Assessment of groundwater potential zones using geospatial techniques in Mangalore Taluk, Dakshina Kannada District, Karnataka, India

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Abstract. Despite sufficient rainfall, a large part of India suffers from water scarcity. Groundwater occurs in weathered or semi-weathered/fractured layers in hard-rock areas whose thickness varies, generally, from 5m to 20m. Satellite pictures are widely being used for groundwater exploration. Study and analysis of remote sensing data is a fast and economical way of finding and exploring. Present study, for assessment of groundwater availability in Mangalore taluk, Dakshina Kannada District, Karnataka state, shows various groundwater potential zones delineated using remote sensing and GIS techniques. Groundwater availability in Mangalore taluk was divided based on its hydro geomorphologic conditions. Satellite imageries are used for preparing various thematic maps, viz. slope, drainage density, lineament, land use/cover, soil, rainfall, geology and geomorphology map, which were transformed to raster class data using the feature to raster converter tool in ArcGIS. All the raster maps were allocated a fixed percentage of influence, after which a weighted overlay tool or technique was used. Each weighted thematic layer was computed statistically for the groundwater potential zones. The results were verified with bore well yield data from India Water Resources Information System (IWRIS). The results yielded a good match with the obtained bore well data with an accuracy of 82.14%.

1 Introduction

Water is a crucial natural resource that exists as both surface water and groundwater. It is essential for all forms of life on Earth. The progress of our society relies heavily on the availability and utilization of sufficient water. This valuable resource can be scarce at times, while at other times, it may be plentiful, but its distribution is often uneven across different regions and periods. Groundwater accounts for the second-largest supply of freshwater resources, making up approximately 30% of the world's freshwater supply.

Groundwater has been a widely utilized water resource in many tropical nations. Due to its ease of extraction, groundwater tends to be shielded from the pollutants that affect surface water. Nonetheless, instances of over-extraction of groundwater are frequent. One main factor hindering the optimal use of groundwater resources is the inadequate understanding of groundwater fundamentals. The integration of remote sensing technology has enhanced groundwater exploration and preparatory studies financially, despite the high costs associated with depleting groundwater resources [1, 2].

Generally, it's recommended to analyse aeronautical photos or satellite images before conducting ground studies and fieldwork. This approach can help identify potential aquifer layers and areas for field investigations. However, it's important to remember that remote sensing does not replace the need for in-situ data collection, which is crucial for validating the accuracy of remote sensing information and its interpretation. Clearly, remote sensing can reduce the amount of field data collection needed [3-5].

Several experts reviewed GIS applications in hydrology and water management during the early to mid-1990s. Their studies highlight the significant role of Geographic Information Systems in these fields, indicating that their use primarily focuses on a structured and instructional approach. This integration of GIS has enhanced our understanding of hydrological processes and improved water management strategies, emphasizing its importance for effective resource planning and environmental sustainability.

2 Study area

Mangalore Taluk in Dakshina Kannada district of Karnataka state, a region on the western coast of India, is the study area of research work as seen in Fig. 1. Mangalore taluk has an area of 834 km^2 and a population of around ten lakhs. Mangalore is the administrative headquarters of the taluk. Mangalore taluk has almost a plain terrain and receives ample rainfall every year.

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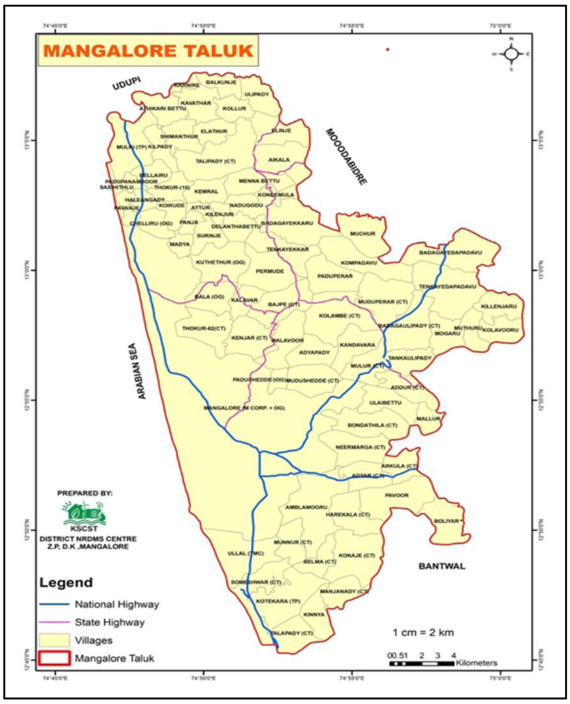

