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Demarcation of Groundwater Prospective Zones in Humid Tropical River Basin: A Geospatial Approach

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Abstract

Groundwater, being a vital resource, needs to be developed with proper understanding about its occurrence in time and space. Unscientific sand mining is a dominant environmental issue in this humid tropical river basin namely Bharathapuzha river basin geographically on central part of Kerala state, southwest part of India. The sandy layers along the river course declines its water holding capacity due to indiscriminate sand mining throughout the river basin. For a sustainable development of water resources, it is imperative to make a quantitative estimation of the available water resources. The purpose of the study is to identify the groundwater potential zones in the Bharathapuzha river basin in Kerala state, India based on Remote Sensing and GIS technology. Thematic layers considered in the study are geomorphology, land use, and lineament derived from IRS P6 LISS IV digital data; drainage network contour and slope maps are generated using toposheets; geology from GSI geology maps, with the help of Arc GIS Software and Erdas Software. Storativity and transmissivity of the study area was prepared using pumping test data. The thematic layers were over layered by weighted overlay method using Arc GIS. Four groundwater potential zones were identified in the study area represented as very good, good, moderate and poor potential zones.

Keywords: *Geospatial Approach, Thematic Maps, Overlay Analysis, Groundwater Potential Zones, Humid Tropical River Basin.*

1. Introduction

Groundwater is a dynamic and replenishing natural resource for sustaining human, animal and plant life. The depletion of groundwater resources in hard rock terrain in the country is alarming because in hard rock terrains availability of groundwater is of limited extent. Occurrence of groundwater in such rocks is essentially confined to fractured and weathered horizons [1, 2]. Indiscriminate development and unscientific management of this resource has led to multiple problems of decline in groundwater level, sea water ingress, in-land salinity, groundwater pollution, land subsidence etc. Groundwater management on scientific lines has become inevitable for sustainability of this vital resource. In order to accomplish these tasks, the systematic planning of groundwater exploitation using modern technologies is essential for the proper utilization of this precious natural resource [3]. To protect the aquifers from over exploitation, an effective groundwater management policy oriented towards promotion of efficiency, equity and sustainability is required.

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In recent years, intensive use of satellite remote sensing has made it easier to define the spatial distribution of different ground water prospect water zones on the basis of geomorphology, hydrogeology and other associated features [4]. Both the remote sensing and GIS technologies have great potential to revolutionize the monitoring and management of vital groundwater resources in the future [5]. Geographic information systems (GIS) are capable of managing large amounts of spatially related information, providing the ability to integrate multiple layers of information and to derive additional information [6]. Integrated remote sensing and GIS can provide the appropriate platform for convergent analysis of diverse data sets for decision making in groundwater resource mapping and planning [7]. Geospatial technology is a cost effective tool for producing valuable data which helps to find out accurate groundwater potential zones.

This work aims to develop and apply integrated methods combining the information obtained by analyzing multi-source remotely sensed data in a GIS environment for better understanding the groundwater resource of the Bharathapuzha river basin. In literature several studies are cited demonstarting the utility of GIS as applied to the mapping and management of various natural resources. [3] have used the GIS technique for generation of groundwater prospect zones towards rural development.[8, 9, 10 and11] have used GIS to delineate groundwater potential zone. [12] Have applied GIS for processing and interpretation of groundwater quality data. [13, 14] have carried out groundwater modeling through the use of GIS. GIS has been applied to groundwater potential modeling [15,16, 17 and 18]. Indiscriminate sand mining is a dominant environmental issue throughout the river basin. The entire river bed is cut up and sand layers holding considerable quantity of water in the spaces between them are disturbed, the water flow through the river gets reduced considerably (Plate 1a & b). Also, the percolation of water through the river bed and its subsequent recharge into the groundwater supply also declines. The villagers along the river basin now face the severe problem of drinking water shortage because of the lowering of the water table. So an investigation has been carried out for demarcation of groundwater prospective zones using geospatial techniques.

