IDENTIFICATION OF GROUND WATER POTENTIAL ZONES USING GIS AND REMOTE SENSING

Aathira Santhosh[1], Devika Varma[2], Gayathry T.J[3] , Nimisha K.J[4], Anjali Ann Johnson[5]
[1,2,3,4]Graduate students, [5]Asst. Professor,Dept. of Civil Engineering,
Adi Shankara Institute of Science & Technology, Kalady,India

Abstract
The issue of unsustainable groundwater utilization is becoming increasingly an evident problem and the key concern for many developing countries. One of the problems is the absence of updated spatial information on the quantity and distribution of groundwater resource. Groundwater evaluation has been usually conducted using field survey which is not feasible in terms of time and resource. This study was conducted in Muvattupuzha block, Ernakulam district, Kerala, India to spatially delineate the groundwater potential areas using geospatial analysis. To do so, eight major biophysical and environmental factors like geomorphology, geology, slope, soil,rainfall,LULC, lineament density and drainage density were considered. The sources of these data were satellite image, digital elevation model (DEM), existing thematic maps and meteorological station data. The geomorphology, soil, land use and land cover(LULC), lineament density and geology of the area were identified and classified through field survey and digitized from existing maps using the Arc GIS 10.3 software. The slope and drainage density of the area were derived from DEM using spatial analyst tools. The rainfall map was prepared using the data obtained from the Indian Meteorological Department (IMD) gauge stations. These data were then spatially interpolated using Inverse Distance Weighted (IDW) method to obtain the rainfall distribution map. Finally, after all these thematic maps were organized, weighted value was computed. At last, all the factors were integrated together and computed using the weighted overlay analysis so that potential groundwater areas were mapped. The result revealed that the study area can be categorized into three different groundwater potential zones: Excellent, medium and low.Subsequent validation with boreholes/well yield data revealed a good correlation with respect to the observed groundwater potential zonation.

Index Terms: GIS software, Ground water potential zones, India, Muvattupuzha, Remote sensing, Weighted overlay analysis.

I. INTRODUCTION

Ground water is the water located beneath the earth's surface in soil pore spaces and in the fractures of rock formation. Groundwater is a globally important and valuable renewable resource. Water bearing formations of the earth's crust act as conduits for transmission and as reservoirs for storing water.Groundwater in any region shows large spatial and temporal variations in its occurrence and distribution. The occurrence of groundwater at any place on the earth is not a matter of chance but a consequence of the interaction of the climatic, geological, hydrological, physiographical and ecological factors.

Groundwater is usually held in porous soils or rock materials. The area where water fills these spaces is called the saturated zone; the top of this zone is called the water table. The water table may be shallow (only a foot below the ground surface) or it may be deep and may rise or fall depending on many factors. Heavy rains or melting snow may cause the water table to rise while an extended period of drought may cause the water table to fall.

Tremendous increase in the agricultural, industrial and domestic activities in recent years has increased the demand for groundwater. Although, this is primarily influenced by the uneven distribution of precipitation, other factors like topography, geomorphology, land use and hydrogeology also play a critical role.

The groundwater occurrence in a geological formation and the scope for its exploitation primarily depends on the formation of porosity. High relief and steep slopes impart higher runoff, while topographical depressions increase infiltration. An area of high drainage density also increases surface runoff compared to a low drainage density area. Surface water bodies like rivers, ponds, etc., can act as recharge zones.

Ground water potential zones are the zones which mark the availability of groundwater. Identification of potential groundwater zones could aid in proper development and utilization of both groundwater and surface water resources for eliminating water scarcity and thereby improving the irrigation practices and agricultural income for standard living conditions of the society. Uneven distribution of ground water within a year and indiscriminate exploitation of water resources often results in floods during the monsoon season and significant water deficit during the non-monsoon season .Appropriate and efficient techniques are necessary to locate potential sites for drilling of wells and for putting up artificial recharge structures in order to ensure sustainability of well yields and counter the problem of water table depletion.

Rapid advances in the development of the GIS provides spatial data integration and tools for natural resource management has been proved to be an efficient and successful tool for groundwater studies .Geographical Information system, also called geo based information system (GIS), is relatively new technology. It is a very powerful tool for processing, analyzing and integrating spatial data sets. The integration of remote sensing and GIS has proven to be an efficient tool in groundwater studies , where remote sensing serves as the preliminary inventory method to understand the groundwater prospects/conditions and GIS enables integration and management of multi-thematic data. It produces valuable data on geology, geomorphology, lineaments and slope as well as a systematic integration of these data for exploration and assessment of groundwater potentials zones. The effective management of groundwater resource can be done only when there is an adequate knowledge about its spatial and temporal distribution. Thus remote sensing techniques give a new dimension to the effective management by satisfying the primary need and helps in real time analysis of such scarce and valuable resources.