Fig. 1. Map of the study area

3 Data collection

Varies of spatial and non-spatial data have been collected for the present study purposes, such as satellite data, topographic maps, groundwater data, meteorological data, etc.

3.1 Satellite data

IRS-LISS III satellite data has been crucial for creating various thematic maps. This data was obtained from the National Remote Sensing Centre (NRSC) in India, ensuring high-quality imagery for analysis. Additionally, other relevant datasets were downloaded for free from their respective websites to support the study.

Cartosat-1 digital elevation model (DEM) data was also sourced from the NRSC's open data section, providing valuable topographic information. The Survey of India toposheet was included to add detailed geographic features. For the analysis and mapping of the thematic layers, Geographic Information System (GIS) and image processing software, specifically ArcGIS, were utilized. This combination of resources enables effective data visualization and analysis, enhancing the overall quality and accuracy of the thematic maps produced [6].

3.2 Data for groundwater evaluation

The data required for the evaluation of groundwater in Mangalore taluk was collected from the different website portal. Geology and Geomorphology data were downloaded from Bhukosh, a geological survey of India website, Rainfall data for the past 10 years from the CHRS portal; Land use land cover from ESRI, Lineament data from Bhuvan of NRSC and Soil map of the world from the Food and Agriculture Organization (FAO) website.

4 Method

For the present study, mainly eight different themes were evaluated: (i) Geomorphology, (ii) Land use Land cover, (iii) lineament density, (iv) Soil, (v) Drainage density, (vi) Geology, (vii) Annual rainfall and (viii) Slope on the raster GIS platform.

A raster GIS model was chosen for its high spatial resolution in representing images and its capacity to encompass large geographic areas effectively. To improve the quality of raw images, several digital processing techniques were applied, including look-up table stretching, histogram equalization, principal component analysis, and high-pass directional filtering. These techniques enhanced image detail, enabling the production of precise geomorphology and lineament density maps, which offer valuable insights into the region's physical characteristics. Additionally, soil maps were digitized and further refined through satellite imagery analysis, ensuring high accuracy in thematic mapping. The integration of these data sources and techniques ultimately led to the generation of comprehensive thematic maps that support further spatial analysis and decision-making processes [7].

In this study, Cartosat-1 DEM data was used to analyse the slope. A stream direction map was generated from the DEM, providing a clear representation of the water flow in the study area. Using the stream direction map as input, a stream accumulation map was produced with ArcGIS tools. The output includes various classes of potential zones, categorized as very high, high, moderate, poor, and very poor [8].