2. Study Area

The Bharathapuzha River, popularly known as Nila or Peraar is the broadest and second longest river in Kerala, India. It has a length of 209 km and basin area of 6186 km^2 in which 4400 km^2 falls within the Kerala state, of which 28 % is occupied by forest. The river is a 6^{th} order stream with a gradient of 9.2 m/km with an average annual stream flow of 5082.9 mm^{3}. For the present investigation, the Bharathapuzha river basin lying between latitudes 10^0 25´ and 11^0 15´ N and longitudes 75^0 50´ and 76^0 55´ E has been selected (Fig. 1). The headwaters of main tributary of Bharathappuzha originates in the Anaimalai Hills in the Western Ghats at a height of 1964 m above the Mean Sea Level (aMSL), and flows westward through Palghat Gap, across Palghat, Thrissur and Malapuram districts of Kerala, with many tributaries joining it. Finally it empties into the Arabian Sea at Ponnani. Bharathapuzha is the one of the most heavily dammed rivers in Kerala, which accommodates nine reservoirs at present on its drainage area, among which seven are in Kerala.

3. Materials and Methods

The overall aim of this study is to contribute towards systematic groundwater studies utilizing remote sensing, field studies, Digital Elevation Models (DEM) and Geographic Information Systems (GIS) in the assessment of groundwater resources of Bharathapuzha river basin. In the present study, the factors like geomorphology, lineament, drainage, geology, slope, relative relief, transmissivity, storativity, land use and water table fluctuation were taken into consideration for evaluating the groundwater potential of the basin. An effective evaluation of groundwater potential zones can be done in an integrated way.

Different thematic maps are prepared with the help of Arc GIS software. Geological map has been prepared by using maps of the Geological Survey of India in a scale of 1:50,000. Geomorphology, land use and lineament maps were generated from the remote sensing imagery (IRS-P6, LISS IV) at a scale of 1:50,000 and the drainage density, relative relief map was prepared from the Survey of India (SOI) toposheet in a scale of 1:50,000 by digitizing the drainage lines and contours. Slope map is prepared from DEM. Pumping test is the commonly used method for estimating hydraulic characteristics of crystalline rocks such as Transmissivity (T,) Storativity (S) etc. The storativity and transmissivity maps were prepared from the pump test data obtained from 35 dug wells for estimating hydraulic properties of shallow aquifer.

Indian remote sensing satellite IRS P6 satellite image (LISS IV, 2006) on 1:50,000 scale has been subjected for present study. The base map has been prepared on 1:50,000 scale using SOI toposheet of the study area by overlying on satellite imagery. With the help of geocoded satellite data, lineament, hydro geomorphology and land use maps have been prepared. From the contour map a Digital Elevation Model (DEM) has been generated and with the help of spatial analyst in Arc Scene software, slope map is prepared as a raster image. All the doubtful areas in the imagery are identified and checked with the ground truth. Their geographical location and accessibility in the ground is verified with the respective toposheet. Proper ranks and weightages were assigned to each component based on their proximity, favouring the occurrence of groundwater. An index is formulated for all categories in thematic maps based on their ranks and weightages. The final groundwater potential map was prepared based on the overall index (Groundwater prospective index-GWPI) obtained by the integration of all thematic layers selected for the study.

4. Result and Discussion

Factors controlling the groundwater potential

The various thematic maps are described above have been converted into raster form considering 20 m as cell size to achieve considerable accuracy. These were then reclassified and assigned with suitable weightages, rank and index (Table1).

Geology

It is a well established fact that geological setup of an area plays a vital role in the distribution and occurrence of groundwater [19]. The Bharathapuzha river flows through different geological sequences that occur in east west transect. Major part of the study area is underlained by Precambrian metamorphic rocks

(Fig.2). Laterites form a thick capping over the Precambrian crystallines and the sedimentary sequences. Calc-granulites and crystalline lime stone has a striking characteristic with a grooved appearance along the foliations because of differential weathering. The limestone is characterized by intense fracturing and solution cavities have developed at places. A prominent dolerite dyke about 42 km length, having a trend NNW–SSE direction is traceable in the SW part of the basin. Various rock types in the study area are classified into 13 classes and ranks were assigned accordingly. It consists of hornblende biotitic gneiss, charnockite, hornblende biotite, Biotite hornblende gneiss, pink granite, pyroxene and norite, pyroxene granulite, quartz syenite, hornblende biotite gneiss with schist, quartzo feldspathic gneiss, coastal alluvium, dolerite and gabro [20]. Texture of rock is more important as it defines the water holding and transmitting capacity of these rocks vis-à-vis the aquifer characteristics.

