Groundwater Potential Zone Assessment using GIS and Remote Sensing

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Abstract: *Over-exploitation of groundwater and marked changes in climate over the years have imposed immense pressure on the global groundwater resources. As demand of water increases across the globe for human consumption, agriculture and industrial uses, the need to evaluate the groundwater potential and productivity of aquifers also increases. This paper aimed to delineate the groundwater potential zones using GIS and remote sensing. Overlay analysis technique is used to develop the groundwater potential prospect zones by integrating different groundwater contributing thematic layers. The thematic layers of land use and land cover, drainage density, lineament density, soil, geology, slope and rainfall were prepared and used for groundwater potential map development by assigning weights to each thematic layer and features. The weights of each thematic layer were assigned based on their importance and relationship with groundwater recharge. Finally, the thematic maps were integrated by Raster calculator tool to develop groundwater potential zones.*

Keywords: GIS, Groundwater Potential, Overlay Analysis, Remote Sensing.

I. Introduction

Groundwater is one of the most precious and limited natural resources on earth. The importance of groundwater for the existence of human society cannot be overemphasized. Groundwater is found underground in cracks and spaces of soil, sand and rocks. Because of its several inherent and natural qualities, recently, groundwater becomes an important and dependable source of water supply for domestic use, agriculture, industry, economic development and ecological diversity in all climatic regions. Being an important factor of the hydrological cycle, its availability depends on rainfall and recharge. The occurrence, origin and movement of groundwater depend mainly on the geologic framework, i.e., lithology, thickness, structures and permeability of aquifers. The rate of groundwater flow is controlled by two properties of the rock porosity and permeability. The main sources of groundwater recharge are precipitation and flow and of discharge include effluent seepage into the streams and lakes, springs, evaporation and pumping.

It is estimated that approximately one third of the world's population use groundwater for drinking. Groundwater is the source for irrigation and domestic purpose. In which 80% of the rural areas are use groundwater for domestic purpose and 50% of the urban areas use the groundwater for domestic purposes. Water is essential for life, and groundwater is estimated to constitute more than ninety five percent of the global, unfrozen freshwater reserves. The remaining freshwater supplies are found in lakes, rivers, wetlands and the atmosphere. Groundwater is a renewable resource which when managed properly. ensures a perpetual supply. The occurrence and movement of groundwater in an area is governed by several factors such as topography, lithology, geology, rainfall, lineament, depth of weathering, slope, drainage, elevation of area, land use etc. GIS and Remote Sensing techniques in combination have proved to be effective tool in delineating groundwater potential zones. The present work accentuated the expediency of remote sensing and geographic information system (GIS) applications in groundwater studies, especially in the identification of groundwater potential zones in Thiruvananthapuram District, Kerala, India. The information on geology, drainage density, rainfall, soil, lineaments, slope and land use/land cover were gathered from Sentinel 2 data and SRTM DEM data in addition, GIS platform was used for the integration of various themes. The composite map generated was further classified according to the spatial variation of the groundwater potential. Three categories of groundwater potential zones namely Low, Medium and High were identified and delineated.

The procedure adopted involves assignment of ranks to each map on the basis of their influence on groundwater movement and storage and then reclassifying them according to the given ranking and giving weightages to each thematic map and then output map scores into different zones using raster calculator. By analysing different thematic layers using the weighting and ranking method, groundwater potential zone map has been generated by giving certain formula for the Thiruvananthapuram District. The resultant groundwater prospect zones map of Thiruvananthapuram District shows three zones such as Low, Medium and High. Most of the study area covers moderate potential zone. Technologies like GIS and Remote Sensing are powerful tools for the development and identification of groundwater potential areas.