5 Results and discussion

5.1 Drainage density map

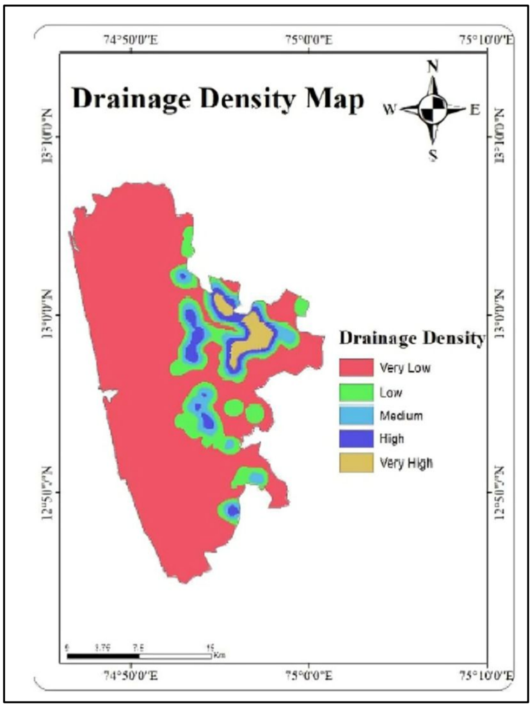

Fig. 2. The map of drainage density

The study area was delineated using freely available Cartosat-1 DEM data from the National Remote Sensing Centre (NRSC) in Hyderabad, India. Drainage density within the area was computed as the total length of streams per unit area in each sub-basin, expressed in km/km². The drainage density values were classified into five categories: Very Low, Low, Medium, High, and Very High. Areas with lower drainage density support higher infiltration rates, suggesting a greater groundwater potential compared to regions with high drainage density. Consequently, greater weights were assigned to regions with low drainage density, while lower weights were allocated to those with high drainage density, as illustrated in Fig. 2.

5.2 Slope map

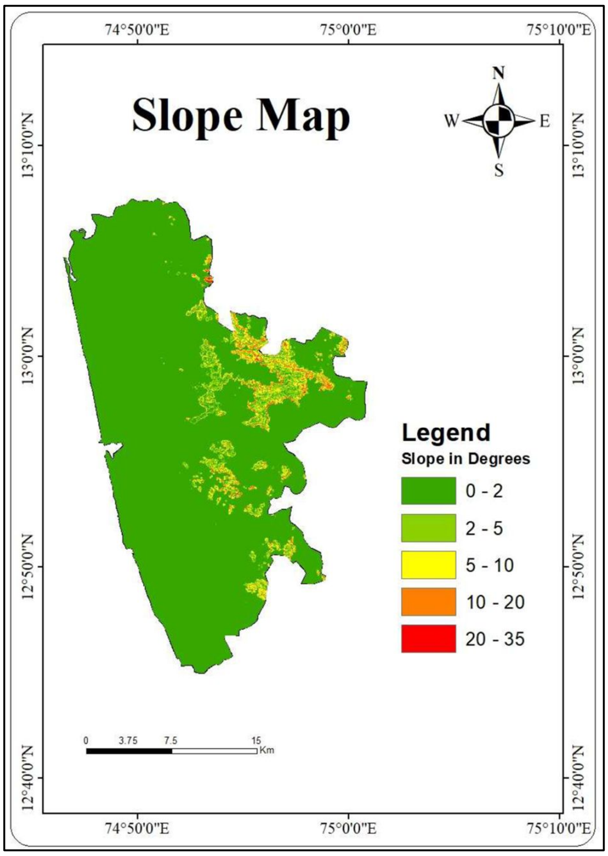

Fig. 3. Slope map

In this study, a slope map created from Cartosat-1 DEM data provided by NRSC in Hyderabad, India, was utilized and is available for free. Most of the area features a predominantly flat landscape, and the slope was categorized into five distinct ranges.

Finally, five classes of slopes in degrees (0-2, 2-5, 5-10, 10-20 and 20-30) were differentiated as shown in Fig. 3, where a steeper slope results in increased runoff and reduced infiltration, leading to poorer groundwater potential compared to areas with gentle slopes. Consequently, greater importance has been given to gentle slopes, while steeper slopes have been assigned less weight.