Slope

Slope is an important terrain parameter and it affects the land stability. Slope is defined as the loss or gain in altitude/unit horizontal distance in a direction. Slope of any terrain is one of the factors controlling the infiltration of groundwater into subsurface hence an indicator for the suitability for groundwater prospect. In the gentle slope area, the surface runoff is slow allowing more time for groundwater to percolate, whereas, high slope areas facilitates high runoff allowing less residence time for rainwater and hence comparatively less infiltration [21]. In the study area slope degree varies from 0 to 84 and the entire basin is classified on the basis of degree of slope as < 3, 3-5, 5-10, 10-15, 15-35, >35 designated as very gentle, gentle, moderate, moderate-steep, steep, and very steep respectively (Fig. 3). As infiltration is inversely related to slope, a gentle slope promote for an appreciable groundwater infiltration. In the study area, majority of the area occupies slope category of 0-5 and is favourable while considering the groundwater potential. High slope area is marked by the northern, northeastern, southern and south western part of the basin. Central portion is characterised by moderate slope (5-10) while eastern part is characterised by very gentle slope where the Palakkad Gap is situated. Higher the slope, higher the runoff and lower the recharge indicated poor infiltration rate.

Geomorphology

The storage capacity of the rock formations depends on the porosity of the rock. Geomorphology reflects various landforms and structural features. Many of these features are favourable for the occurrence of groundwater and are classified in terms of groundwater potentiality [21].

Table 1. Weightages, rank and index assigned for different groundwater controlling parameters to derive groundwater Potential zones of the Bharathapuzha river basin.

Sl no	Parameter	Class	Rank	Weight	Index
1	Drainage Density	< 1	4	7	28
		1 – 3	3		21
		3 – 4	2		14
		> 4	1		7
2	Slope	< 8	4	9	36
		8- 16	3		27
		16 – 24	2		18
		> 24	1		9
3	Geo morphology	Coastal plain	1	12	12
		Pediment zones	2		24
		Structural hills	2		24
		Residual hills	2		24
		Less disected plateau	3		36
		Moderately disected plateau	3		36
		Channel bars	3		36
		Plateau	3		36
		Moderately dissected pediment zone	4		48
		Valley fills	4		48
4	Geology	Gabro	1	10	10
		Dolerite	1		10
		Charnokite	1		10
		Pink granite	1		10
		Pyroxene and Norite	1		10
		Pyroxene granulite/Charnockite	1		10
		Quartz syenite	1		10
		Hornblende biotite gneiss with schist	2		20
		Quartzofeldspathic gneiss	2		20
		Biotite hornblende	3		30
		Hornblende biotite	3		30
		Hornblende biotite gneiss	3		30
		Coastal alluvium	4		40
5	Relative Relief	<40	4	5	20
		40 - 80	3		15
		80 – 120	2		10
		>120	1		5
6	Lineament Density	<0.5	1	15	15
		0.5-1	2		30
		1-1.5	3		45
		>1.5	4		60
7	Transmissivity	<60	1	12	12
		60-120	2		24
		120-180	3		36
		>180	4		48
8	Storativity	<0.24	1	12	12
		0.24 – 0.27	2		24
		0.27 – 0.29	3		36
		>0.29	4		48
9	Landuse	Rubber plantation	1	8	8
		Stony waste	1		8
		Open jungle	2		16
		Wasteland without scrub	2		16
		Built-up lands	2		16
		Land with scrub	2		16
		Land without scrub	2		16
		Open scrub	2		16
		Fairly dense jungle mainly teak	2		16
		Scrub land	2		16
		Open jungle with bamboo	2		16
		Open mixed jungle	2		16
		Waste land with scrub	3		24

		Fairly dense jungle	3		24
		Mixed vegetation	3		24
		Paddy	3		24
		Mixed jungle	3		24
		Sand deposits	4		32
		Dense mixed jungle	4		32

Geomorphological mapping of pediments, buried pediments, valley fills and their characterization is very useful in groundwater investigations. Thus the study of the hydro geomorphology using remote sensing technique has much utility in groundwater studies. The present study follows the classification of geomorphology by National Remote Sensing Center (NRSC). Based on the ground truth verification, the geomorphology of the study area has been classified into 13 categories with their areal extent (Table 2) and shown in Fig. 4. Valley fills and flood plains are rich in groundwater and are very good locations for induced recharge. The evolution of the present landscape is the result of weathering and denudation. Thus the landforms are the result of the action of various endogenic and exogenic forces operating on the earth crust. These elements and their characteristics directly or indirectly affect the hydrological conditions [22]. Even though water body, reservoir and braided drainage are the groundwater potential areas, they are not included in the geomorphology classes to achieve more accuracy.