In the recent years, there have been wide applications of RS and GIS in hydro geological researches. A number of workers such as Edet et al. (1997), Murthy (2000), Obi Reddy et al. (2000), Pratap et al. (2000), Singh and Prakash 2002 and Jaiswal et al. (2003) have used GIS to delineate groundwater potential zone, while Sreedevi et al. (2001) also applied remote sensing techniques in the delineation of groundwater potential zones. Furthermore, many authors such as Krishnamurthy et al. (1996), Murthy (2000), Srivastava and Bhattacharya (2006), Shahid et al. (2000) and Khan and Maharana (2002) have applied both remote sensing techniques and GIS applications in groundwater exploration, delineation of groundwater potential zones as well as identification of artificial recharge sites. In addition, El-kadi et al. (1994), Novaline et al. (1999), Shahid et al. (2000), Boutt et al. (2001), Saraf et al. (2004) Rokade et al. (2007) and Gumma and Pavelic (2013) have carried out groundwater modelling through the use of GIS. In addition, GIS has also been considered for multi-criteria analysis in resource evaluation, for example Saraf et al. (2004) and Rao and Jugran 2003 have used GIS technology for processing and interpretation of groundwater quality data.

The present study employed GIS and RS techniques to integrate geological, geomorphologic as well as climatic data in respect of groundwater resources evaluation of the Muvattupuzha block. The intent is to identify the groundwater potential zones of the study area and to develop a prospective guide map for groundwater exploration/exploitation so as to ensure optimum and sustainable management of this vital resource. The composite map generated was further classified according to the spatial variation of the groundwater potential namely poor, moderate, good and very good were identified.

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Objective

- The primary objective of the study is to contribute towards systematic groundwater studies utilizing Remote Sensing and Geographic Information Systems (GIS) in the identification of groundwater potential area of Muvattupuzha block and validate the results.
- To counter ill effects caused by the overexploitation of groundwater .
- To assess the potential zone of groundwater recharge for the protection of water quality and the management of groundwater systems.
- To remove water stress condition over the years , caused by the increasing need for of groundwater.
- To find a cost and time effective technique for proper evaluation of groundwater resources and management planning to prevent the unscientific exploitation of groundwater.

A. Study area

Study area selected is Muvattupuzha block which is situated near Muvattupuzha river basin.It is having an area of 225 Km2. Muvattupuzha river is one of the major perennial rivers in central Kerala. It originates from the western Ghats and drains mainly through highly lateritised crystalline rocks. It debouches into Vembanad estuary near Vaikom. It is bounded by Periyar river basin on north and Meenachil river basin on south. The Muvattupuzha drainage basin enjoys characteristic tropical humid climate. The high altitude areas of this basin have a temperate climate. The average annual rainfall of the study area is 2677 mm

Fig1:Map of the study area

B. SOFTWARE USED

Arc GIS 10.3 of Esri was used as the spatial platform for integrating various maps. Arc GIS deals with information on location patterns of features and their attributes. It can be considered a higher order computer coded map which permits storage, selective dedicated manipulation, display and output of spatial information.It is a very powerful tool for processing, analyzing and integrating spatial data sets.The integration of remote sensing and GIS has proven to be an efficient tool in groundwater studies , where remote sensing serves as the preliminary inventory method to understand the groundwater prospects/conditions and GIS enables integration and management of multi-thematic data

II. METHODOLOGY

Details of data Collected:

- Digital Elevation Model (DEM) was downloaded from ASTER and updated using toposheet of 1:25000 scale.
- Map of Muvattupuzha block have been downloaded from Kerala State land use board.
- Drainage, drainage density and slope maps were obtained from DEM map.
- Geology, Geomorphology, land use land cover(LULC) and lineament density maps were obtained from Kerala State Land use board.
- Annual rainfall data for the period 2016-17 was got frommetrologicalDepartment,Thiruvananthapuram.
- Soil map was got from the Dept. Of soil survey & soil conservation.
- Ground water level data was collected from Groundwater Department, Kakkanad.