5.3 Lineament density map

Lineaments are crucial for groundwater recharge in hard rock terrains, and areas near these lineament zones typically exhibit significantly higher groundwater potential. The lineament map sourced from the Bhuvan website was integrated into ArcGIS, allowing for the digitization of the lineaments within the analysis area. This digitized lineament map was then utilized to calculate lineament density using the line density tool, which helps in understanding the spatial distribution of these features. Polygons exhibiting higher lineament density values are anticipated to support greater groundwater recharge, thereby enhancing overall groundwater prospects in those regions. As can be seen from Fig. 4, to provide a clearer assessment, the lineament density was classified into five distinct intervals: Very Low, Low, Medium, High, and Very High. Among these categories, the interval with the highest lineament density received the most significant ranking, reflecting its greater importance for groundwater potential and recharge capacity.

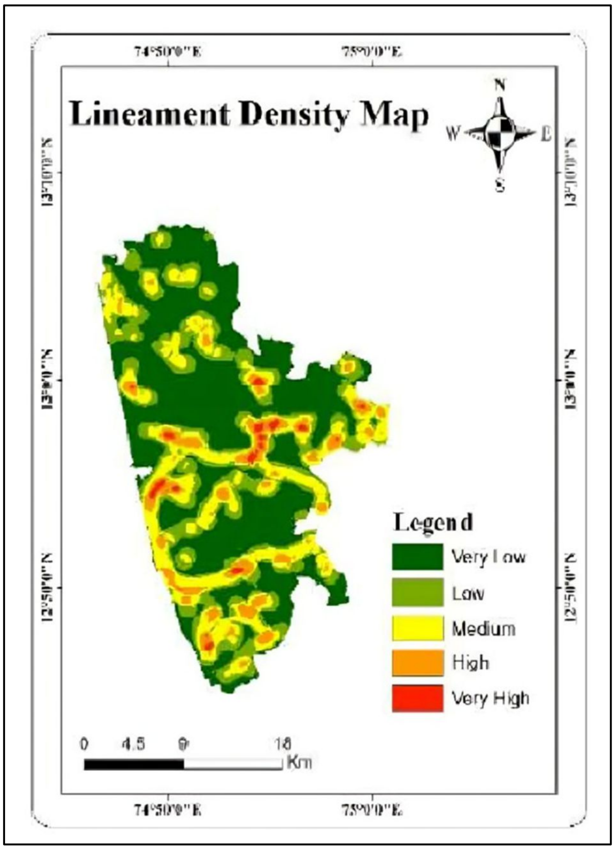

Fig. 4. Lineament density map

5.4 Geomorphology map

The meaning of Geomorphology has an important meaning in the Chambers dictionary, i.e. "the scientific study of the nature and history of landforms on the surface of Earth and other planets, and the processes of their creation".