Table 2. Spatial distribution of various geomorphological units with their areal extent in the Bharathapuzha river basin.

Sl No.	Description	Area (Km^2)
1	Moderately dissected Plateau	1258.38
2	Valley fills	892.04
3	Structural hills	813.96
4	Pediment zones	359.26
5	Less dissected plateau	338.97
6	Moderately dissected pediment zone	310.53
7	Plateau	233.45
8	Residual hills	50.61
9	Water body	47.11
10	Channel bars	42.22
11	Coastal plain	28.79
12	Reservoir	24.53
13	Braided drainage	0.14
Total		**4400**

Drainage Density

Drainage density characterizes the run off in the area or the quantum of rain water that could infiltrate. It provides a numerical measurement of landscape dissection and run-off potential. Drainage density is significant in the case of artificial recharge because it indirectly indicates the permeabilty and porosity of the terrain. The low Dd is an indication of the prevalence of highly resistant/ permeable strata under dense vegetation and low relief, whereas, high Dd prevails in the weak/impermeable rocks under sparse vegetation and mountainous relief regions. More the drainage density, higher would be runoff and lesser the drainage density, higher is the probabiltiy of recharge or potential groundwater zone. The spatial arrangement of streams with structural control can act as conduit for groundwater recharge and storage at places [23]. The Bharathapuzha River is characterised by dendritic drainage pattern which is typical of granitic terrain.

Density factor is related to climate, type of rocks, relief, infiltration capacity, vegetation cover, surface roughness and run off intensity index. Low drainage density generally results in the areas of highly resistant permeable subsoil material, dense vegetation and low relief. High drainage density is the resultant of weak or impermeable subsurface material, sparse vegetation and mountainous relief. The observed drainage density of the area ranges from less than 1 to the value between2 to3 km/km^2. Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture. Majority of the area is marked by low drainage density (< 0.5), indicating the river basin has permeable subsoil and dense vegetation, which results in a coarse drainage texture. The very low value of drainage intensity implies that drainage density and stream frequency have very little effect on the extent to which the surface has been lowered by agents of denudation. The drainage density is an important parameter as it is one of the factors that control the speed of run-off following a period of precipitation. It also helps to define the texture of dissection. In the present study, the highest drainage density is seen at the north, northeast, south and southeastern parts of the basin (Fig. 5) and hence these areas are characterized with fine drainage texture. It is classified into 4 classes and respective ranks were given.

Lineament Density

Geomorphological studies coupled with hydro-geological and structure/lineaments have been proved to be very effective to locate groundwater potential zones [24, 25].The lineaments are linear or curvilinear feature patterns and play a vital role particularly in geomorphic and structural analysis. The lineaments like joints, fractures etc, developing generally due to tectonic stress and strain, provide important clue on sub-surface features and also act as conduits for movement and storage of groundwater [26, 1].

Lineament density map is a measure of quantitative length of linear feature expressed in grid. Lineament density of an area has a direct influence on groundwater prospective of the area. Areas with high lineament density are good for groundwater development [27]. Maximum lineament density is found at the extreme north, south and the central part of the basin where as majority of the basin is marked by the lower lineament density (Fig.6). The high value of

Lineament density reveals that the area is having good groundwater potential.

Land use

Land use plays a significant role in the development of groundwater resources. It controls many hydrological processes in the water cycle viz., infiltration, evapotranspiration, surface runoff etc [28]. Surface cover provides roughness to the surface, reduce discharge thereby increase the infiltration. In the forest areas, infiltration will be more and runoff will be less whereas in urban areas rate of infiltration may decrease [29].

Table 3. Spatial distribution of various land use/land cover units with their areal extent of the Bharathapuzha river basin.

