

A GIS-based Methodology to Delineate Potential Areas for Groundwater Development: A Case Study on Sarada Gadda sub-watershed, Rajam, North-Coastal Andhra Pradesh

Dr. Ch. Ramesh¹ and Dr. Ch Kannam Naidu²

¹Professor, Dept. of CSE, AITAM, Tekkali, A.P, India & Principal Investigator for the DST sponsored project “A critical study for sustainable development of ground water resources using Remote Sensing and GIS technology: A case study of Sarada gadda sub-watershed, Rajam, North-Coastal Andhra Pradesh”

² Professor, Dept. of Civil Engg , AITAM, Tekkali, A.P, India & Co- Principal Investigator

Abstract

Groundwater, which is in aquifers below the surface of the earth, is one of the nation's most important natural resources. Ground water has emerged as the backbone of India's agriculture and drinking water security. It is the source for more than 85 percent of India's rural domestic water requirements, 50 percent of its urban water requirements and more than 50 percent of its irrigation requirements and is depleting fast in many areas of the country due to over exploitation of underground water, lack of replenishment of underground water, cutting of trees, lack of vast open spaces, insufficient rains etc. In such areas, there is need for artificial recharge of ground water by augmenting the natural infiltration of precipitation or surface water into underground formations. In the present study, the favorable locations have been identified by employing remote sensing, GIS and image processing techniques for artificial recharge and apposite artificial recharge structures have been proposed thereof.

Keywords: Ground water, Remote sensing, GIS, Image processing, Artificial recharge.

1. INTRODUCTION

Groundwater is a replenishable and dynamic natural resource widely distributed on the earth [1]. In fact the largest source of fresh water lies underground and it accounts for 97 percent of the fresh water excluding glaciers. The arid and semi-arid regions depend more on ground water for major part of its water requirements and as such it is imperative to evaluate the available ground water and relevant measures have to be developed to accomplish the same.

The challenges to facilitate the livelihood pertaining to any region demanding scientific and judicial utilization of land and water resources for sustainable well-being are huge, diversified, quite complex and dynamic [2]. The major problems like over-exploitation, under-utilization and miss-utilization of water resources cause significant regional conflicts and ultimately jeopardize the local environment from micro to macro levels. In view of the above, spatial analysis of water resources and their utilization for human welfare with environmental safeguards are of paramount need in the current scenario [3].

Assessment and Development of Groundwater study is multi-disciplinary in approach encompassing hydrology, geology, hydro metrology, geophysics, hydrogeology, well hydraulics and engineering [4].

As different factors like morphology, slope, drainage pattern, rock type, altitude of the rock, joint patterns, texture and structure control the occurrence and distribution of ground water, detailed investigations of these aspects have been carried out in the present study with the help of geological maps, topographical maps and high resolution satellite images [5].

Groundwater recharge is a process by which excess surface water is directed into the ground – either by spreading on the surface by means of recharge wells or by altering the natural conditions to increase infiltration to replenish an aquifer that refers to the movement of water through man-made systems from the surface of the earth to underground water-bearing strata wherein it may be preserved for future use [6].

Groundwater Recharge by roof top harvesting and by water harvesting structures (WHS) like trenches and percolation tanks can be preferred which are normally cheap and can be erected locally [7,8]. Different structures are used depending upon the location of the area and the purpose of water being used for particular area and application [9].