Remote sensing is the acquisition of information about an object or phenomenon without making physical contact with the object and thus is in contrast to on-site observation. The term is applied specially to acquiring information about the Earth Remote sensing is used in numerous fields, including geography, land surveying and most Earth science disciplines (for example, hydrology, ecology, meteorology. oceanography, glaciology, geology); it also has military, intelligence, commercial, economic, planning, and humanitarian applications, among others. A geographic information system is a computer system for capturing, storing, checking, and displaying data related to positions on Earth's surface. By relating seemingly unrelated data, GIS can help individuals and organizations better understand spatial patterns and relationships.: GIS allows viewing, understanding questioning, interpreting and visualizing data in many ways that reveal relationships, patterns and trends in the form of maps, globes, reports and charts.

ArcGIS is an information system for geographical data presentation and analysis developed by Environmental System Research Institute (ESRI) Like all information system ArcGIS has a well-defined model for working with data. This model called geodatabase (geographic database) defines all the types of data that can be used in ArcGIS.

II. Application Of GIS And Remote Sensing In Groundwater Potential

Groundwater is dynamic and replenishes able resource. The exploitation and exploration of groundwater resources needs to understanding geology, geomorphology of that area. The data and thematic maps such as satellite images, soil data, geology data, drainage data and rainfall data, are helpful for mapping of groundwater potential zones. Remote sensing data combined with Geographical Information System technique is very efficient in identification of groundwater potential of any region. The study results that the integration of thematic maps prepared from conventional and remote sensing techniques using GIS gives more and accurate results. Groundwater is available when water infiltrates below the earth surface and soil beneath the earth surface is porous. Groundwater table reduces when pumping rate is more than the rate of usage. Hence, it can be concluded that areas of high withdrawal rates may lead to reduction of groundwater zones. This may lead to reduced water level in wells, lakes and streams. Groundwater is a hidden natural resource and cannot be directly detected therefore; mapping of this resource can be a challenging task. Depiction of groundwater potential zones (GWPZ) is necessary for the optimal usage of available water resources to meet the needs of the communities Stratigraphy analyses and test drilling are the traditional and effective techniques for identifying the locations of an aquifer, but these processes are cost and time-consuming Integration of remote sensing data in the geographical information system surroundings represents an effective alternative for the identification of GWPZs.

Remote sensing offers a repetitive coverage of an area in a systematic, synoptic, fast, and low-cost way with a combination of different ranges of the electromagnetic spectrum radiated from various earth features. Remote sensing (RS) represents an exclusive and powerful tool for obtaining spatiotemporal data of sizable areas in a short period of time based on indirect analyses of some directly observable terrain features Application of RS in hydro geological investigation and monitoring can provide significant information in spatial and temporal scales, which is important for effective analysis, prediction, and validation of water resources models. The ability of satellite imagery to cover large spatial scales is essential for the depiction of basins physiographic characteristics, such as land use/land cover, slope, and drainage density as well as structural characteristics such as fractures, faults, and cleavages. Such characteristics are major requirements for groundwater resources evaluation and exploration and were used by many researchers for GWPZS delineation. Geographic information system provides a distinguished work environment for efficiently processing and storing geo-referenced data compiled from various sources such as satellite imagery, maps, and land surveys RS and GIS capabilities of collecting and manipulating data covering large scales within a short time represent handy tools in demarcating, assessing, and conserving groundwater resources. With such capabilities, many databases can be integrated to generate conceptual models for the identification of GWPZs of an area.

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III. Study Area

Thiruvananthapuram District is the southernmost district in the Indian state of Kerala. The study area lies between 8°17′ to 8°51′ N latitude and 76°41′ to 77°17′ E longitudes. The district was created in 1949, with its headquarters in the city of Thiruvananthapuram, which is also Kerala's capital The present district was created in 1956 by separating the four southernmost Taluks of the erstwhile district to form Kanyakumari district. The district is home to more than 9% of total population of the state. The district covers an area of 2,192 square kilometers (541,655 acres) It had a population of 34,545,868 making it the second most populous district in Kerala after Malappuram district. The district is divided into six sub districts: Thiruvananthapuram, Chirayinkeezhu, Neyyattinkara, Nedumangadu, Varkala, and Kattakada. The urban bodies in the district are the Thiruvananthapuram Corporation, and the Varkala, Neyyattinkara, Attingal, and Nedumangadu municipalities.