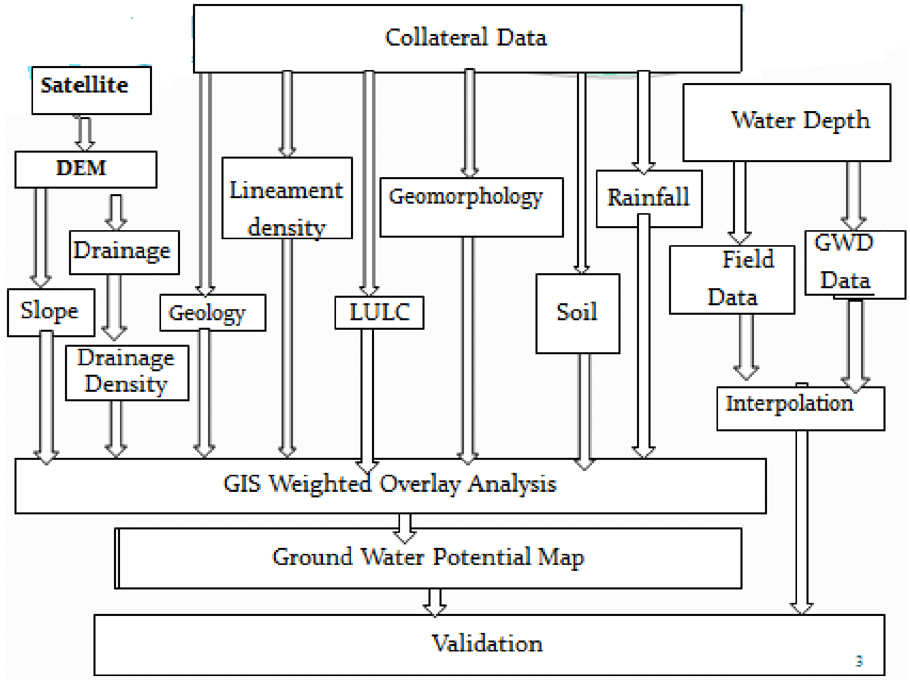

Fig.2:flowchart showing methodology.

Stages of work:

Integrated remote sensing and GIS based approach is a powerful tool for assessing groundwater potential zones based on which suitable locations for ground water withdrawals could be identified. Methodology for preparing ground water potential zones map in the study area is presented. It involves in the following steps:

- The first stage includes map preparation .Drainage map, drainage density map and slope map were prepared by analysing DEM. Drainage map was updated using toposheet.
- Geology, Geomorphology, land use land cover(LULC) and lineament density maps were geo referenced , edited using Arc tools .
- The collected annual rainfall data of 5 stations for the period 2016-17 had information about the particular rain gauge station so the method Inverse Distance Weightage (IDW) in ArcGIS was used to find out overall rainfall variation in the study area
- Weighted Overlay Analysis is used for assigning weightage (%) and ranks to various themes and features class by assessing the suitability to hold ground water. Highest rank (5) was given for the factor that has more influence on ground water recharge and the lowest rank(1) for the least influential one. The weights and ranks are presented in Table (1).
- All the themes are further converted into raster format, processed and analysed in Overlay and finally Ground water potential map was prepared.
- The composite map generated was further classified according to the spatial variation of the groundwater potential. Four categories of groundwater potential zones namely poor, moderate, good and very good were identified and delineated.
- For ground truth verification,the groundwater level data (attributes) were imported into spatial theme for GIS analysis.

III. FACTORS INFLUENCING GROUND WATER POTENTIAL ZONES

A. Drainage Density map

A drainage basin is a natural unit draining runoff water to a common point.Drainage map consists of water bodies, rivers, tributaries, perennial & ephemeral streams, ponds.Drainage map is prepared by the analysis of DEM map of the study area. The Hydrology tools are used to extract hydrologic information from a DEM.

Drainage density is defined as the closeness of spacing of stream channels. It is the measure of total length of stream segment of all orders per unit area. Drainage density is an inverse function of permeability. The less permeable a rock is, the less the infiltration of rainfall which conversely tends to be concentrated in surface runoff. Slope affects the drainage density and it produces differences from place to place. The line density tool of spatial analyst is used to get density map from the drainage map According to drainage density, study area is divided into 4 classes: very low, low, medium, high and very high.