2. STUDY REGION AND DATA SOURCE

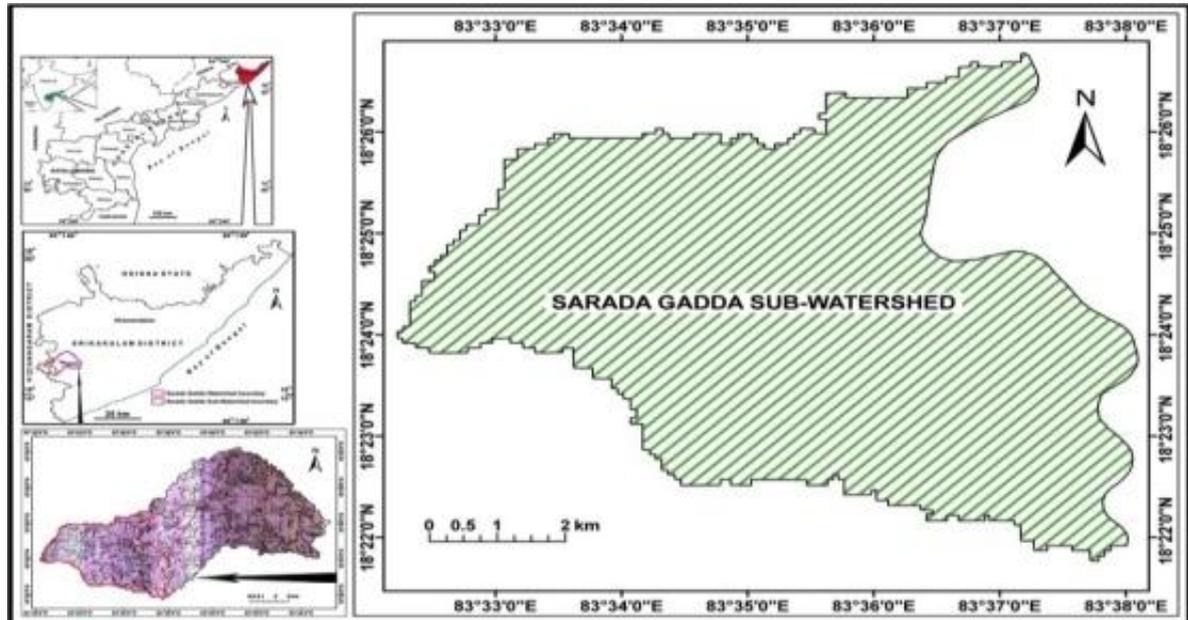


Fig.1 Location map of sarada gadda sub-watershed

The present study area (Fig. 1) Sarada gadda sub watershed is located near rajam in Srikakulam district of North Coastal Andhra

Pradesh, India. It lies between latitudes from 18°21'46.361"N to 18°26'47.987"N and longitudes from 83°32'12.884"E to 83°38'6.31"E. The study area falls in the Survey of India toposheet no.65N/11. It covers a geographical area about 51.02 Sq.km. It consists of 19 revenue villages. Geologically the area comprises consolidated rocks of Gneiss, Khondalite and Charnockite. The minimum and maximum temperature ranges vary from 28⁰C to 42⁰C in general. Agriculture is the main occupation of the dwellers of the watershed. The following data sources are used in this study.

- Survey of India toposheets no.65N/11 on 1:50000 scale
- Satellite imagery LANDSAT 7 ETM+
- Satellite imagery KOMPSAT from NRSC of 1 meter resolution
- Electrical Resistivity meter
- Ground truth data
- Well inventory data
- ArcGIS and Erdas

3. METHODOLOGY

The step by step methodology adopted in the present work is outlined in the following flowchart (Fig. 2)

