GROUND WATER EXPLORATION, MANAGEMENT AND DEMARCATION OF POTENTIAL ZONES WITH GIS AND REMOTE SENSING TECHNIQUES IN UPPAR ODAI SUB-BASIN AREA

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Abstract: Sustainable management of groundwater is extremely necessary for supporting domestic, agricultural and industrial activities. Although fairly distributed throughout the world, increase urbanization, high utilization in the agricultural sector and rapid industrialization resulted in depletion and degradation of these resources. Thereby to manage these resources with adequate information, Remote Sensing and GIS techniques have emerged as a very effective tool for proper assessment, monitoring and conservation of groundwater resources. In a basin area, groundwater potential mapping depends on features, like lithology, geomorphology, soil structure as well as the nature of precipitation and infiltration. In this study Uppar Odai sub-basin of the Amaravati River basin is selected for sustainable groundwater potential mapping through Geo-informatics. In this context, electrical resistivity data, geomorphology and lineaments were assessed with the help of satellite imagery for the overall configuration of aquifer zones. Further, the spatial integration, in line with ArcGIS 9.3 software, carried out to demarcate the highly, moderate and least favorable groundwater potential zones. Hence, the data obtained from GIS spatial integration validated with water level data to suggest a sustainable groundwater planning draft in this study area.

Keywords: Groundwater, Remote Sensing and GIS, Electrical Resistivity Analysis, Vertical Electrical Soundings (VES), Hard rock terrain, Thematic maps, Groundwater Potential Zone

Introduction

As a most precious resource to the mankind, groundwater has a critical role in modern industrial and agricultural growth. Growing urbanization has resulted in increasing demand for groundwater resources due to inadequate availability of surface water. As the release of untreated wastes is polluting the groundwater, therefore an integrated research study should be conducted in line with satellite image data interpretation techniques and geographical information systems (GIS) technology. It is expected that by using the parameters of geological, hydrogeological, remote sensing and hydro geomorphological, this systematic study can identify the best quality groundwater resources in respect of time as well as space constraints. Sustainable water resource management is a major issue in the arid and semi-arid regions across the globe (Magesh et al., 2011). Thereby, mapping of existing groundwater resources and forecasting of their future use form a critical aspect of this geophysical study.

GIS and remote sensing techniques are vital tools for delineating different ground features with indirect analysis of topographic expression. This integrated study presents a realistic data of various groundwater potential zones by using the information inferred from the characteristics of rocks and subsurface geographical conditions. In context of potential mapping of groundwater potential zones, this study uses integrated techniques of GIS, remote sensing and geophysical data for thematic layers analysis, which also provide a better estimation of the aquifer system structure. By conducting a geophysical resistivity survey, aquifer characterization can be done with the help of borehole litholog data. The quantitative estimation of the aquifer parameters depends on the assessment of geophysical resistivity data and other terrain features (Khodaei & Nassery, 2013). High resolution remote sensing techniques provide these useful data which ultimately help in accurate mapping of potential groundwater zones in hard rock terrain. Further, the interpretation of aquifer storage estimation is possible by a Digital Basement Topographical Map (DBTM), generated from these effective data. This study is mainly conducted for mapping of potential groundwater zones in southern India with the demarcation of the same for sustainable development (Kavitha, Mohana & Naidu, 2011). Moreover, it also considers potential groundwater mapping, resistivity layers at different depth configuration and status of groundwater development for accurate interpretation of potential aquifers within the framework of sustainable planning and development.

Study Area Description

The present study covers the Uppar Odai sub-basin of Tamil Nadu, India. Located in the Amaravati River basin, the study area lies in between 77°6′36″E–77°32′24″E longitude and 10°26′40″N–10°55′48″N latitude. With an aerial coverage of 1280 Km^2, this sub-basin encompasses the major area of Tiruppur district and a small portion of Coimbatore district. In comparison to the state average rainfall of 970 mm, this area has a record of much lower annual average rainfall of 625 mm. In this region a subtropical climate prevails with charting maximum temperature of 27- 35°C and minimum of 17- 23°C. In this area mainly four distinct seasons are observed, namely northeast monsoon, hot weather period, southwest monsoon and winter season (Jothibasu & Anbazhagan, 2016). The precipitation is mostly uncertain, uneven or unequally distributed at the rainfall stations. The rainfall pattern in the central and western parts is slightly higher, whereas the northern as well as eastern parts are experiencing lesser rainfall. The central part of the sub-basin has experienced highest average annual rainfall of 738 mm, while the northern part has recorded the lowest rainfall of 573 mm.