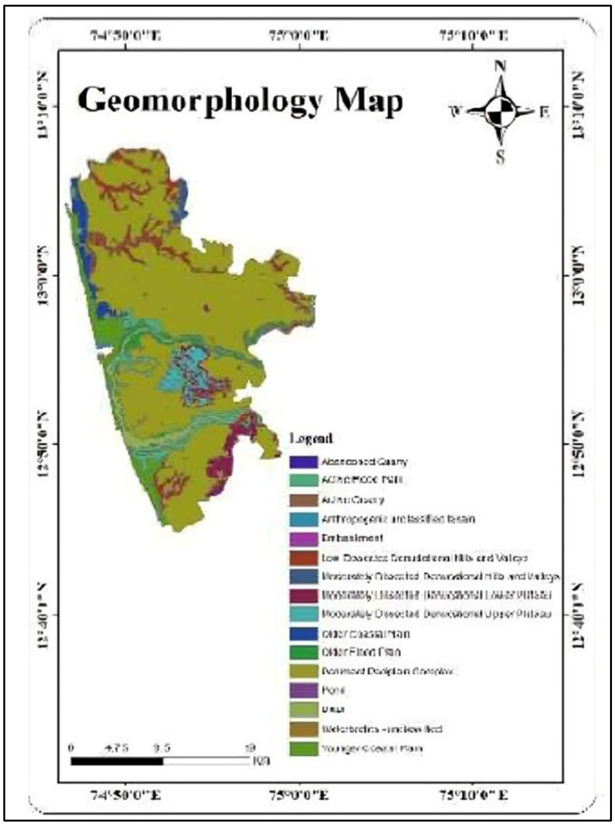

Fig. 5. Geomorphology map

The geomorphological units within the study area were delineated using satellite imagery, and various classes were identified and represented accordingly. The geomorphology map was obtained from the BHUKOSH-Geological Survey of India website. Through the application of the clipping tool in ArcGIS, the geomorphological map specific to the study area was derived. Anthropogenic terrain was assigned a lower weight as a result of human activities. In contrast, the Pediment-Pediplain was assigned the highest weight due to its composition of predominantly bare rock, potentially covered by a thin veneer of alluvium or gravel, which serves as the primary source of groundwater recharge in the region. Highly dissected hills and valleys received the lowest weight, as these areas are characterized primarily by surface runoff (Fig. 5).

5.5 Annual rainfall map

Rainfall plays a major role in groundwater potential; since rainwater is a source for the occurrence of groundwater, the rainfall or precipitation data of the area is very crucial for the delineation of the groundwater potential map. Precipitation data was downloaded from the Centre for Hydrometeorology and Remote Sensing (CHRS) website for the past 10 years. This data was interpolated to obtain the average annual rainfall data of the study area. Annual rainfall map has been divided into 6 categories with rainfall in cm (379-381, 381- 382, 382-384, 384-385, 385-387, and 387-388). As Shown in the Fig. 6, the weights given were proportional to the rainfall.