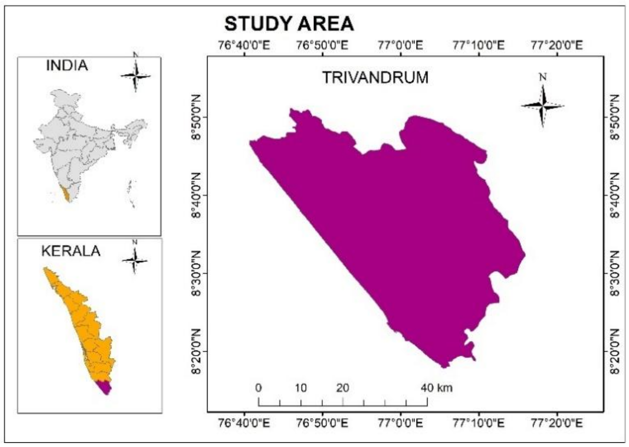

Figure 1: Study area map

The district has a climate that borders between tropical savanna climate and tropical monsoon climate, In a broad sense, it can be said that the district experience a tropical monsoon climate. The annual variation of mean air temperature at Thiruvananthapuram district is from 21° C to 34° C. The humidity is high and rises about 90% during the monsoon season. The average annual rainfall of the district is 2035mm. It is significant that the district gets benefits of both monsoon-southwest monsoon and northeast monsoon. The district is characterized by very high precipitation which is spread over very few wet days and a long dry season (December- May) and a marked gradient from the eastern hilly region to the sea rapidly re conveying the rainfall back to the sea through short, fast, west flow.

IV. Methodology

The study aims to identify the areas favorable for recharge of groundwater by integrating various thematic layers prepared using remote sensing and GIS technologies. Both spatial and attribute data were used for preparation of various thematic layers. The SRTM DEM data were used for the landscape analysis. Sentinel 2 data was used for the preparation of Land use map. Geology map was prepared from the data available from Geological Survey of India. Soil data was obtained from Soil Survey of India. Monthly Rainfall data was obtained from the website Soda. The lineament data was downloaded from Bhukosh. The weighted overlay analysis technique was employed to determine the groundwater potential zones. The weightages of individual themes and feature score or rank were prioritized depending upon their suitability to hold groundwater. Of several methods available for determining interclass/intermap dependency, a probability weighted approach has been adopted that allows a linear combination of probability weights of each thematic map and different categories of derived thematic maps have been assigned scores depending upon their suitability to hold groundwater. Spatial analyst extension of Arc GIS 10.2 was used for converting the features to raster and also for final analysis in this method, the total weights of the final integrated map were derived as sum or product of the weights assigned to the different layers according to their suitability.