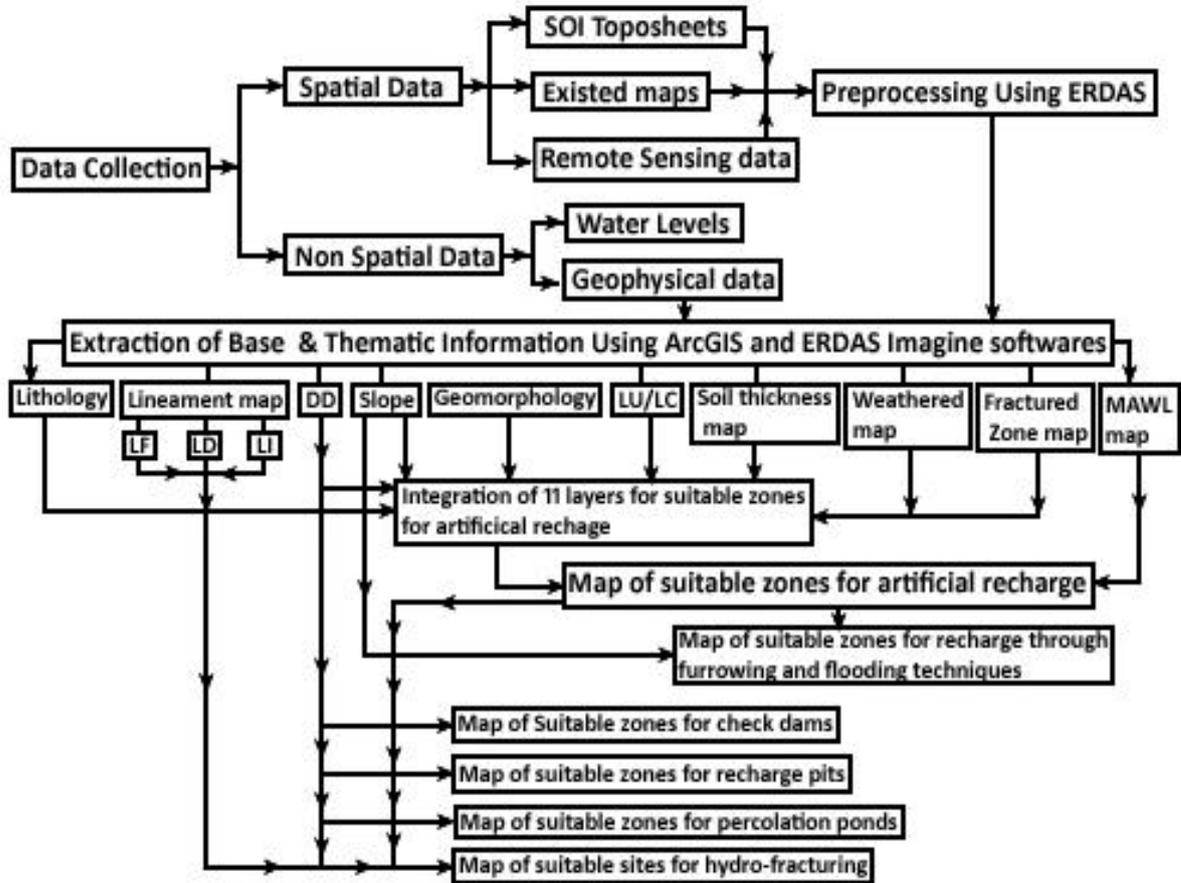


Fig. 2 Methodology flow chart

3.1 Lithology:

The geological units in the study area includes; Gneiss, Khondalite and Charnockite. The lithology map is obtained from central ground water board [10].

3.2 Lineaments:

Lineaments represent the zones of faulting and fracturing resulting in increased secondary porosity and permeability [11]. These may be used to infer groundwater movement and storage. The lineaments map for the study area is prepared from the Landsat 7 ETM + satellite image. The mapped structural lineaments were analyzed

using the lineament frequency (LF), lineament density (LD) and lineament intersection (LI) parameters [12].

3.3 Drainage Density:

Drainage map is prepared by using Survey of India (SOI) topographic maps of the study area on 1:50,000. All the streams and tanks existing in the study area are marked in this map. These streams are further classified based on stream ordering [13].

3.4 Slope Map:

The slope function in Arc GIS calculates the maximum rate of change between each cell and its neighbors. Every cell in the output raster has a slope value. The lower slope value indicates that the terrain is flat and the higher slope value, that it is steep. The output slope raster can be calculated either in percent of slope or degree of slope. Slope map was prepared from the DEM.

3.5 Geomorphology:

Geomorphological factors which predominantly control the groundwater prospects have been obtained from the NRSC bhuvan website [14].

3.6 Land Use / Land Cover:

The groundwater recharge depends on the land use / land cover by way of affecting the percolation into the aquifer. Built-up lands and pavements result in more surface runoff and less recharge [15]. On the other hand agricultural areas, farm lands and areas with thick vegetation increase the percolation resulting in more groundwater recharge. The land use/land cover map for the study area is prepared from the satellite images and was verified via necessary field check.

3.9 Integration of layers(3.1- 3.7): The layers land use / land cover, lithology, geomorphology, slope, drainage density, lineament frequency, lineament density, lineament intersection, top soil , weathered zone and fractured zone are integrated in the GIS environment to identify suitable locations for artificial recharge.