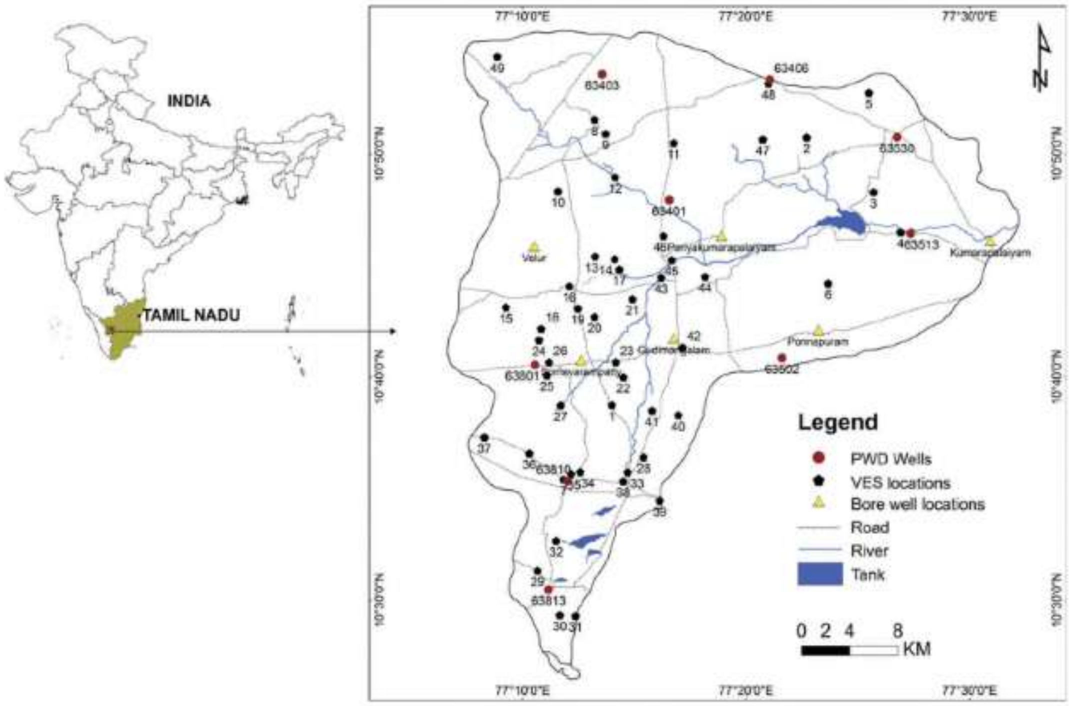

Fig 1: Map of Uppar Odai sub-basin (Tamil Nadu, India), including locations of vertical electrical soundings (VES), PWD wells and bore wells
Source: https://www.tandfonline.com/doi/abs/10.1080/02626667.2014.990966?journalCode=thsj20

Geology and Hydrogeology of the Area

This complex zone of the southernmost Indian Peninsula is characterized by abundant granulite facies, gneisses, amphibolite facies and supracrustal rocks. While some of these rocks are of lower grade, the sub-basin is underlined by a wide range of high grade metamorphic rocks of the Peninsular Gneissic Complex. The study area has a wide variety of rocks, including gneiss, ultrabasic, migmatite, granites and granulite. Groundwater exists, irrespective of geological formations, at an average depth of 10 m below ground level (b.g.l) in the sub-basin area (Gupta & Srivastava, 2010). During the pre-monsoon period, water level reaches the maximum depth of 18 m b.g.l. Such declining is believed to be due to improper pumping, persistent demand and obviously for inadequate rainfall.

Methodology

In this study Survey of India topographic maps, electrical resistivity data, geology map published by GSI (1998), satellite data, water level and other required data for groundwater exploration as well as management were used. For data generation and spatial integration, the ArcGIS 9.3 software was utilized. All these sources of information were utilized for collecting data and by analyzing the same a resistivity contour map generated at various depth perception and resistivity profiles (Agarwal & Garg, 2016). On the basis of depth of sounding, apparent resistivity and location, the electrical resistivity data were accumulated and included in the Excel spreadsheet. After that they were converted into the dbf format and imported to GIS by using 'add XY data' tool. The inverse distance weighting (IDW) method used to spatially interpolate the file, imported with point data as well as Geo-references.