Fig3: DEM map of Muvattupuzha

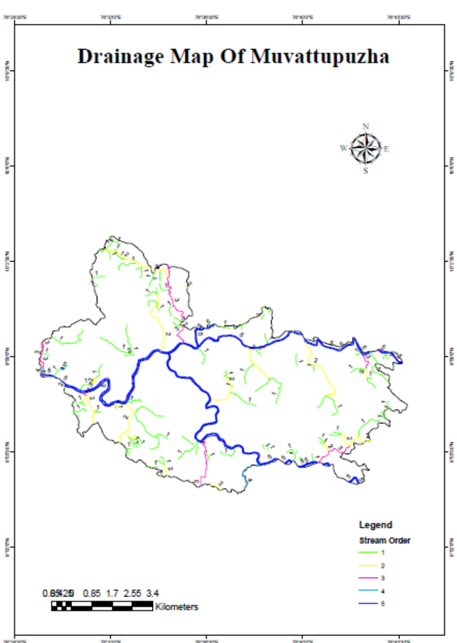

Fig 4 :Drainage map of the study area

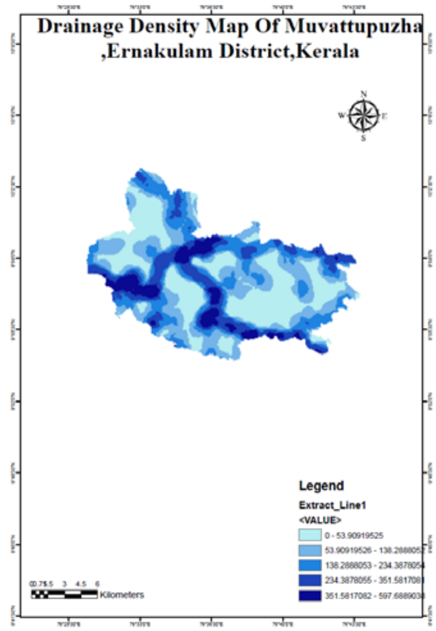

Fig 5: Drainage density map of study area

B. Slope map

Slope is the rate of change of elevation and it is considered as the principal factor of the superficial water flow since it determines the gravity effect on the water movement. Slope is directly proportional to run-off. In steep slopes ground water recharge will be less. 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 Digital Elevation Model (DEM). In this study, slope is given the maximum weightage. Different classes of slopes are nearly level, very gently sloping, gently sloping, moderately sloping and Strong sloping. Moderate slopes were categorized as “good” due to slightly undulating topography which gives maximum percolation or partial runoff. The steep class, having high surface runoff with a negligible amount of infiltration was assigned to the “poor” category.

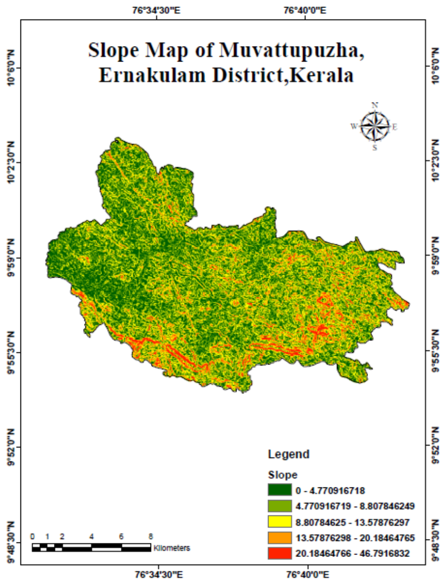

Fig 6: Slope map of study area

C. Geology map

Ground water holding capacity of rocks depends on compactness of the rocks.Compactness in turn depends on the presence of pore spaces within the rocks(porosity) and permeability. Geology map was obtained from Kerala state Land use board. Our study area consists of basic rocks,Charnokite,Khondalite,and Migmatite complex. The water-bearing properties vary from one rock type to another rock type. The geology influences both the permeability of aquifer rocks and the distribution of fracture pattern.

Khondalites are the oldest meta-sedimentary rocks typical in southern parts of Kerala.Charnokites are mineralogically a bit different from khondalites.They are hypersthene bearing granites of gneisses with different texture.Our study area consist mostly of Charnokite as we can see from the map obtained. Highest value is given for Khondalites and lower for Migmatite complex according to its water holding capacity.

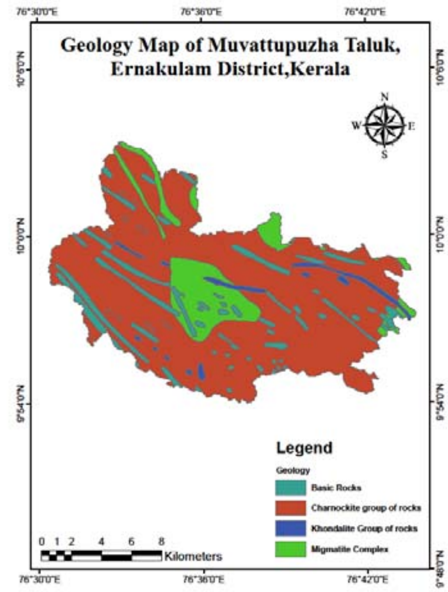

Fig 7: Geology map of study area

D. Geomorphology map

Geomorphological maps portray important geomorphic units, landforms and underlying geology and aid understanding of the processes, materials/ lithology, structures and geological controls relating to groundwater occurrence, as well as to groundwater potentials.It can be considered as surface indicators for identification of subsurface water conditions.A systematic study of these maps are helpful for selecting ground water potential zones and artificial recharge sites. This information provides a reliable base for effective planning, development and management of groundwater resources of an area. The distribution and extent of these geomorphological features are highly variable in accordance with the lithological variation. It is a major factor influencing ground water recharge and hence given higher weight. Geomorphology map was obtained from Kerala state Land use board.