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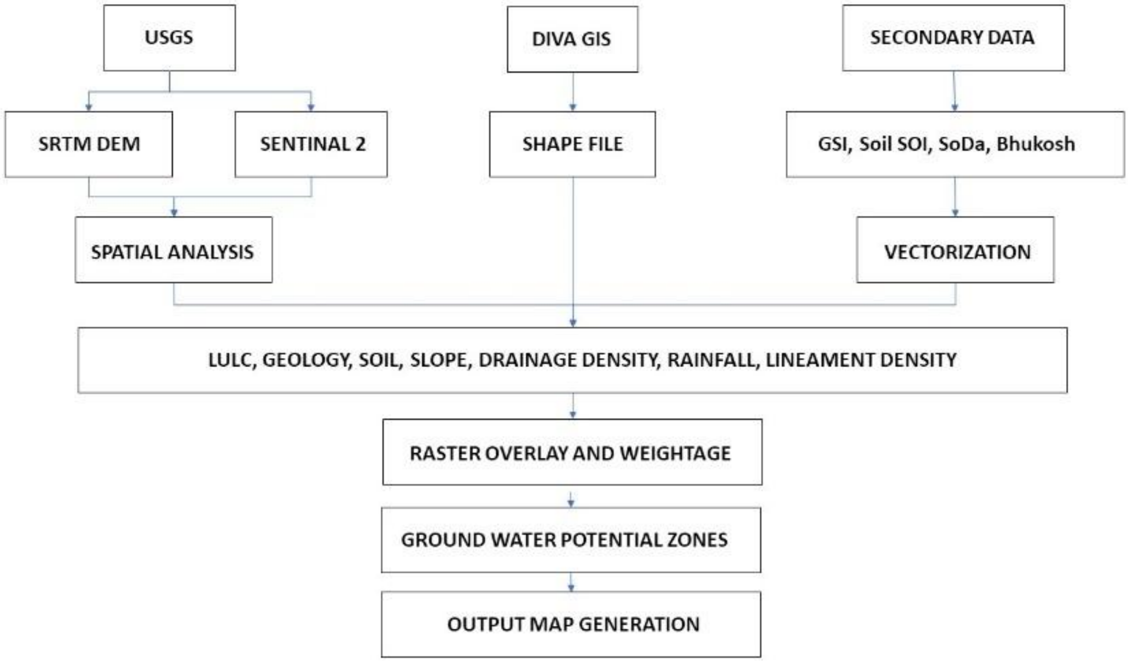

Figure 2: Workflow diagram

V. Results And Discussion

The various thematic data derived for the analysis of groundwater potential zones and the resultant composite map this obtained are discussed below in detail.

5.1 Rainfall

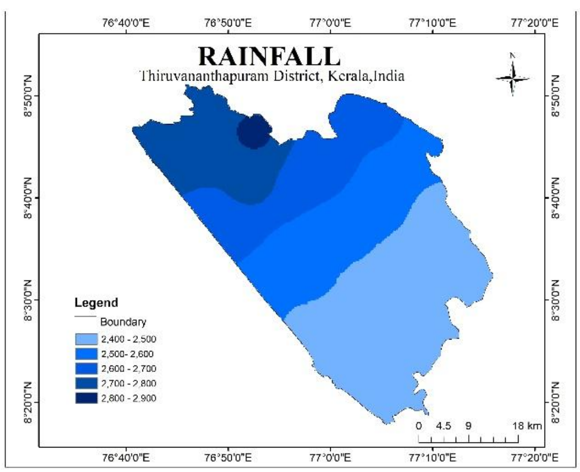

Figure 3: Rainfall map

Rainfall is one of the important factors which highly influence the recharge rate into aquifers. The water that could be percolating into the groundwater system is largely a function of the amount of rainfall. This is due to the fact that main source of the natural hydrologic cycle, which are largely controls Groundwater potential. The monthly rainfall for one year period was obtained from 20 rainfall measurement stations within the study area. Finally the rainfall map of the study area was prepared from the average monthly rainfall of each station using IDW interpolation method in ArcGIS 10.2 software. The average annual rainfall of the area ranges from 2413.78 – 2841.5 mm. The rainfall map was classified into five ranks from rank 5 to rank 1. Since the rainfall directly influences the amount of water availability for infiltration into the subsurface, areas with high amount of rainfall are classified as very good prospect sites for groundwater recharge and vice-versa for areas with low rainfall amount.