Sl No	Description	Area (Km^2)
1	Mixed vegetation	1744.50
2	Paddy	640.76
3	Dense mixed jungle	503.26
4	Land with scrub	380.29
5	Rubber plantations	356.24
6	Open scrub	219.18
7	Waste land with scrub	195.50
8	Waste land without scrub	116.03
9	Water body	53.14
10	Town	49.06
11	Sand deposits	37.93
12	Open mixed jungle	31.37
13	Open jungle with bamboo	22.26
14	Reservoir	22.21
15	Land without scrub	9.01
16	Fairly dense jungle	6.53
17	Mixed jungle	4.09
18	Fairly dense jungle mainly teak	3.62
19	Open jungle	2.27
20	Scrub land	1.55
21	Stony waste	1.05
22	Buildup lands	0.09
23	Ponds	0.06
Total		**4400**

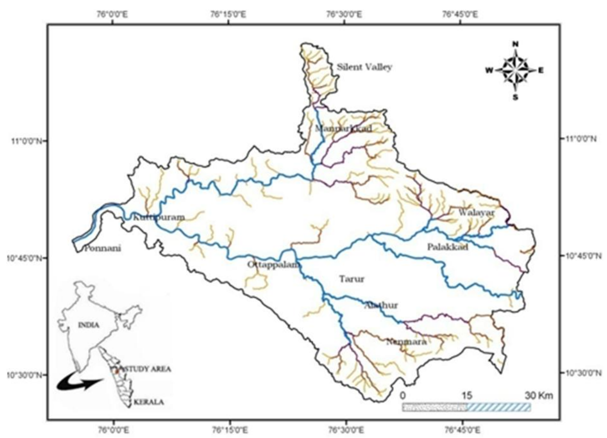

Fig.1. Location map of study area.

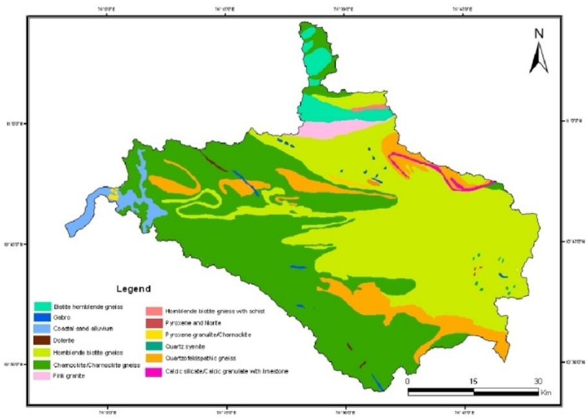

Fig.2. Geology map of Bharathapuzha River Basin.

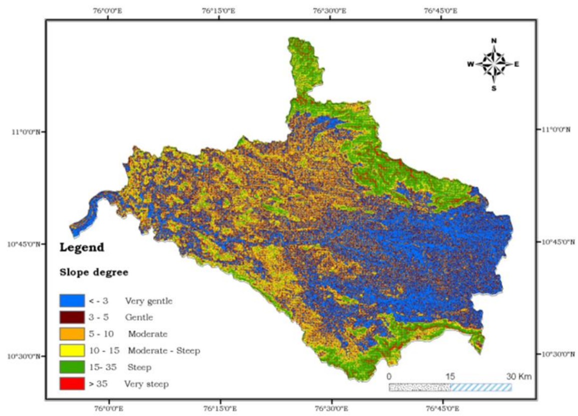

Fig.3. Slope map of study area.

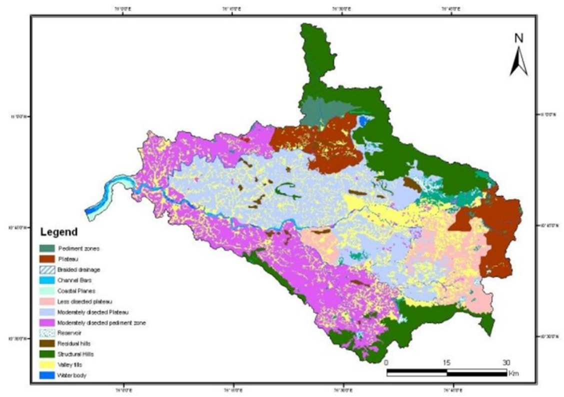

Fig.4. Geomorphology map of Bharathapuzha River Basin.

Land use classification (Fig.7) of the Bharathapuzha river basin has been prepared using the False Colour Composite (FCC) images through visual interpretation based on the classification decoded by National Remote Sensing Centre (NRSC). Based on these classification 23 types of land use are recognised in the basin and is given in the Table.3. The area with fine drainage texture is blessed with dense vegetation.