Some of the prominent units identified in the study area are Valley, Lower plateau, Denudational hills, Flood plain, Structural hills and residual hills. Some act as ground water storage reservoirs and some of as recharge and runoff zones. The structural hills are controlled with complex folding, faulting and criss-crossed by numerous joints which facilitate some infiltration and mostly act as null off zones. The denudational hills are marked by sharp to blunt crest lines with rugged tops indicating that the surface runoff at the upper reaches of the hills has caused hill erosion.Isolated hills and elevated landform that are undergoing dilapidation due to weathering processes are categorized as residual hills.

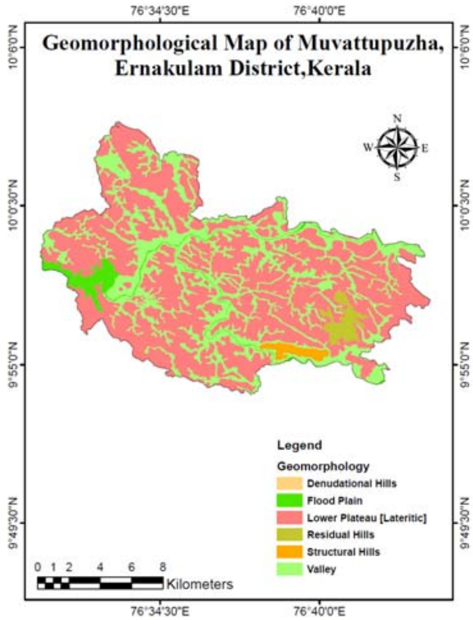

Fig 8:geomorphology map of study area

E. Soil map

Soils are derived from rocks due to weathering. Soil characteristics have a considerable role on the infiltration of water. The rate of infiltration largely depends on grain size of soil.Different types of soils identified from the study area are alluvium,hill soil and laterite. Lateritic soil is the most extensive soil type found in the area. The movement and infiltration of water in these three types of soil is not same so based on its property the weightages have been assigned. Alluvium soil is given more weightage and hill soil less weightage.Soil map was obtained from Department of soil survey and soil conservation board.

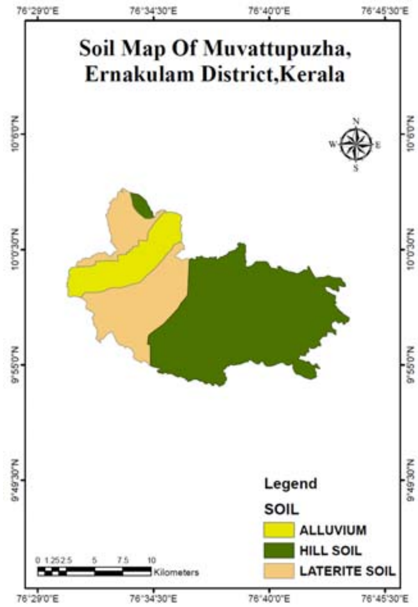

Fig9: Soil map of study area

F. Lineament and Lineament density map

Lineaments are structurally controlled linear or curvilinear features which are identified from satellite imagery by their relatively linear alignments.Lineaments represent zones of faulting and fracturing resulting in increased permeability. They are hydro-geologically very important since they act as path ways for ground water movement.Lineament density of an area can directly reveal the ground water potential since the presence of lineaments usually denotes permeable zone.Area with high lineament density are good for ground water potential zones. The study area was divided into grids of (1 km×1 km) and the total lengths of all lineaments in each grid were calculated in order to determine the lineament density values per sq. km. These values were regrouped to produce a lineament density map that was classified into five categories, namely, very high , high , moderate , low and very low .Source of lineament map is Kerala state Land use board.