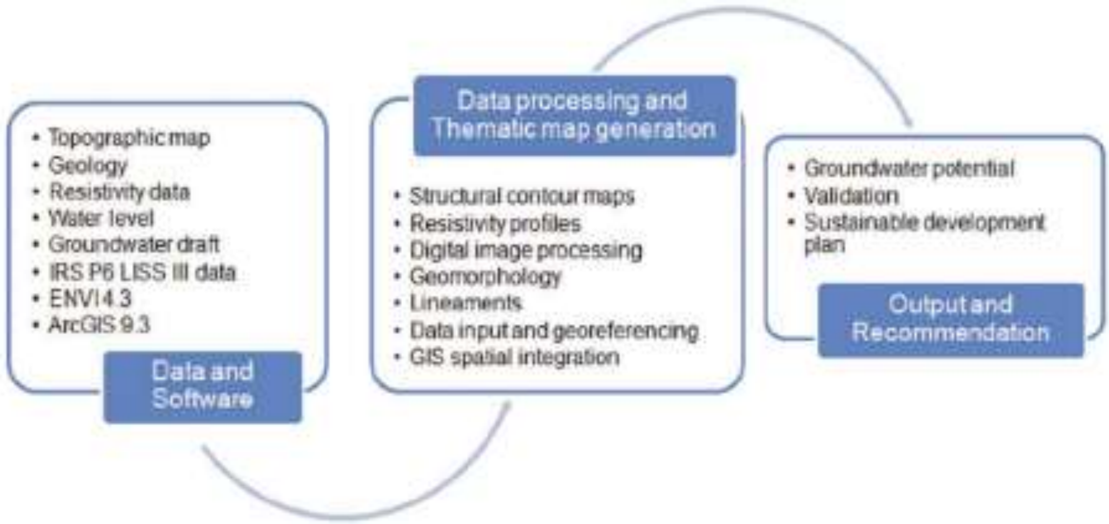

Fig 2: Flow chart of the methodology adopted in the research study
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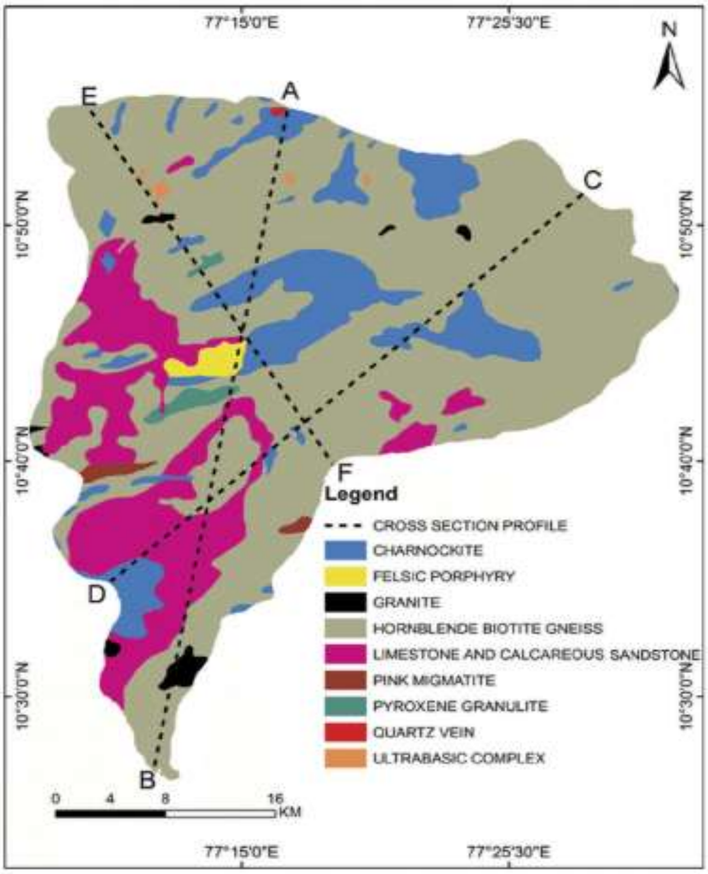

Fig 3: Geology of the Uppar Odai sub-basin on the basis of geo-electrical resistivity profiles
Source: https://www.tandfonline.com/doi/abs/10.1080/02626667.2014.990966?journalCode=thsj20

The National Remote Sensing Center (NSRC) provided the IRS P6 LISS III satellite data of 2012 and helped in interpreting geomorphology and lineaments. After receiving the pre-processed geometrically rectified satellite data in BIL format, they were digitally processed with the ENVI 4.3 image processing software. Apart from false color composite (FCC), pseudo-color composite (PCC) and histogram equalization, 'add data module' was used to import the processed satellite raster outputs to GIS (Anbazhagan & Balamurugan, 2011). Then the 'shape file' was created with the help of raster outputs for interpretation and digitization of geomorphology and lineaments. After projection of all thematic maps to the geographic coordinate system, the structural contour maps were built up by using the 'weighted overlay analysis' method in GIS. Hence, by using the integrated data, this method helped in mapping of potential groundwater zones and their demarcation for sustainable development.

Resistivity Data Analysis and Contour Map

For groundwater potential mapping, vertical electrical soundings (VES) is considered as a significant method to analyze the nature of sub-surface formation with variations in their electrical properties. Due to its features of conducting the smooth operation at low cost with the capability of making a distinction between fresh and saline water zone, ground water exploration becomes much easier. Throughout the India, this method was tested widely in different geographical situations. By correlating well with borehole data, this method can chart more accurately resistivity and depth, directly from the field data, in a linear graph. In this study by using RESIST Version 1.0 sounder software, the resistivity vs current electrode separation of each location was plotted on graphs (Asadi et al., 2012). Further, by analyzing the thickness of the subsurface layers from the graphs, the respective resistivity values were obtained. The resistivity contour maps for different below ground levels (b.g.l) were prepared in this study on the basis of interpretation of resistivity soundings. By analyzing resistivity soundings and 2D coverage of the entire area, elevation contour maps or structure contour maps can be prepared to provide useful information on the subsurface interfaces at different thematic layers. Further, the structure contour maps provide good correlation of subsurface geology and the electrical resistivity. With the help of resistivity value analysis at particular depth in different locations of the study area, favorable groundwater potential zones can be located (Kolawole et al., 2016). Moreover, structure contour maps indicate the continuation of a low resistivity zone from one level to next as the favorable condition for the groundwater potential.

Resistivity Profiles in Context of Lithology

As a major factor, Lithology analyzes the characterization of different distributed rock units in the study area. The groundwater yield capacity, qualitative and quantitative occurrence depend on different types of lithological units, like igneous, metamorphic and sedimentary rocks. Due to their high porosity and permeability than metamorphic, the sedimentary rocks have high potential for groundwater existence. According to sub-surface geological conditions, the geo-electrical resistivity profiles were drawn along AB, CD and EF sections across the sub-basin. The electrical resistivity profiles analyze the subsurface layer configuration as fractured, weathered, partially weathered and massive rock formations. The resistivity profiles clearly depict the maximum aquifer thickness across the sub-basin. It moreover shows the characterization of different parts and presence of shallow aquifers as well as productive dug wells in the western as well as eastern regions (Anbazhagan & Balamurugan, 2011). Apart from these, geo-electrical profiles and borewell litholog data present satisfactory correlation with four-layer subsurface configuration at most of the locations. On the basis of those analyses, out of three resistivity profiles, locations from northwest to southeast show the potential aquifer zones in the sub-basin.