5.2 Slope

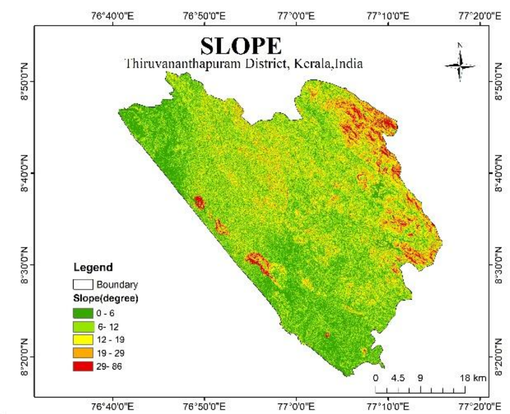

Figure 4: Slope

Slope is the rate of change of elevation and considered as the principal factor of the superficial water flow since it determines the gravity effect on the water movement. The slope is directly proportional to runoff and groundwater recharge will be lesser in the areas with steep slope. The water flow over the gently undulating plains is slow and adequate time is available to enhance the infiltration rate of water to the underlying fractured aquifer. The slope was estimated from the SRTM Digital Elevation Model (DEM) which was obtained from the USGS earth explorer. The slope of the study area ranges from 0 to 23 degrees and is classified into five classes. The slope less than 6% is considered as relatively flat, which is usually a very good subsurface recharge zone because of low runoff. Most of the study area comes under the rank 5.

5.3 Drainage Density

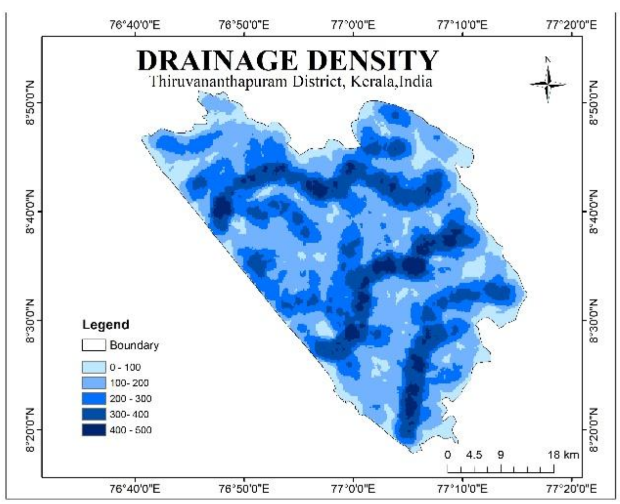

Figure 5: Drainage density map

Drainage density is expressed terms of length of channels per unit area, and indicates the closeness of the spaces between stream channels. It is the inverse of permeability which plays a vital role in the runoff distribution and level of infiltration. It provides a quantitative measure of the average length of stream channels within different parts of the area. High drainage density is related to higher recharge and higher Groundwater potential zone. Drainage density map of the study area was calculated by using line density analysis tool in ArcGIS 10.2. The drainage density is classified as five ranks. High drainage density has high rank and vice-versa.

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5.4 Soil

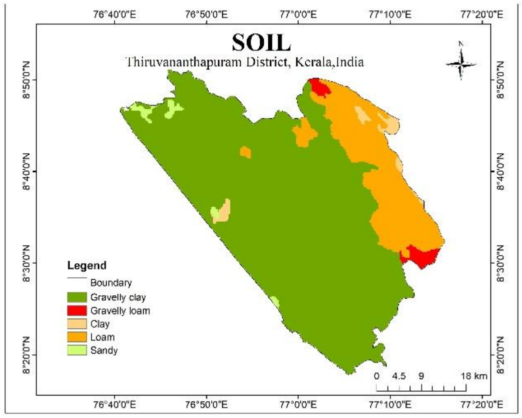

Figure 6: Soil

Soil is an important medium which highly determines the rate of groundwater recharge potential by using characteristic nature of transmissivity and water- bearing capacity. It significantly affects the movement of surface water into aquifer system and they are directly related to rates of infiltration, percolation and permeability. Soil characteristics have a considerable role on the infiltration of water. The rate of infiltration largely depends on the grain size of soils. There are mainly five soil types in the study area which include Gravelly clay, Gravally loam, Clay, Loam and Sandy. In these, Riverine alluvium has the highest rank which followed by Coastal alluvium, Brown hydromorphic soil and Lateritic soil.

