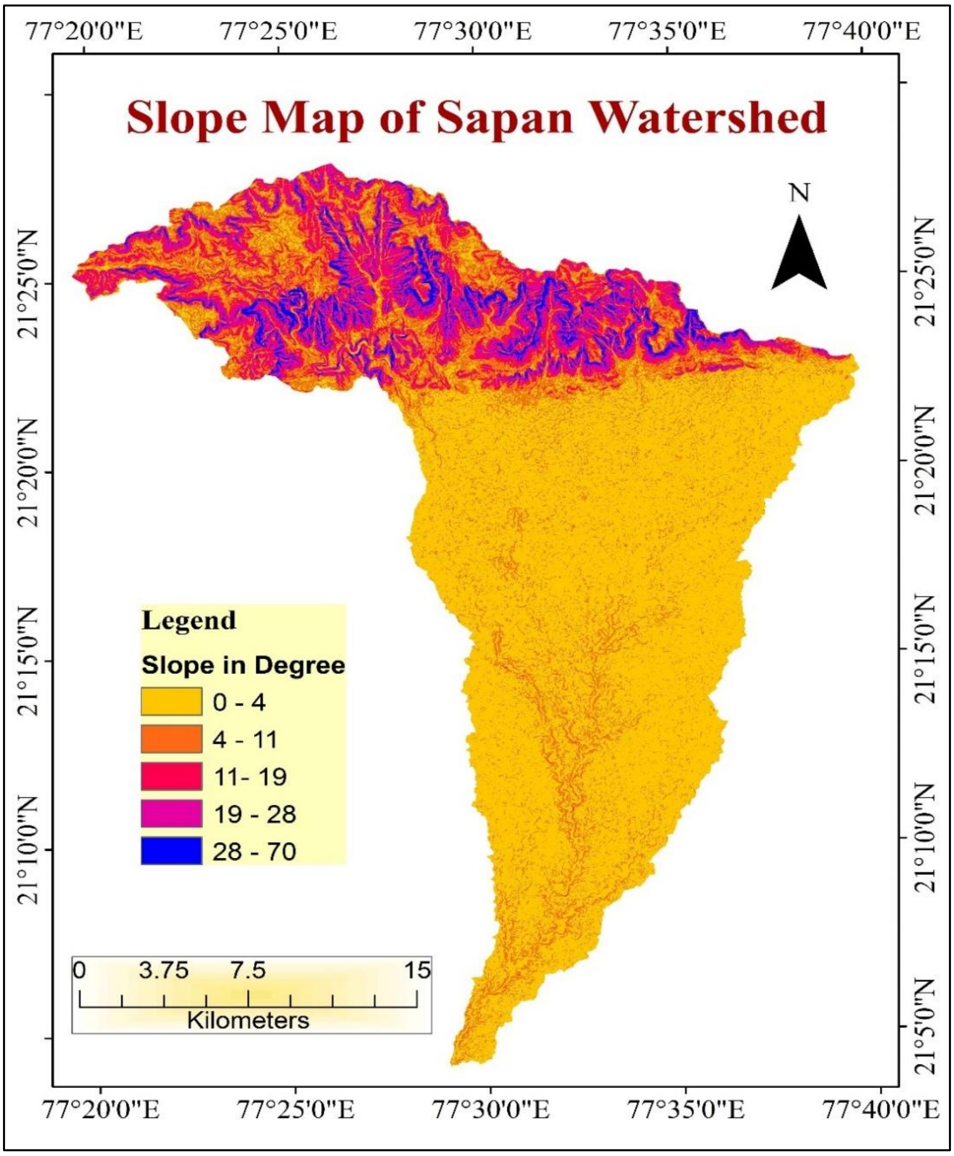


Fig. 9. Slope Map of study area

4.9 Delineation of Groundwater potential zone

The eight thematic layers were developed using a geographic information system (GIS) framework. To support overlay analysis, each layer was assigned a weight using the Analytic Hierarchy Process (AHP), producing normalized weights and rankings for the different parameters. These rankings have been used to delineate groundwater potential index (GWPI) zones according to Eq.1. Based on this index, the data were classified into five groundwater potential zones: very high, high, moderate, low, and very low, each indicating varying levels of groundwater potential across the region. In study area very high potential zone, covering 92.90 km² (16.94%), is concentrated in the central and northern parts of the study area, where both lineament density and rainfall are high. The high-potential zone encompasses 91.50 km² (16.68%) and is distributed throughout the watershed, often adjacent to areas of very high potential. The moderate potential zone covers approximately 110.32 km² (20.11%) and is primarily located in the southern part of the study area. While, low potential zone encompasses 97.21 km² (17.72%), and very low potential zone covers 156.40 km² (28.52%), primarily located in the extreme north, northeast, and far south. In the extreme north, high rainfall coincides with low lineament density, whereas in the far south, all rainfall, drainage density, and lineament density are low. These spatial differences in groundwater potential are shaped by factors such as lineament density, geology, landforms, slope, and soil type, which are crucial for the occurrence and development of groundwater in the region.

Table 4. Groundwater potential zone (GWPZ)

| Sr. No. | Zone | Area ($Km^2$) | % Area |
|---|---|---|---|
| 1 | Very Low | 156.40 km² | 28.52% |
| 2 | Low | 97.21 km² | 17.72% |
| 3 | Moderate | 110.32 km² | 20.11% |
| 4 | High | 91.50 km² | 16.68% |
| 5 | Very High | 92.90 km² | 16.94% |