3.10 Integration of layers(3.1- 3.8): The layers land use / land cover, lithology, geomorphology, slope, drainage density, lineament frequency, lineament density, lineament intersection, top soil , weathered zone, fractured zone and mean annual water levels are integrated in the GIS environment to identify suitable locations for artificial recharge.

3.11 Artificial recharge structures: we have identified the suitable locations in the study area for artificial recharge structures like furrowing and flooding techniques, check dams, recharge pits, percolation ponds and hydro-fracturing.

3.7 Geophysical data:

At 28 locations of the study area, the geophysical survey has been conducted by using electrical resistivity meter [16] to generate the top soil, weathered zone, fractured zone maps.

4. RESULTS AND DISCUSSIONS

4.1 Base map

Base map was generated from number 65 N/11 top sheet, which is having 1:50000 scale. (Fig.3). This shows villages with road network of the study area

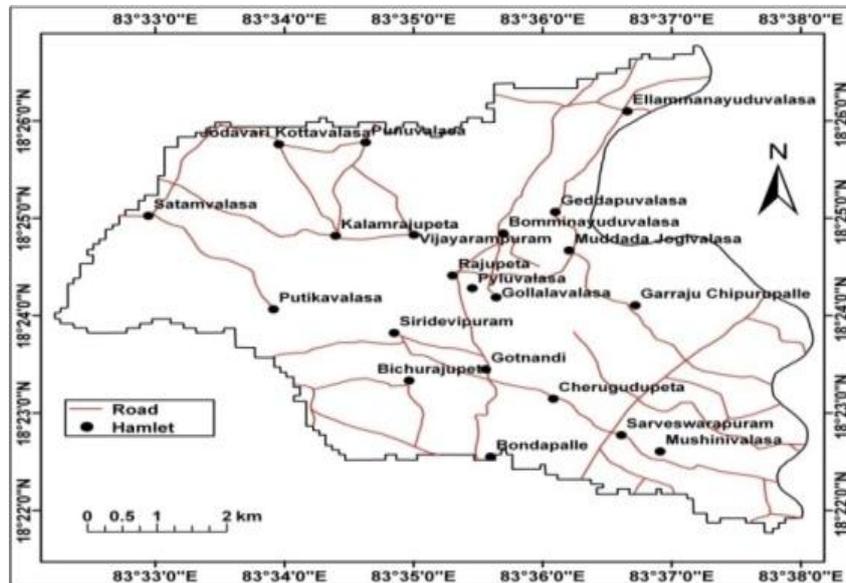


Fig. 3 Base map of the study area

3.8 Well inventory data:

The seasonal wise (pre and post monsoon)

Water level depths have been collected for the years 2013 to 2015 in 88 open wells of the study area. The mean annual depths have been calculated for the collected data [7].

Thereafter the mean annual water level map has been generated.

4.2 Lithology

The study area consists of Gneiss, Khondalite and Charnockite.(Fig. 4) Gneiss covered an area of 21.72 km² (42.6%), Charnockite covered an area of 70 km² (5.3%) and Khondalite covered an area of 26.60 km² (52.1%).

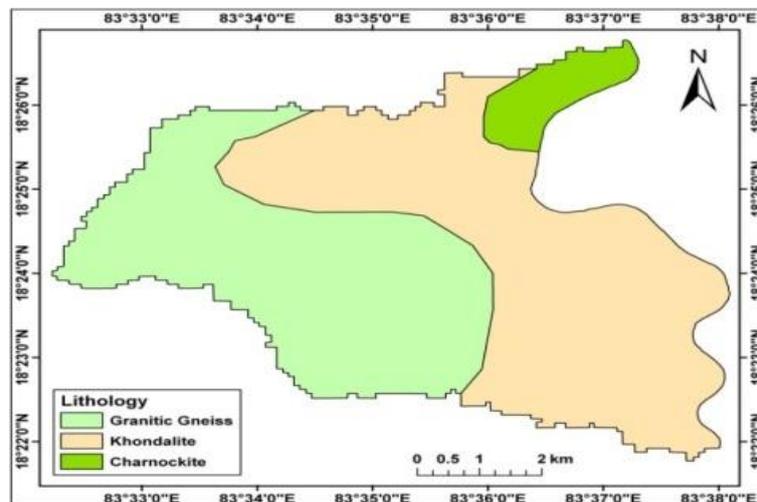


Fig. 4 Lithology of the study area

4.3 Lineaments

The total length of the lineaments in the study area is 26.5 km (Fig. 5). The mapped structural lineaments were analyzed using the lineament frequency (LF), lineament density (LD) and lineament intersection (LI) parameters.