The area with less forest area has to be prioritized with high value.

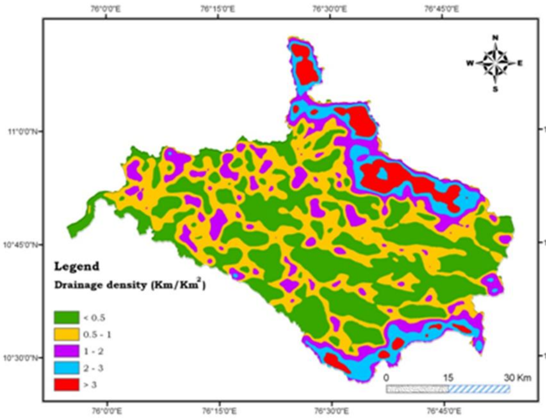

Fig.5. Drainage density map of study area.

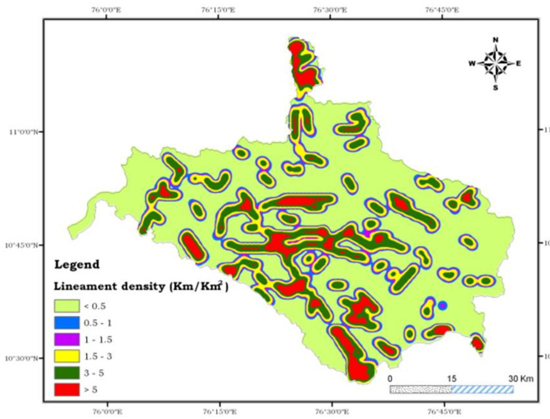

Fig.6. Lineament density map of Bharathapuzha River Basin.

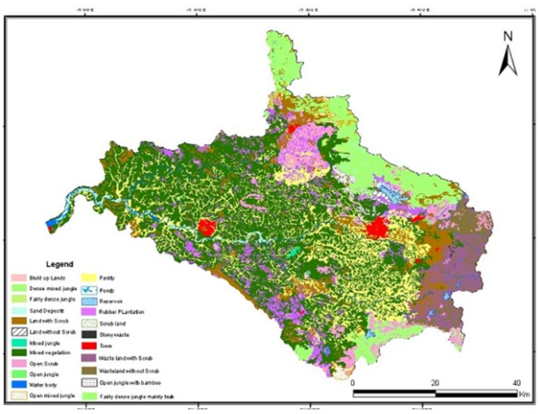

Fig.7. Land use map of study area.

Transmissivity and Storativity

Storativity and transmissivity values are the hydraulic properties of water bearing formations are important for identifying the potential zones because they govern the groundwater storage and transmitting characterization. In the basin, transmissivity values are classified into four categories. Highest transmissivity values are seen as patches seen in the northwestern and central part of the basin (Fig.8). Majority of the area of the basin has transmissivity values of 60-120 m^2/day. The storativity of the study area is categorized in to 4 classes. Majority of the area exhibits a highest storativity values (Fig.9). Least storativity values are seen as patches in northern, eastern and western side of the basin.

Relative Relief

The basin was divided into grids of 1 km^2 each and the difference in maximum and minimum altitude (relative relief) was obtained for each grid. The relative relief map drawn for the Bharathapuzha river basin indicates the western part of the basin is characterized by low relative relief and maximum height is recorded at the northeastern side of the basin. Most of the study area shows a relative relief of <50 m. Higher values of relative relief is seen at the North, northeastern and southern part of the basin.

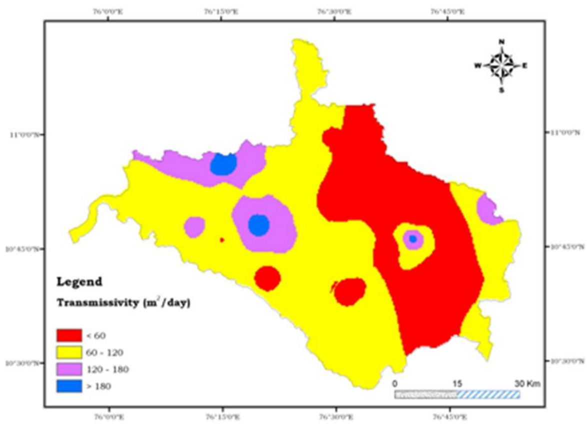

Fig.8. Transmissivity map of study area.