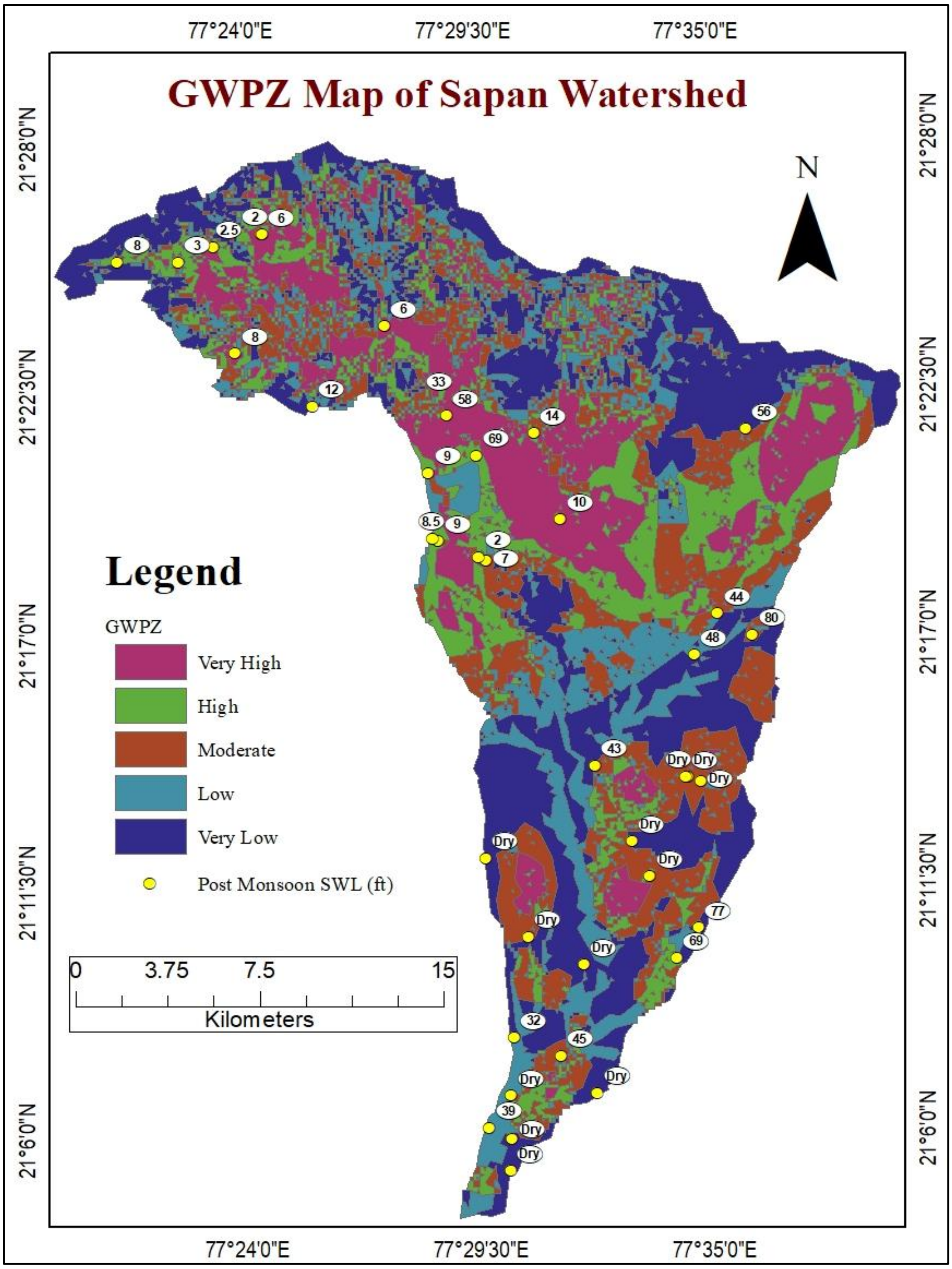


Fig. 10. GWPZ Map of study area

The pre-monsoon and post-monsoon shallow water level data from the actual field data collected during the previous year were cross-checked with the obtained groundwater potential zone. In the study region, about 40 wells were chosen, and the results show a correlation with the ground water potential zone. Because this region is primarily governed by high lineament density, strong rainfall, and highly and moderately dissected rock formation, very high and high GWPZ exhibits good relationship with SWL. Due to extensive groundwater extraction through borewells, which causes groundwater depletion and dry wells, moderate GWPZ shows some mismatch in agricultural areas. Due to low rainfall, low lineament density, and heavy groundwater extraction by borewell in agricultural fields, very low and low GWPZ is associated with poor groundwater potential. Thus, our work demonstrates that although GWPZ mapping represents natural hydrogeological potential, anthropogenic activity actually has a major impact on groundwater availability.

Table. 5 Pre & Post Monsoon SWL (ft.)