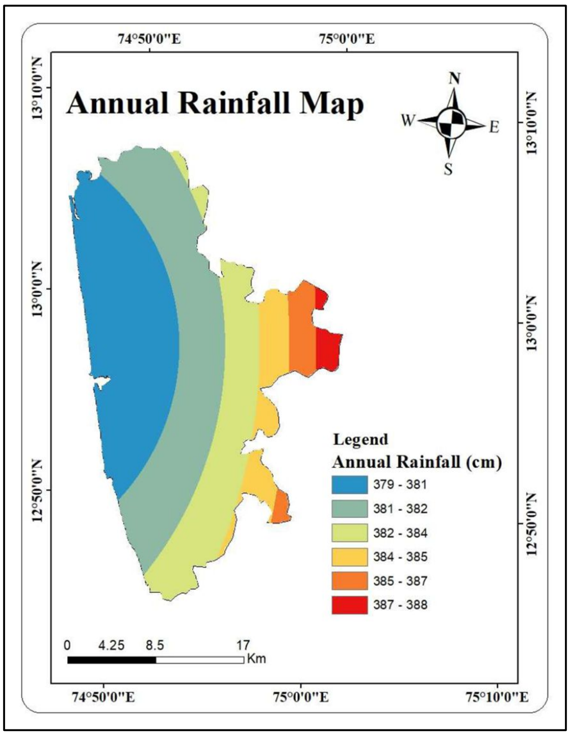

Fig. 6. Annual rainfall map

5.6 Geology map

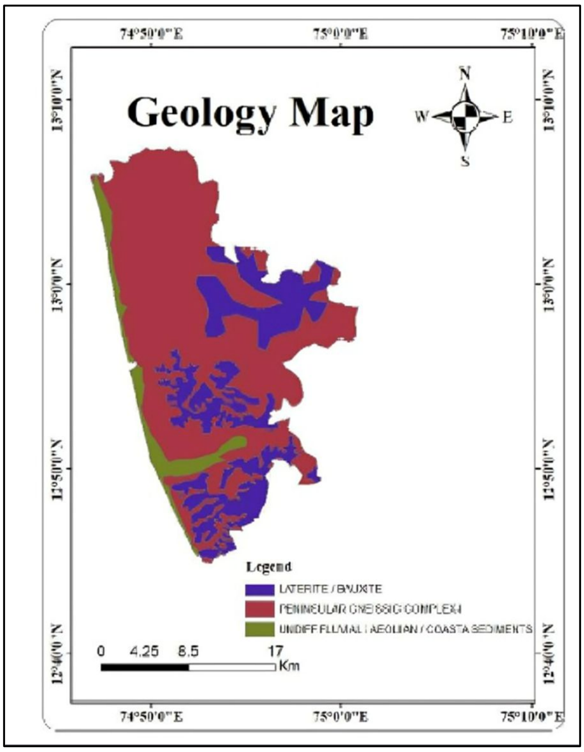

Fig. 7. Geology map

The lithological characteristics of the study area are considered one of the primary controlling factors that influence both the flow and occurrence of groundwater. The arrangement and distribution of different lithological units, as well as the interactions between them, play a crucial role in determining the infiltration capacity of the region. This capacity, in turn, affects how water penetrates the subsurface layers, contributing to groundwater recharge. The porosity and permeability of these lithological units are significant as they determine both the storage capacity and the ability to transmit water through the subsurface. Thus, these properties are essential in supporting the occurrence, movement, and accumulation of groundwater within the region.

The geological map of the study area was acquired from the BHUKOSH-Geological Survey of India website, and the specific map relevant to the study was extracted using the ArcGIS clipping tool. The study area is characterized by three major groups of rock units, which include laterite and the Peninsular Gneiss Complex. These geological formations play a vital role in shaping the hydrological characteristics of the region, influencing both surface-water interaction and groundwater recharge potential (Fig. 7).

5.7 Soil map

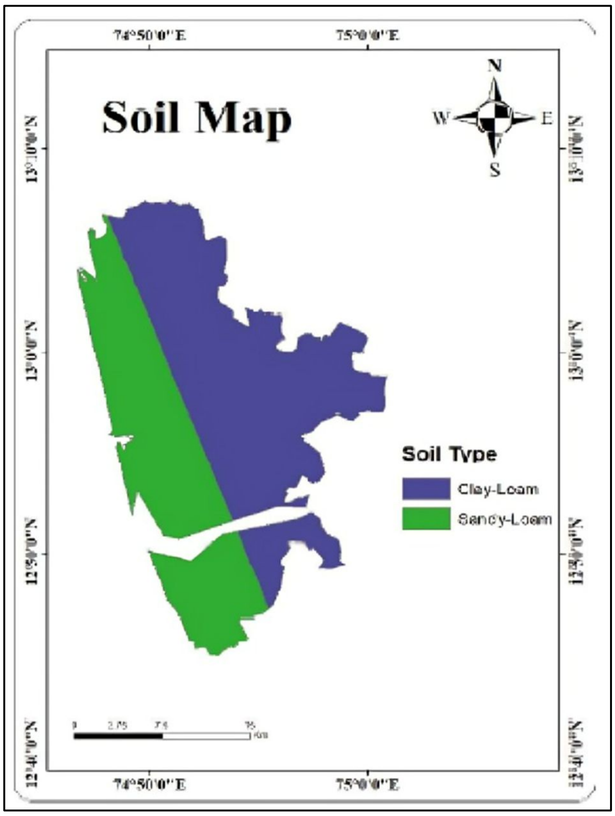

Fig. 8. Soil map

Soil is a critical factor in identifying zones with potential groundwater occurrence. The texture of the soil in a given area significantly influences both surface runoff and the infiltration of rainfall. Soils with a sandy texture exhibit low runoff rates and are associated with high groundwater potential, while clay soils tend to have higher runoff rates and minimal groundwater potential. Sandy soils allow for a high rate of water infiltration, in contrast to clayey soils, which possess a much lower infiltration capacity. These properties make soil texture an essential consideration in groundwater recharge assessments. The soil map of the world was downloaded from the Food and Agricultural Organization (FAO) soil portal. The clip tool in ArcGIS was used to clip the map with our study area. The map is divided according to the legend of the soil map of the world. The study area consists of two types of soil, i.e., sandy loam soil and clay loam (Fig. 8).