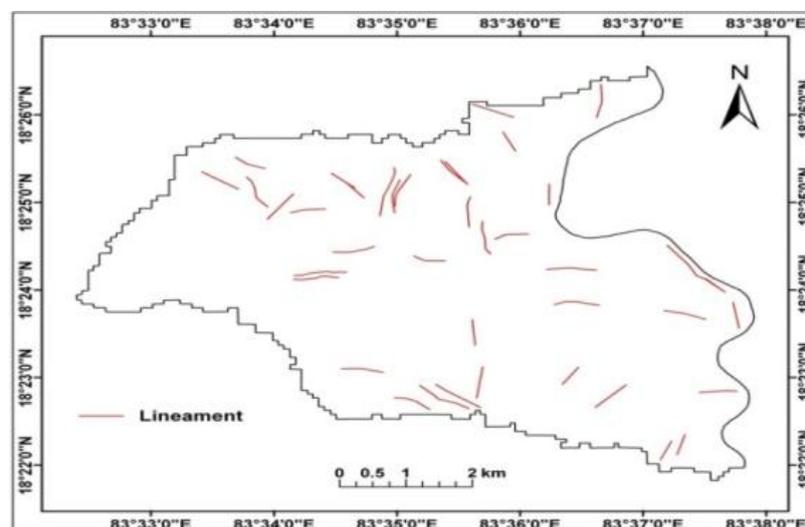


Fig.5 Lineaments of the study area

4.3.1 Lineament Frequency

The study area is divided into two zones (Fig. 6) i.e minima (<2 No/sq km) and maxima (>2 No/sq km). Minima zone covers an area of 36.94sq.km (72.4%) and Maxima zone covers an area of 14.08 sq.km (27.6%) of the total study area.

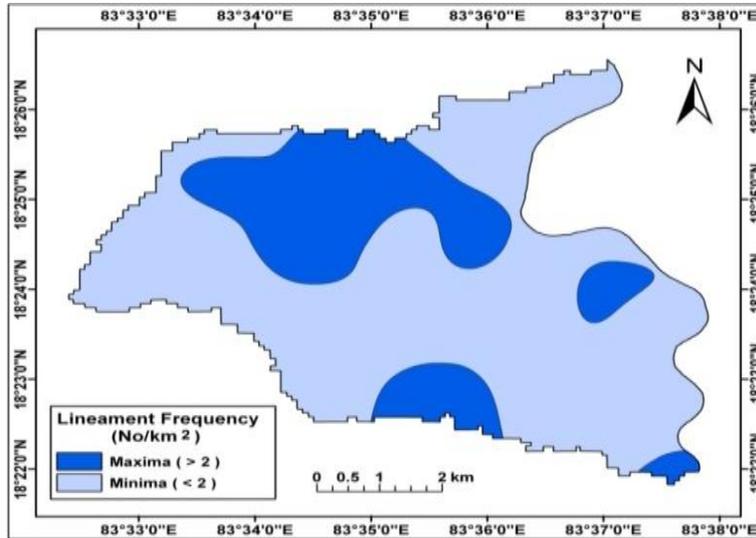


Fig. 6 Lineament frequency of the study area

4.3.2 Lineament Density

The study area is divided into two zones (Fig. 7) i.e maxima (>2 km/km²) and minima (<2 km/km²). Maxima zone covers an area of 5.99 sq.km (11.7%) and minima zone covers an area of 45.03 sq.km (88.3%) of the total study area.