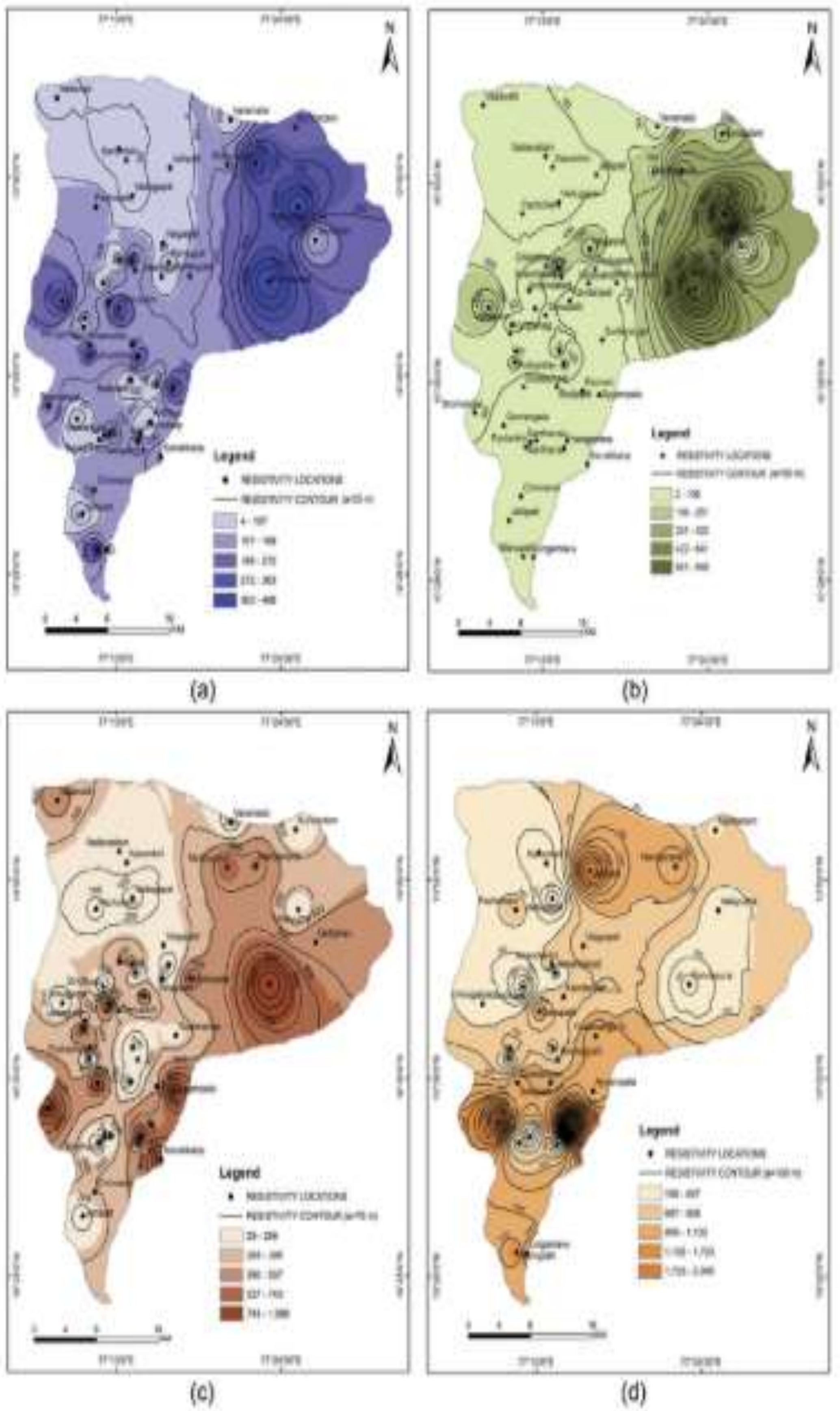

Fig 4: Structure contour maps at different depth configuration on the basis of electrical resistivity data
Source: https://www.tandfonline.com/doi/abs/10.1080/02626667.2014.990966?journalCode=thsj20