5.5 Lineament Density

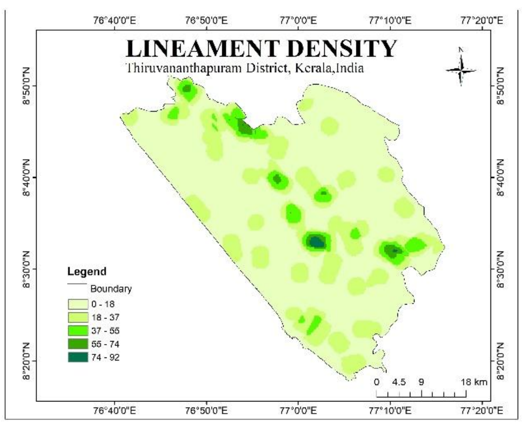

Figure 7: Lineament density map

The lineaments are linear features, developed by the tectonic activity; reflect a general surface manifestation of underground fractures, with inherent characteristics of porosity and permeability of the underlying materials. Lineaments are the main conduits of groundwater in impermeable rocks worldwide. Indeed, the fracture planes constitute the useful void volume corresponding to the potential space able to be occupied by the water in such medium. Lineament density is one among important governing factor to identify the Groundwater potential zones. Only a small lineament is seen in the study area.

5.6 Geology

Geology plays a great role in porosity and permeability of rock. The higher the porosity contributes to higher groundwater storage and higher permeability contributes to higher groundwater yield. The geology of Thiruvananthapuram district contributes Basic rocks, Charnockite Group, Khondalite Group. Laterite, Migmatite complex, Sand and Silt, Sandstone and clay with lignite interc.

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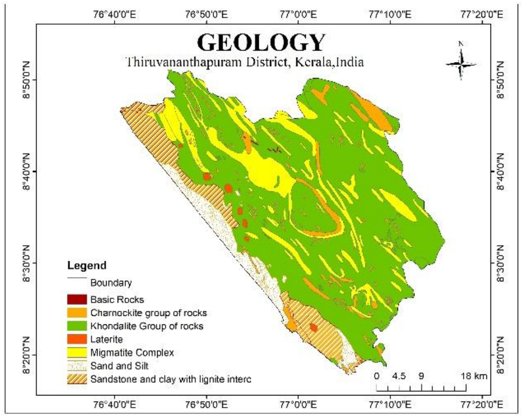

Figure 8: Geology map

5.7 Land use/ Land cover

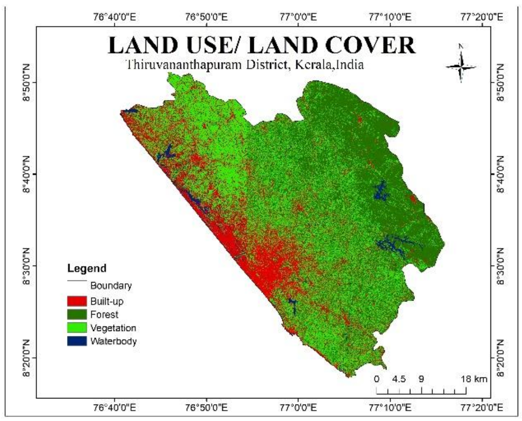

Figure 9: Land use and land cover map

The Land use / Land cover (LU/LC) gives the necessary information on infiltration, soil moisture and surface water and highly determines the occurrence and development of groundwater. The LU/LC patterns of the study area identified by using cloud free Sentinel 2 images of 2022. The LU/LC pattern of the study area includes Built-up, Forest, Vegetation and Water body. The dominant land use class is water body so this has given the high rank and is followed by Forest, Vegetation and finally Built up. The weightage of individual features and their ranks are given in Table 1.

Table 1: Weightages and Rankings Assigned to Thematic Layers for Assessing Groundwater Potential Zones

No	Factor	Domain effect	Rank	Map weight
1	Rainfall	2400 – 2500	1	23
		2500 – 2600	2	
		2600 – 2700	3	
		2700 – 2800	4	
		2800 – 2900	5	
2	Slope	0 – 6	5	20
		6 – 12	4	
		12 – 19	3	
		19 – 29	2	
		29 – 86	1	
3	Drainage Density	0 – 100	1	
		100 – 200	2	