5.8 Land use land cover map

The Land Cover tiled imagery layer for the study area was obtained from the ESRI website, and the imagery was clipped using the study area's shapefile in ArcGIS. The classification scheme applied to the resulting map adheres to ESRI's categorization standards, a widely respected authority in geographic information systems. In this study, the Land Use/Land Cover (LULC) data were organized into seven key classes: water bodies, tree cover, flooded vegetation, agricultural crops, built-up areas, bare soil, and rangelands. Each category is integral to understanding the landscape's ecological dynamics and hydrological processes.

Furthermore, within each land use/cover class, specific subclasses were assigned distinct weights based on their respective contributions to groundwater infiltration. This weighting system is crucial for understanding how different land uses impact water absorption and movement within the soil profile. The implications of these classifications and weightings are visually represented in Fig. 9, which provides a clear depiction of the relationships between land use types and their influence on groundwater dynamics. This comprehensive approach enhances our understanding of land management practices and their effects on water resources.

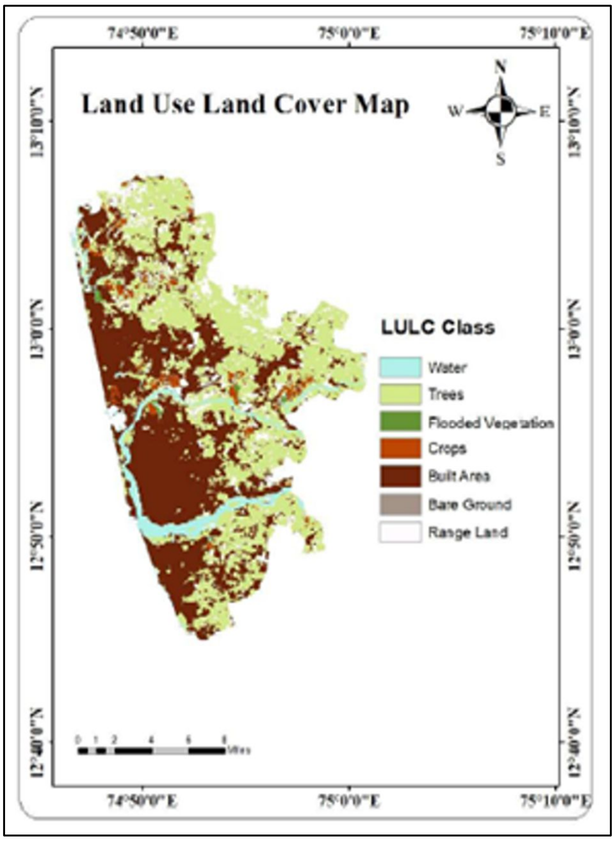

Fig. 9. Land use land cover map

5.9 Preparation of groundwater potential map

Each category within the primary eight thematic layers—geomorphology, geology, slope, drainage density, annual rainfall, lineament density, soil, and land use/land cover—is assigned specific weights according to its influence on groundwater potential. This weighting process ensures that each layer accurately reflects its relative importance in assessing groundwater availability. Each class within a specific thematic layer has been assigned appropriate rankings on a scale from 0 to 5, reflecting their respective contributions to groundwater potential. The percentage influence of each thematic map has been determined based on its overall contribution to groundwater potentiality. Both the weighted values and percentage influence have been allocated to various classes across all thematic layers, ensuring that their role in groundwater recharge and availability is accurately represented. All the thematic maps have been integrated using the union command. A final groundwater potential map is prepared using the above technique. Groundwater potential in the area has been classified into five classes, namely Very low, Low, Medium, High and Very High potential areas (Fig. 10).