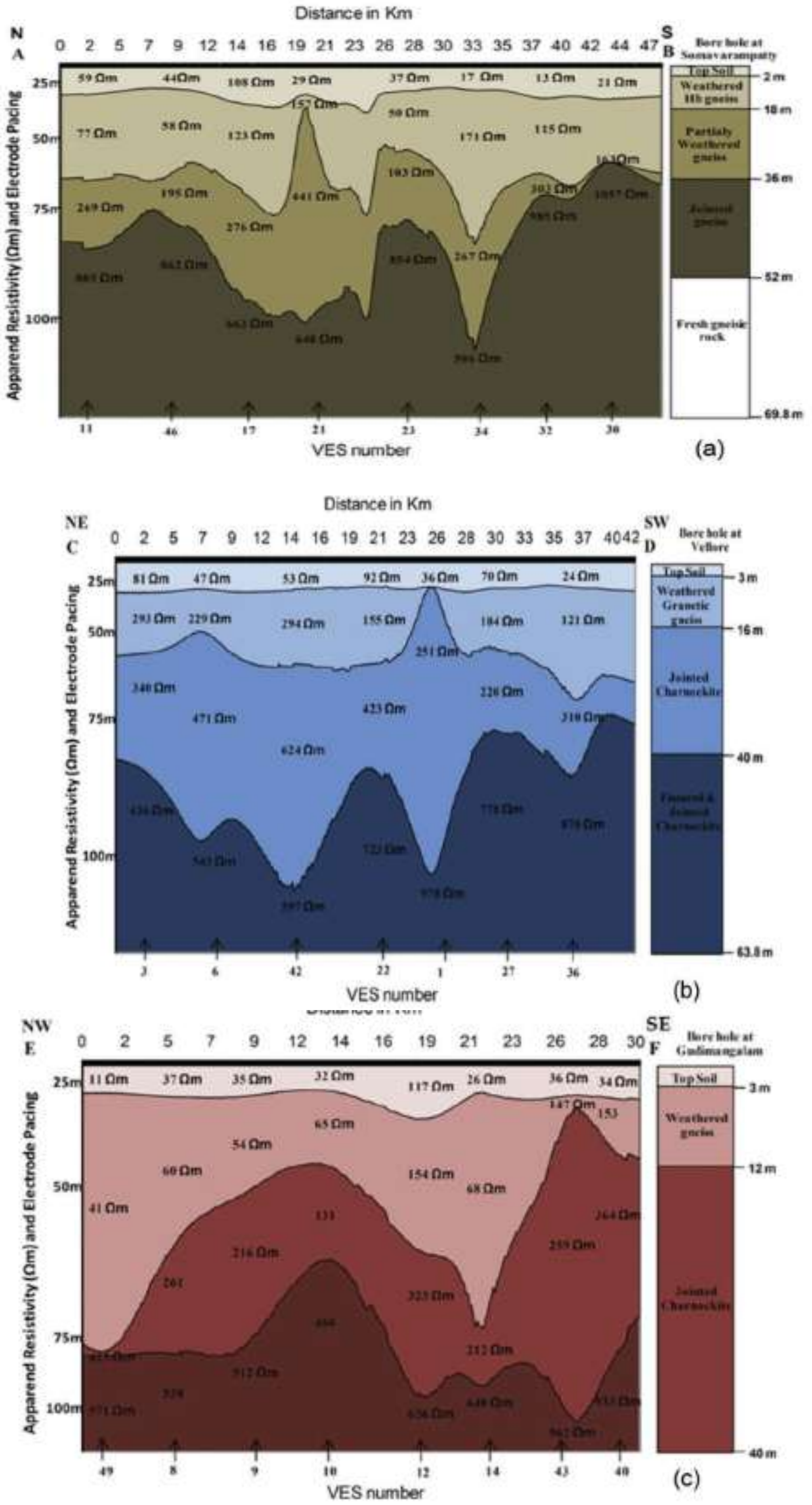

Fig 5: Resistivity profiles and borewell lithology data along (a) AB, (b) CD and (c) EF sections
Source: https://www.tandfonline.com/doi/abs/10.1080/02626667.2014.990966?journalCode=thsj20

Geomorphology and Lineaments

The movement and occurrence of the groundwater in a sub-basin area are controlled by the geomorphology. This important parameter on the basis of satellite data easily demarcates the spatial distribution of groundwater prospective zones in recent years. The various geomorphic units were interpreted by using IRS P6 LISS III color composite images as well as field observations, like topography, soil, relief, aspect factor and vegetative cover. Since geomorphology investigates the delineation and mapping of landforms along with drainage characteristics, therefore it can easily identify the various landforms of the sub-basin with different groundwater prospects (Agarwal & Garg, 2016). However, it is observed among the different geomorphic units, buried pediments and shallow pediments (associated with canal-irrigated pediplain zones) have the controlling features of major hydrological activities in the study area.