| Sr. No. | LONG | LAT | State | District | Taluka | Village | Pre Mon SWL (Ft) | Post Mon SWL (Ft) |
|---|---|---|---|---|---|---|---|---|
| 1 | 77.560 | 21.195 | Maharashtra | Amravati | Achalpur | Meghnathpur | 70 Dry | Dry |
| 2 | 77.553 | 21.208 | Maharashtra | Amravati | Achalpur | Bhugaon | 50 Dry | Dry |
| 3 | 77.539 | 21.236 | Maharashtra | Amravati | Achalpur | Shekapur 01 | 70 | 43 |
| 4 | 77.538 | 21.115 | Maharashtra | Amravati | Achalpur | Yelki | 37 Dry | Dry |
| 5 | 77.534 | 21.162 | Maharashtra | Amravati | Achalpur | Wasani Bk. | 60 Dry | Dry |
| 6 | 77.527 | 21.327 | Maharashtra | Amravati | Achalpur | Wadura | 16 | 10 |
| 7 | 77.524 | 21.129 | Maharashtra | Amravati | Achalpur | Danoda | 50 | 45 |
| 8 | 77.517 | 21.359 | Maharashtra | Amravati | Achalpur | Mhasona | 21 | 14 |
| 9 | 77.512 | 21.173 | Maharashtra | Amravati | Achalpur | Mukindpur | 60 Dry | Dry |
| 10 | 77.506 | 21.136 | Maharashtra | Amravati | Achalpur | Yevta | 35 | 32 |
| 11 | 77.504 | 21.099 | Maharashtra | Amravati | Achalpur | Yesurna | 65 Dry | Dry |
| 12 | 77.504 | 21.114 | Maharashtra | Amravati | Achalpur | Sawali Kh. | dry | Dry |
| 13 | 77.504 | 21.087 | Maharashtra | Amravati | Achalpur | Nimbbhari | 60 dry | Dry |
| 14 | 77.498 | 21.312 | Maharashtra | Amravati | Achalpur | Dhotarkheda 01 | 18 | 7 |
| 15 | 77.496 | 21.202 | Maharashtra | Amravati | Achalpur | Naigaon | 110 Dry | Dry |
| 16 | 77.495 | 21.103 | Maharashtra | Amravati | Achalpur | Khanapur Chichkheda | 45 | 39 |
| 17 | 77.494 | 21.313 | Maharashtra | Amravati | Achalpur | Dhotarkheda 02 | 15 | 2 |
| 18 | 77.494 | 21.351 | Maharashtra | Amravati | Achalpur | Malhara | 80 | 69 |
| 19 | 77.487 | 21.372 | Maharashtra | Amravati | Achalpur | Buradghat | 42 | 33 |
| 20 | 77.483 | 21.366 | Maharashtra | Amravati | Achalpur | Wazhar | 80 | 58 |
| 21 | 77.479 | 21.320 | Maharashtra | Amravati | Achalpur | Sawali | 14 | 9 |
| 22 | 77.476 | 21.321 | Maharashtra | Amravati | Achalpur | Sawali 2 | 18 | 8.5 |
| 23 | 77.475 | 21.345 | Maharashtra | Amravati | Achalpur | Eklaspur | 34 | 9 |
| 24 | 77.602 | 21.283 | Maharashtra | Amravati | Chandur bazar | Lakhanwadi | 100 Abv | 80 |
| 25 | 77.600 | 21.359 | Maharashtra | Amravati | Chandur bazar | Subhanpur | 64 | 56 |