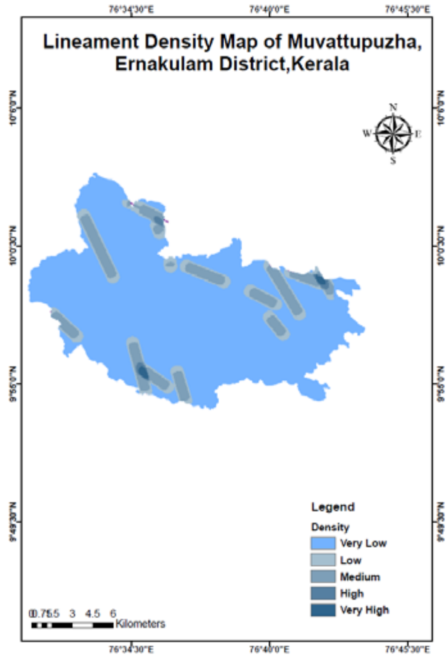

Fig 10: lineament density map of study area

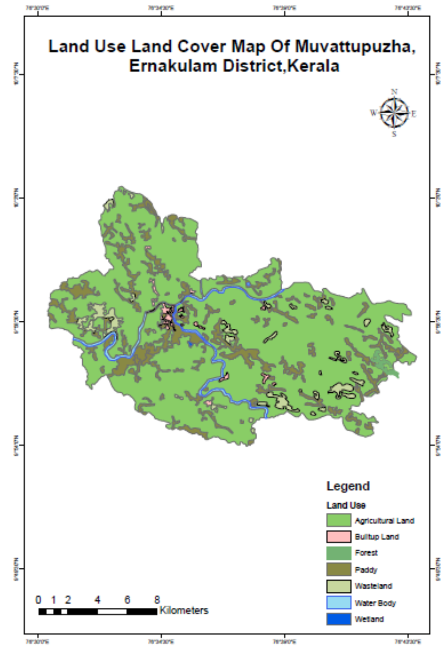

Fig 11:LULC map of the study area

G. *Land use and land cover(LULC)*

Land use refers to man's activities in land, various uses which are carried out on land, etc.Land cover denotes the natural vegetation, water bodies, rocks etc that resulted due to land transformation. LULC affects evapotranspiration volume, timing and recharge of ground water system. It is observed that spatial variation in the amount of groundwater storage occurs due to changes in land use and vegetation cover, so proper understanding of LULC is necessary to estimate the water resources, and it has therefore been included in this study.

Identified features from the study area are built up land,paddy area,rocky area,mixed crop,forest,cultivable waste land and water body. Forest and agricultural ecosystem together occupy major portion of Muvattupuzha block. Water body is classified as "very good" zones and given the maximum rank. Mixed crop, paddy area and built up land are classified as "good" zones.Rocky area is given the least value since it has less contribution towards ground water storage.

H. *Rainfall map*

Rainfall is the main source of ground water recharge. It plays an important role in the hydrologic cycle, which controls groundwater potential. And it determines the amount of water that would be available to percolate into the groundwater system. Although region receives very high rainfall on an annual basis, its uneven distribution within a year and indiscriminate exploitation of water resources often results in flood. Flat areas are capable of holding the rainfall and facilitate recharge to groundwater as compared to steep slope area where water moves as runoff quickly. Rainfall measurement is a point observation and may not be used as a representative value for the area under consideration. Therefore, it is necessary to obtain effective uniform depth of rainfall of the study area to get a more reliable and representative results.

The rainfall map was prepared using the data obtained from the Indian Meteorological Department (IMD) gauge stations.Five stations viz, Aluva, Piravom,Perumbavur,Thodupuzha and Vaikom was selected.From the data obtained it is clear that the study area has experienced a minimum annual rainfall of 2709.62mm and a maximum of 3436.25mm during the period 2016-2017.These data were then spatially interpolated using Inverse Distance Weighted (IDW) method to obtain the rainfall distribution map. The interpolated values for IDW surfaces are a weighted average of the values of a set of nearby points, weighted so the influence of nearby points is greater than that of distant points (that is, with the inverse of the distance).

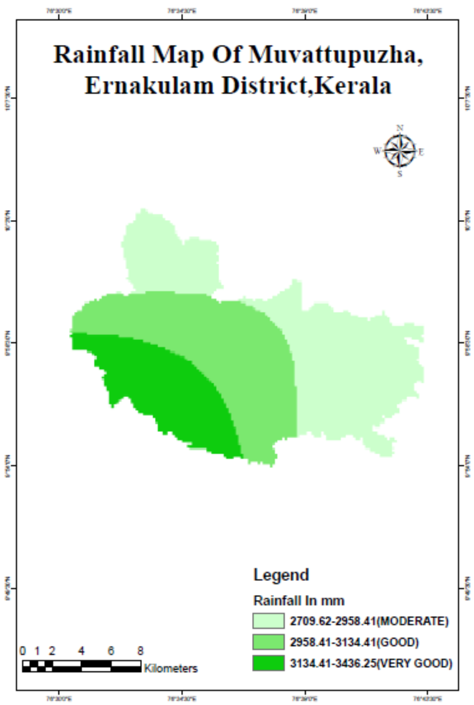

Fig 12:Rainfall map of the study area

IV. RESULTS AND DISCUSSIONS

Assessment of ground water potential zone

The groundwater potential zones are obtained by overlaying all the thematic maps in terms of weighted overlay Analysis (WOA) using the spatial analyst tool in ArcGIS 10.3. The advantage of WOA is that human judgment can be integrated with analysis. A weight represents relative importance of parameter and the objective. During the weighted overlay analysis, the ranks have been given for each individual parameter of each thematic map and the weight is assigned according to the influence of the different parameters. The ranks 1 ,2 ,3,4 and 5 denotes very poor, poor, moderate, high and very high potential zones respectively. The weights and rank have been chosen based on judgment of researchers who had carried out similar work on ground water potentiality mapping

All the thematic maps are converted into raster format and superimposed by weighted overlay. For assigning the weight, rainfall was assigned higher weight, whereas the geology was assigned the lower weight. After assigning weights to different parameters, individual ranks are given for sub variable. The maximum value is given to the feature with highest groundwater potentiality and the minimum given to the lowest potential feature.The overall analysis is tabulated in Table(1). The generated output shall consist of various classes of ground water potential zones viz. Good, Moderate and Poor Zones from ground water potential point of view.