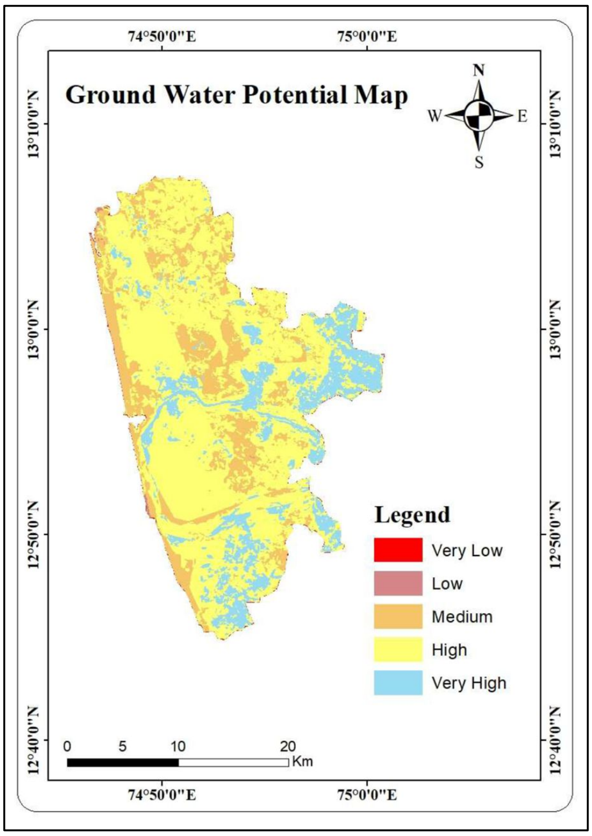

Fig. 10. Groundwater potential map

5.10 Validation

The groundwater potential map was verified using borehole data from the India Water Resource Information System (I-WRIS) portal. Borehole locations were plotted onto the generated groundwater potential map, and the actual yield from each borehole was compared with the predicted values on the map, as illustrated in Fig. 11.

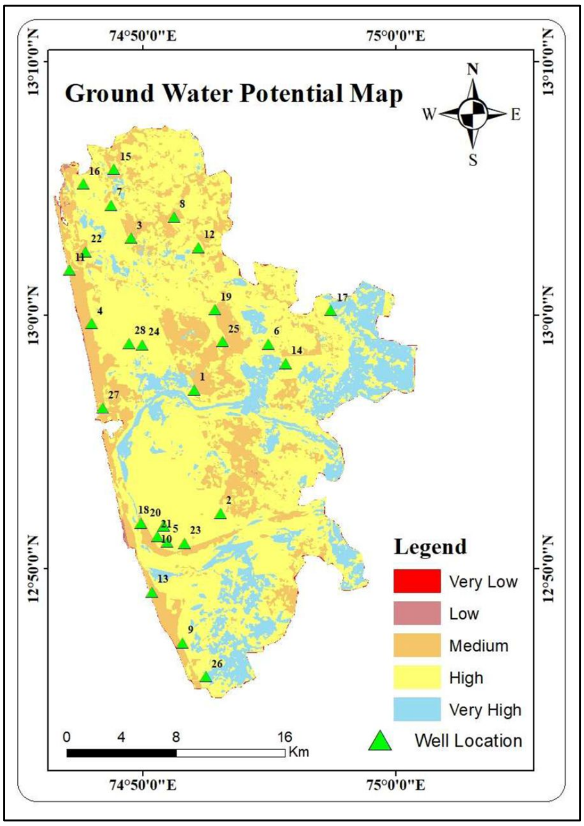

Fig. 11. Groundwater potential map with well location

6 Conclusion

Advanced remote sensing and GIS techniques will be applied to assess and identify potential groundwater zones spatially. Thematic layers will be developed and weighted according to each influencing factor using weighted overlay analysis, ensuring accurate delineation of groundwater potential zones.

The groundwater potential zones were classified into five categories: very low, low, medium, high, and very high potential areas. This classification aids decision-makers in developmental planning. The resultant map was validated using data from 28 bore wells obtained from the India WRIS portal. Of these, 23 bore wells validated the produced map, while 5 bore wells did not, resulting in a map accuracy of 82.14%.

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