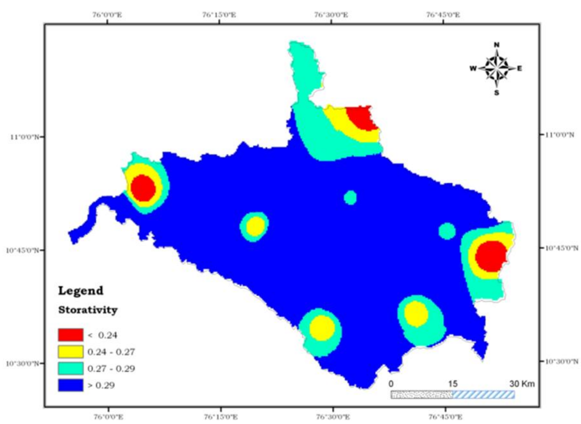

Fig.9. Storativity map of Bharathapuzha River Basin.

GIS ANALYSIS –Groundwater Prospect

The selected parameters like geomorphology, lineament, drainage, geology, slope, relative relief, transmissivity, storativity, land use and water table fluctuation were integrated on the GIS platform by overlay analysis. The weightages and rank are given to each categories of all thematic layers based on the field investigation. The resultant map was divided into four zones of groundwater potential namely, poor potential zones, moderate potential zones, good potential zones and very good potential zones. The groundwater potential map of the Bharathapuzha river basin is depicted in Figure 10.

Very good potential zones are seen in the central and western parts of the basin. They are mainly concentrated in areas having moderate to high lineament density, comparatively less slope area and valley fills. Majority of the Bharathapuzha river basin is good potential zone where as the northern and southern part of the basin shows poor to moderate potential zone. Poor potential zones are mainly distributed in highly elevated area of the Bharathapuzha river basin. These areas are characterized with steep slopes and high drainage density which create higher run-off and hence the groundwater potential is very low.

5. Conclusion

The groundwater potential zones of the basin are classified into four namely, poor potential zone, moderate potential zone, good potential zones and very good potential zones. The patches of land near the river mouth and areas towards the northern and central part of the study area are coming under the zone designated as very good (25% of the basin area). 45% of the basin area is having an appreciable amount of ground water resource, thus the area is designated as good zone. The extreme north-east and south-east part of the basin area is deficient in groundwater availability and i.e 7% of the basin area is coming under the zone poor. The upstream side of the reservoir and its premises is showing poor ground water availability. The rest 23% is coming under the zone moderate. In the structural hill seen in the northern and southern part of the basin are characterised by poor groundwater potential zone. This is due to the steep slope and high drainage density which create higher runoff. The moderately dissected pediment zone and moderately dissected plateau are marked by high potential area. The very good potential area is characterised by high lineament density. The generated groundwater potential zone map is verified with the field data to ascertain its validity; it is found that it agreed with the wells yield data. The occurrence of groundwater in the study area is controlled by geology, lineaments and landforms as revealed from GIS and field investigations. Innovative technique like remote sensing and GIS have an immense role for the preparation of groundwater prospective zone mapping, for the sustainable development and more realistic data for the decision making policy. This potential map would provide first hand information to local authorities and planners about the area suitable for pinpointing the exploration of prospective wells and quality of the groundwater.

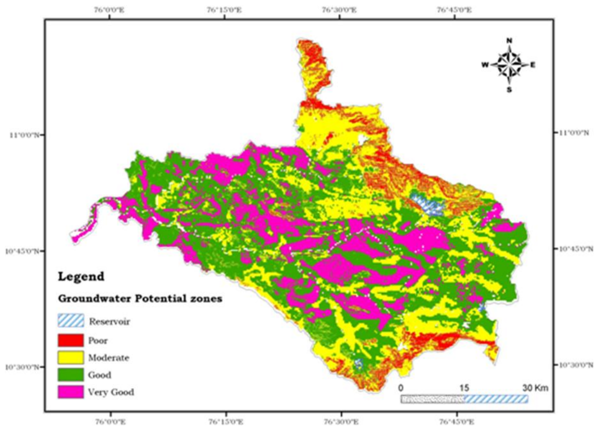

Fig.10. Groundwater potential map of study area.

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