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Table 1.: Rank and weight for different parameter of groundwater potential zone

Sl No.	Parameter	Classes	Rank	Weight
1.	Geomorphology	Valley	5	16
		Lower plateau	4	
		Denudational hills	2	
		Flood plain	5	
		Structural hills	2	
		Residual hills	4	
2.	Slope(degrees)	Nearly level (0-5.026317)	5	19
		Very gently sloping (5.02631-9.494)	4	
		Gently Sloping (9.4941-14.799712)	3	
		Moderately Sloping (14.799-22.897)	2	
		Strong Sloping (22.8976-71.206161)	1	
3.	Drainage density(km/km2)	Very low (0-53.90919525)	5	11
		Low (53.90919525-138.28880)	4	
		Medium (138.28880-234.38780)	3	
		High (234.38780-351.5817081)	2	
		Very high (351.58170-597.6889)	1	
4.	Lineament density(Km/Km2)	Very low (0-0.259872993)	1	9
		Low (0.2598729-0.7337590)	2	
		Medium (0.733759-1.13885)	3	
		High (1.138855-1.5210213)	4	
		Veryhigh (1.52102-1.94904)	5	
5.	Land use/land cover	Built up land	4	13
		Paddy area	4	
		Rocky area	1	
		Mixed crop	4	
		Forest	2	
		Cultivable waste land	2	
		Water body	5	

6.	Rainfall(mm)	Moderate (2709.62-2958.413)	3	22
		High (2958.413-3134.41)	4	
		Very High (3134.41-3436.25)	5	
7.	Geology	Basic rocks	3	4
		Charnockite	3	
		Khondalite	4	
		Migmatite complex	3	
8.	Soil	Hilly soil	2	6
		Laterite	4	
		Alluvium	5	

The generated output shall consist of various classes of ground water potential zones namely Excellent, Moderate and Poor Zones from ground water potential point of view. It is observed that the good potential zones possess suitable surface and subsurface conditions such as occurrence of lineaments and permeable soil formations. It has been observed from groundwater potential map that the gentle slope has more potential for groundwater. The very good potential zones having suitable surface and subsurface conditions such as occurrence of lineaments, permeable formations and nearness to recharging factors like streams provide conducive environment for higher water yield as well as favourable discharge. Area statistics of different groundwater prospect zones of the study area is given in table 2.

Table 2.:Area statistics of different Groundwater Prospect Zones

Category of ground water potential zone	Area in Km2	Area in %
Excellent	27.672	12.28
Moderate	148.31	65.81
Low	48.30	21.43

It shows that high potential zones occur within very low drainage density. Greater portion of the study area (148.31 km^2) representing about 65.81 % of the total area, fall within the medium groundwater potential zone. The study concludes that 'Excellent' potential zones (Very Good category) cover an area of 27.672 km2 (12.28% of the study area).'Poor' groundwater potential zones are confined to mostly the hilly terrain which acts as runoff zone and having total area of 48.30 km2(21.43%).After overlay all these maps we have obtained the ground water potential zone map .The study can be further extended to identify the sites and suitable artificial recharge methods for augmentation of groundwater resources in moderate and poor potential zones.

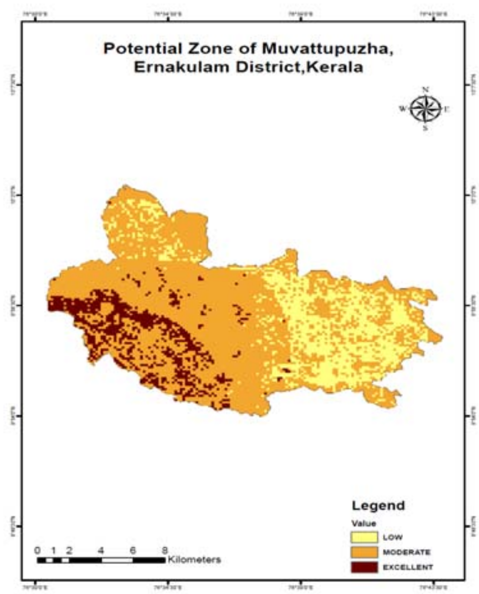

Fig.13:Ground water potential zone map

Validation

Only developing the Groundwater Potential Zone (GPZ) with the help of remote sensing and GIS was not sufficient for the study area.In order to validate the classification of ground water potential zones obtained by remote sensing and GIS based ground water potential map,data on existing well were collected. For a well to be classified as favourable, water level should remain stable during pre- and post-monsoon seasons. Depth to water table of pre- and post-monsoon seasons were measured by field investigations and enquiry in 10 dug wells of randomly selected villages. Using this data, water level fluctuations were calculated.The validation clearly highlights the efficiency of the integrated RS and GIS methods employed in this study as useful modern approach for proper groundwater resource evaluation and sustainable groundwater development