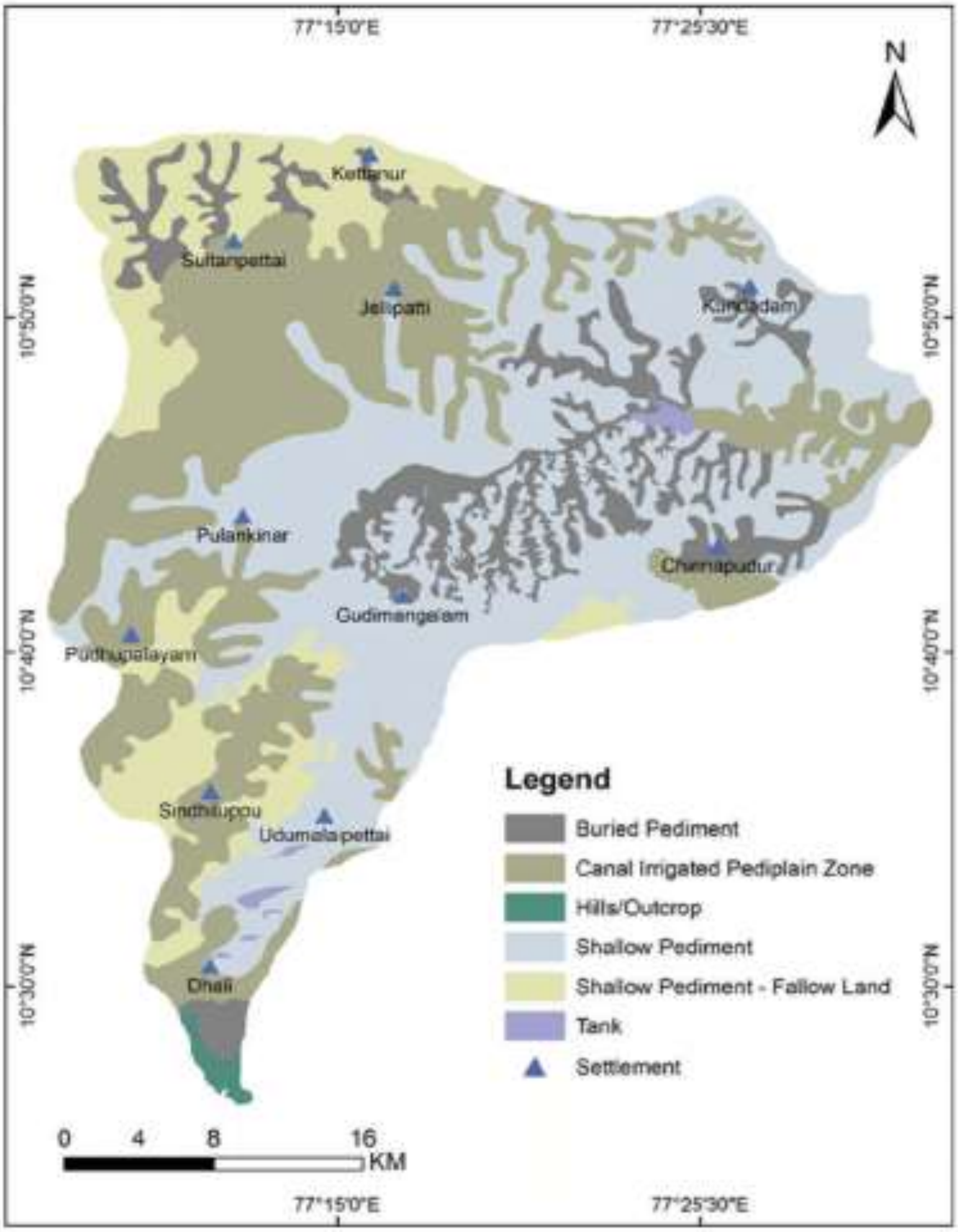

Fig 6: Geomorphology of the Uppar Odai sub-basin from interpretation of satellite data
Source: https://www.tandfonline.com/doi/abs/10.1080/02626667.2014.990966?journalCode=thsj20

The hidden architecture of the rock basement is revealed by the lineament, which reflects the surface manifestations of buried structures. As the features of weak planes, like fractures, faults, joints and dykes, are controlling the lineaments, thereby these act as conduits for movement and occurrence of the groundwater. For mapping of potential groundwater zones, in this study GIS used lineament data derived from SPOT imagery. Further, in this study remote sensing data analyzes the lineament data to compare with aquifer parameters (Gupta & Srivastava, 2010). In the sub-basin area lineament density, derived from the output satellite imagery, was segregated into high, moderate and low density zones. However, the higher lineament density is directly related to favorable groundwater potential zones.