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		200 – 300	3	15
		300 – 400	4	
		400 – 500	5	
4	Soil	Gravelly clay	2	12
		Gravelly loam	4	
		Clay	1	
		Loam	3	
		Sandy	5	
5	Lineament density	0 – 18	1	10
		18 – 37	2	
		37 – 55	3	
		55 – 74	4	
		74 – 92	5	
6	Geology	Basic rocks	1	10
		Charnockite Group	1	
		Khondalite Group	2	
		Laterite	3	
		Migmatite complex	2	
		Sand and Silt	4	
		Sandstone and clay with lignite interc	4	
7	Land use and land cover	Built-up	1	10
		Forest	3	
		Vegetation	2	
		Water body	4	

5.8 Groundwater Potential Zone

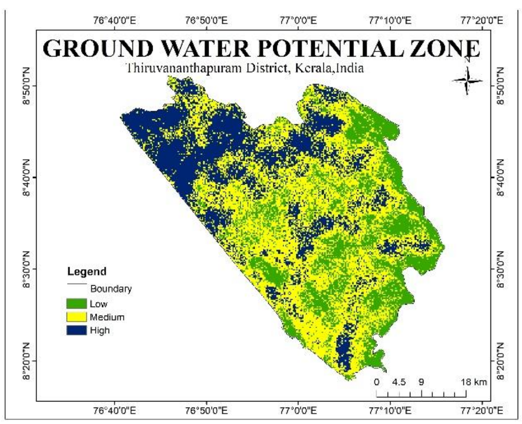

Figure 10: Groundwater potential zone map

The investigation was conducted with objective to delineate the areas with promising groundwater zones in Thiruvananthapuram District and the composite map of groundwater potential zones summarizes the results. In the present study, the choice among a set of zones for development of groundwater is based upon multi criteria evaluation technique, which gives linear combination of probability weights for different themes taken for the study.

A better understanding of the ground water potential is of paramount important for planning and sustainable development of an area. Such information is essential for the design and implementation of structures for corrective measures to improve the groundwater recharge processes. The parameters that are considered here are Rainfall, Soil, Lineament density, Drainage density, Geology, Soil and Slope. The weighted overlay method has been applied to generate the groundwater potential zones in the Thiruvananthapuram District. The groundwater potential zone of the study area is classified into three classes which include, High, Medium and Low. As seen from the figure, most of the high and medium groundwater potential zones occur predominantly on the slopes of less than 6° regions. Also, high ground water potential zones are confined generally to high rainfall regions, which in turn have a high infiltration potential.

VI. Conclusion

With the increasing demand for water, it would become necessary to use more and more of groundwater. Groundwater became a precious commodity and its quantity and quality is threatened by various factors such as deforestation, urbanization, unscientific agriculture practices, pollution etc. For the sustainable management of groundwater resource, effective measures need to be taken into increase the recharge into the groundwater reserves. The Remote sensing and Geographic Information System approach is very constructive because this integrates various geospatial information, especially in groundwater potential zone mapping. The study has focused on the effectiveness of remote sensing and GIS in the identification and delineation of groundwater potential zones of Thiruvananthapuram District, Kerala, India.

The identification of groundwater potential zone revealed that most of the region with moderate groundwater potential and soil types indicate possibility for the storage of water. The spatial distribution of various zones of groundwater potential obtained generally shows regional prototypes related to geology, landforms, soil and lineaments. Groundwater potential map is the result of a systematic effort of integration of various factors which influence the water yields. The present study using GIS and Remote Sensing techniques has helped in delineating the study area into different zones of groundwater recharge potential such as low, medium and high. Such zonation assumes importance in planning strategies for effective management of the water resources. Remote sensing and GIS tools are less time consuming and cost effective, which provide sufficient support in groundwater studies. The overall results demonstrate that remote sensing and GIS provide potentially powerful tools for studying groundwater resources and designing a suitable exploration plan The integrated map could be useful for various purposes such as sustainable development of groundwater as well as identification of priority areas for implementation of water conservation projects and programmes in the area. The overall study reveals that the Thiruvananthapuram District mostly consists of medium groundwater potential zone.

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