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Table 3.: Ground water data obtained through field investigations

Sl.No.	Place name	Latitude	Longitude	Depth to water level in meters		Water level fluctuation
				Post-monsoon	Pre-monsoon	
1	Perumattom	9.9934844	76.5960512	1.78	4.87	3.09
2	Pezhakkapily	10.0145626	76.5669526	1.98	6.14	4.16
3	Arakuzha	9.9293692	76.5957139	2.03	5.35	3.32
4	Kadalikad	9.9237669	76.6742785	0.67	6.72	6.05
5	Paingottor	9.9914808	76.7067144	0.62	3.72	3.1
6	Kadathi	9.981	76.551	1.02	5.15	4.13
7	Marady	9.95505	76.558178	1.28	4.06	2.78
8	Pothanikkadu	10.007298	76.677365	2.46	4.45	1.99
9	Eranellur	9.986171	76.565127	5.48	6.756	1.276
10	Muvattupuzha	9.989423	76.578975	3.67	5.68	2.01

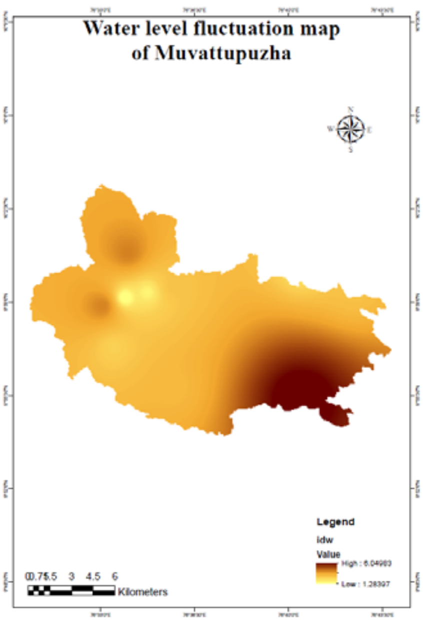

Fig14: water level fluctuation map of study area.

V. CONCLUSION

From the above study and by use of various maps we could successfully say that remote sensing and GIS can provide the appropriate platform for convergent analysis of large volume of data and decision making for groundwater studies. These techniques have been successfully used and demonstrated for evaluation of groundwater potentiality of the Muvattupuzha block, Kerala ,India. Use of weighted overlay method was found to be very useful in mapping of ground water potential zones of the study area. The digital elevation model was also used for geomorphologic mapping and identification of ground water potential zones.

Remote sensing and GIS techniques has helped in:

- Efficient use of cost, time, and labour.
- Integration of eight thematic maps such as drainage density, rainfall, LULC, slope, geology, geomorphology, lineament density and soil which gives information to local authorities and planners about the areas suitable for groundwater exploration.
- Generation of ground water potential map of the area.
- To extract useful information from satellite images.

Following conclusions were obtained from the study:

- Considering the influence of different geomorphic and lithological units on groundwater regimes, three groundwater prospect zones such as (i) Excellent (ii)moderate and (iii) Low zones were identified.
- Greater portion of the study area (148.31 km^2) representing about 65.81 % of the total area fall within the medium groundwater potential zone. The study concludes that 'Excellent' potential zones (Very Good category) cover an area of 27.672 km2 (12.28% of the study area.'Low' groundwater potential zones are confined to mostly the hilly terrain which acts as runoff zone and having total area of 48.30 km2(21.43%).
- The excellent zones are distributed along the lineaments
- The area around the alluvial plain, low slope, flat topography near river plain is good in groundwater prospects. On the other hand, areas with high slope, high-drainage density, low lineament density are low in groundwater prospects.
- Geological characteristics, lineament, drainage and slope shows direct influence on ground water conditions in the study area.
- The drainage density map shows the network of the steams in the sub-basin.
- Drainage density is an inverse function of permeability. The less permeable a rock is, the less infiltration of rainfall.
- Use of Inverse Distance weightage method was found to be very useful in mapping of rainfall distribution of the study area.
- There is no problem of water during rainy season spanning from June to December. If there is shortage of monsoon, problem of water scarcity arise early in hilly region and later towards the low slopes and planes.
- Subsequent validation with boreholes/well yield data revealed a good correlation with respect to the

observed groundwater potential zonation.

Future Scope

Remote sensing and GIS tools are less time consuming and cost effective, which provide sufficient support in groundwater studies where the region lacks previous hydrogeological investigations and data. 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.

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