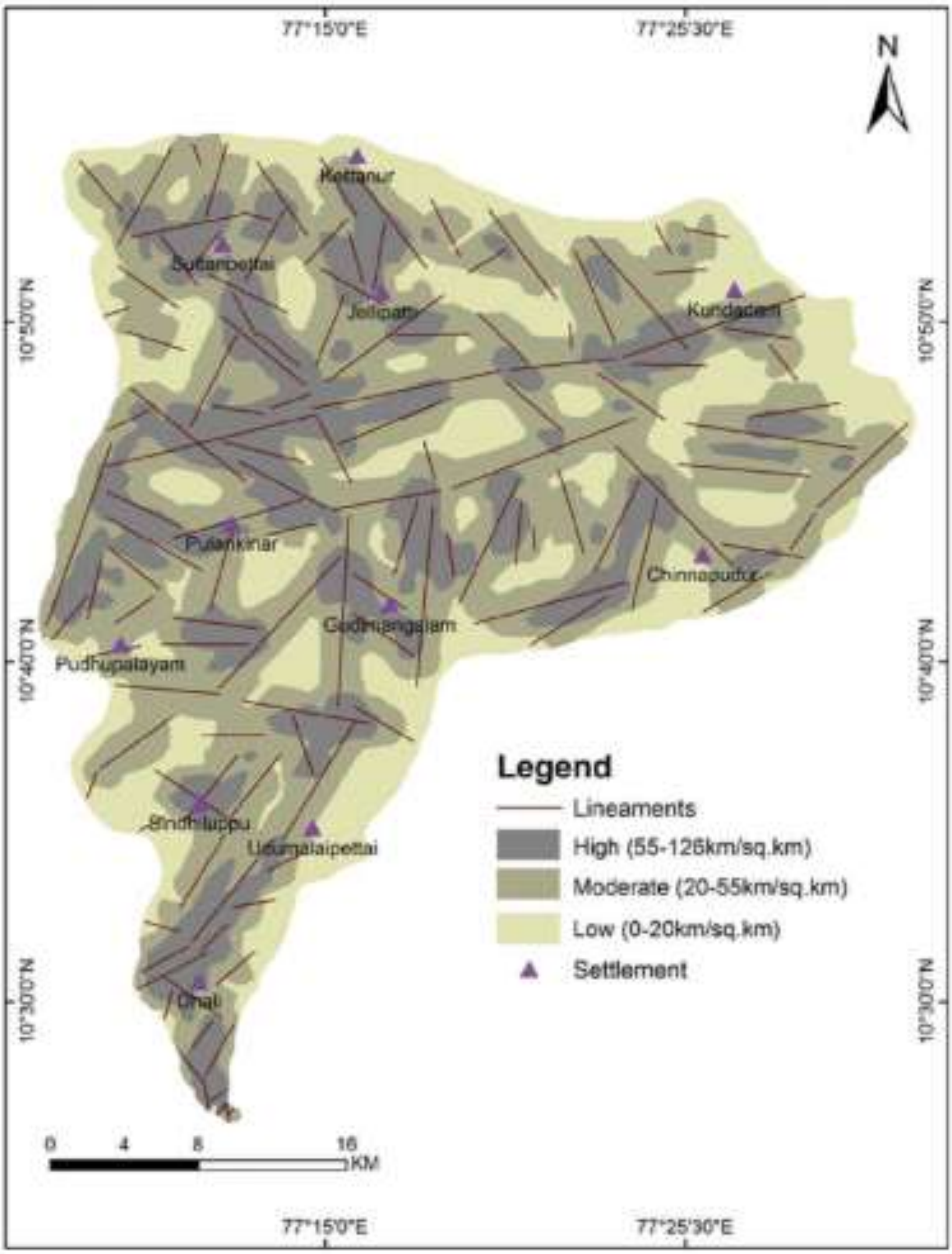

Fig 7: Lineament density map of Uppar Odai sub-basin
Source: https://www.tandfonline.com/doi/abs/10.1080/02626667.2014.990966?journalCode=thsj20

Results and Discussion

For potential groundwater mapping thematic maps significantly reflect the subsurface geological conditions. The spatial analysis tool of the ArcGIS 9.3 software, along with features of structure contour maps, used here to identify the potential groundwater zones. Further, the weighted overlay analysis assessed each individual thematic layer and subsequently generated integrated output map of favorable zones. The resistivity values in the different depth configuration were analyzed to indicate different landforms with aquifer conditions (Jothibasu & Anbazhagan, 2016). The low resistivity zones indicate the available thickness of aquifer zones at different depths, including the favorable groundwater conditions.

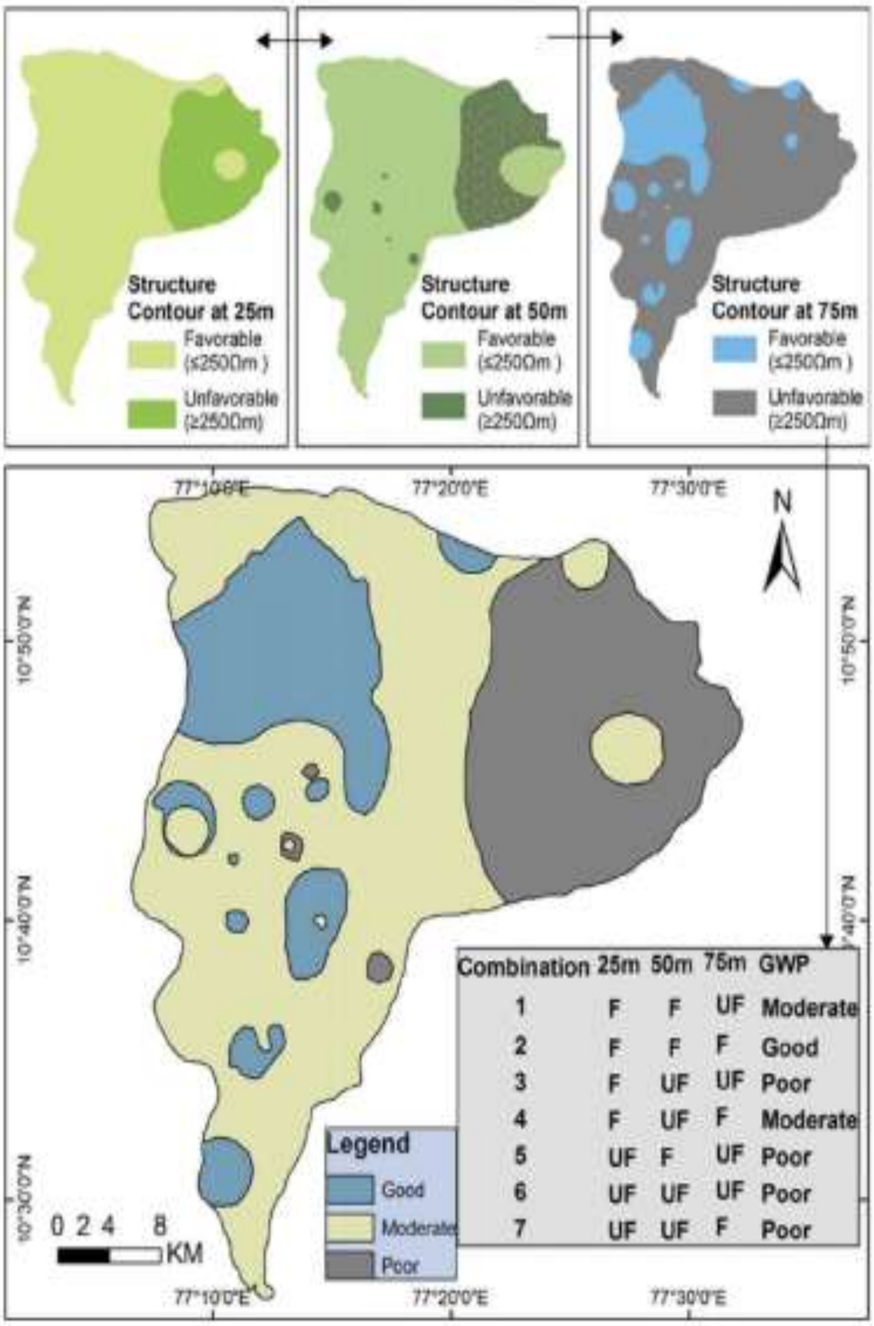

Fig 8: Thematic layers of low resistivity zones at different depth configurations and integrated groundwater potential zones of Uppar Odai sub-basin