| 26 | 77.588 | 21.291 | Maharashtra | Amravati | Chandur bazar | Somthana | 65 | 44 |
| 27 | 77.581 | 21.229 | Maharashtra | Amravati | Chandur bazar | Belaj 01 | 100 Dry | Dry |
| 28 | 77.579 | 21.175 | Maharashtra | Amravati | Chandur bazar | Tamaswadi | 90 | 77 |
| 29 | 77.579 | 21.276 | Maharashtra | Amravati | Chandur bazar | Kavitha Bk | 60 Dry | 48 |
| 30 | 77.576 | 21.231 | Maharashtra | Amravati | Chandur bazar | Belaj 02 | 100 Dry | Dry |
| 31 | 77.575 | 21.231 | Maharashtra | Amravati | Chandur bazar | Belaj 03 | 100 Dry | Dry |
| 32 | 77.570 | 21.164 | Maharashtra | Amravati | Chandur bazar | Talni | 80 | 69 |
| 33 | 77.459 | 21.399 | Maharashtra | Amravati | Chikhaldara | Bihali | 19 | 6 |
| 34 | 77.430 | 21.370 | Maharashtra | Amravati | Chikhaldara | Bhilkheda | 29 | 12 |
| 35 | 77.411 | 21.434 | Maharashtra | Amravati | Chikhaldara | Salona 02 | 16 | 6 |
| 36 | 77.411 | 21.434 | Maharashtra | Amravati | Chikhaldara | Salona 01 | 15 | 2 |
| 37 | 77.400 | 21.390 | Maharashtra | Amravati | Chikhaldara | Madki | 20 | 8 |
| 38 | 77.392 | 21.429 | Maharashtra | Amravati | Chikhaldara | Nala | 9 | 2.5 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 39 | 77.378 | 21.424 | Maharashtra | Amravati | Chikhaldara | Bori | 5 | 3 |
| 40 | 77.354 | 21.424 | Maharashtra | Amravati | Chikhaldara | Tetu | 25 | 8 |

## V. CONCLUSION

The integration of geographic information systems and the AHP method provides spatial and visual analysis of thematic layers. This method was used to delineate groundwater potential zones in the Sapan watershed. The resulting zones were classified into five classes, very high potential zone (16.94%), high potential zone (16.68%), moderate potential zone (20.11%), low potential zone (17.72%), and very low potential zone (28.52%). The study concludes that integrating geospatial technology with AHP provides reliable & cost-effective groundwater information. These findings help planners determine optimal locations for well drilling and artificial recharge measures. The resulting groundwater potential map produced by this study enables policymakers to develop more effective groundwater management strategies to enhance the socioeconomic status of the region.

## VI. ACKNOWLEDGEMENT

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