Source: https://www.tandfonline.com/doi/abs/10.1080/02626667.2014.990966?journalCode=thsj20

On the basis of that concept, the study area is segregated into three layers of potential zones and the good one extends to a maximum of 75 m depth. If out of three layers, two has the features of low resistivity zones, then it can be classified as a moderate potential zone (Jothibasu & Anbazhagan, 2016). Whereas, if one layer supports low resistivity features, out of three, then it belongs to poor one. On the basis of this prospect, the ranking assigned to individual units of each thematic layer. In this context, the following table represents the features of the study area-

Table 1: Thematic layers (ranking and weight aspects) for GIS spatial integration

Thematic layer	Groundwater prospective zones	Rank	Weight	Score
Electrical resistivity	Good	10	40	400
	Moderate	8		320
	Poor	1		40
Geomorphology	Good	10	25	250
	Moderate	6		150
	Poor	1		25
Lineament density	High	10	35	350
	Moderate	6		210
	Low	2		70

Source: https://www.tandfonline.com/doi/abs/10.1080/02626667.2014.990966?journalCode=thsj20

Further, groundwater yield data obtained through GIS spatial integration to validate potential zones. However, the water level data are used alternatively in the absence of yield data. The water level data reflect the actual recharge condition and groundwater potential of a location (Asadi et al., 2012). On the basis of GIS integrated analysis, a comparative study carried out between water level profile and groundwater potential zones. On the basis of the data, following figure shows the water table condition across the sub-basin.

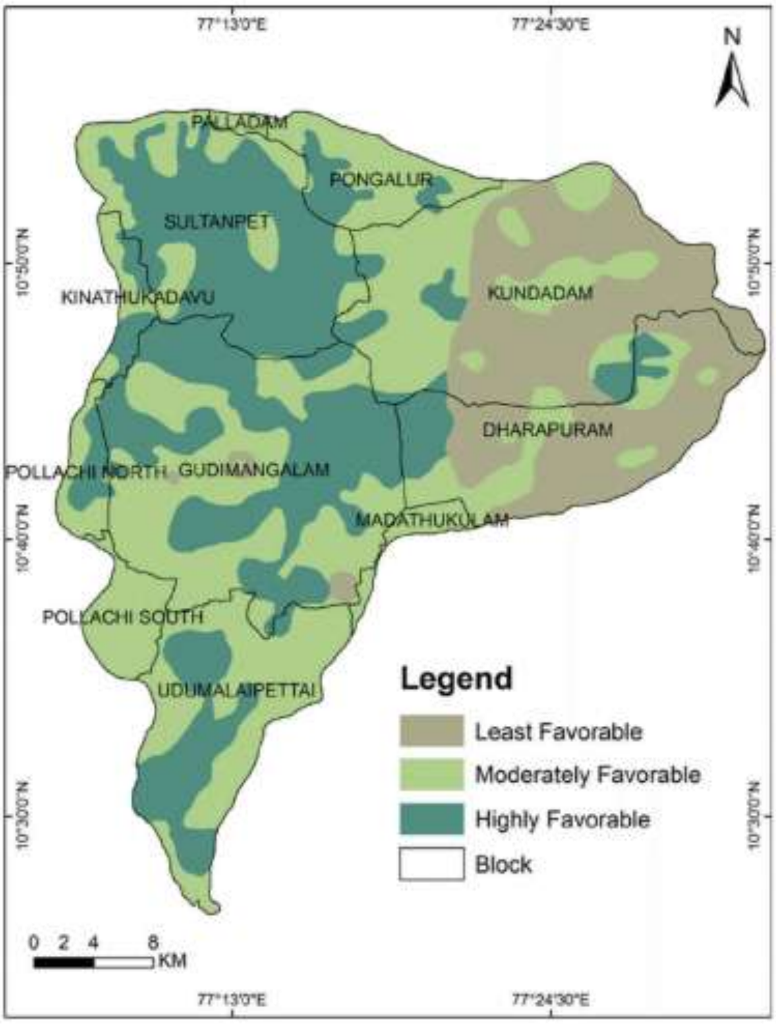

Fig 9: Sustainable groundwater potential zones in Uppar Odai sub-basin
Source: https://www.tandfonline.com/doi/abs/10.1080/02626667.2014.990966?journalCode=thsj20

Thereby, a sustainable planning can be possible by comparing the final groundwater potential zones with the current level of groundwater. On the basis of development percentage of groundwater in various blocks, the sub-basin can be segregated into different categories. Criticality of these categories will prioritize the attention toward those distinct blocks for reducing groundwater extraction through constructive framework and practices (Kolawole et al., 2016).

Conclusion

For potential mapping and sustainable planning, integrated geophysical, remote sensing and GIS analyses provided significant output. The structure contour maps with resistivity data analysis presents the lateral as well as vertical distributions of favorable aquifer conditions. The geomorphology and lineament studies provided sub-surface manifestations with the help of satellite output data. So, the favorable groundwater exploration and their clear demarcation can be possible by weighted overlay analysis in line with GIS spatial integration. On the basis of the data, the study area is segregated into high, moderate and least favorable potential zones. This helps in groundwater and alternative cropping pattern management in perspective of farmers. Hence, the sustainable planning and long-term groundwater development practice in the sub-basin area are possible by validating the comparative potential study results of current water level and groundwater development data.

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