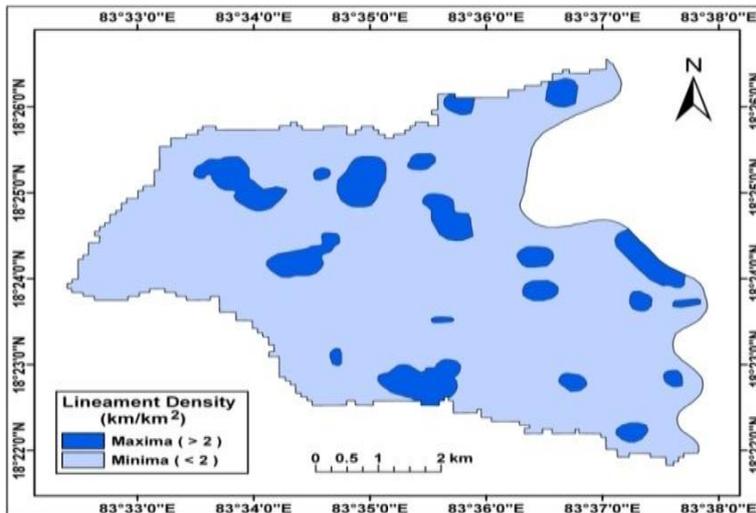


Fig. 7 Lineament density of the study area

4.3.3 Lineament Intersections

The study area do not possess any lineament intersections (Fig. 8).

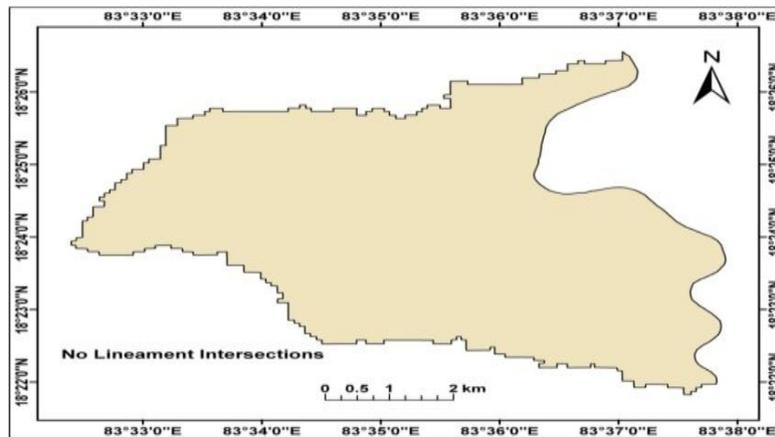


Fig. 8 Lineament intersections

4.4 Drainage Density

The study area is divided into two zones (Fig. 9) i.e minima ($< 1 \text{ km/km}^2$) and maxima ($1-14 \text{ km/km}^2$). Minima covers an area of 33.76 km/km^2 (66.2 %), and maxima covers an area of 17.26 km/km^2 (33.8 %) of the total study area.

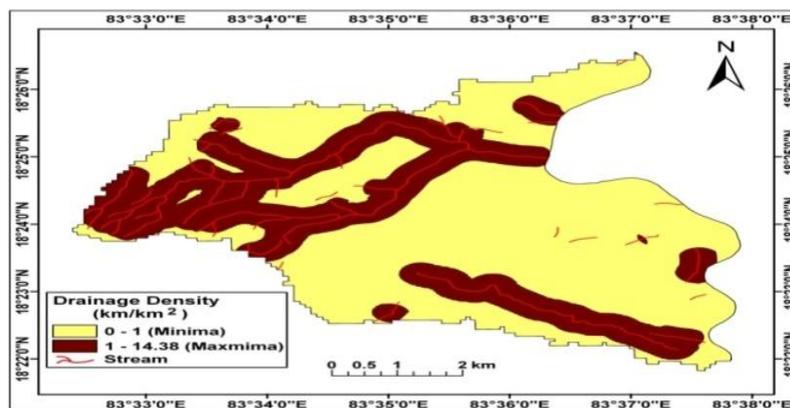


Fig. 9 Drainage density of the study area

4.5 Slope

The study area is divided into three zones (Fig. 10) i.e low/null ($<5\%$), moderate ($5-20\%$) and high ($>20\%$). Major part of the study area is covered by under low/ null slope zone, which spans an area of 47.54 km^2 (93.2%), followed by moderate and high slope zones

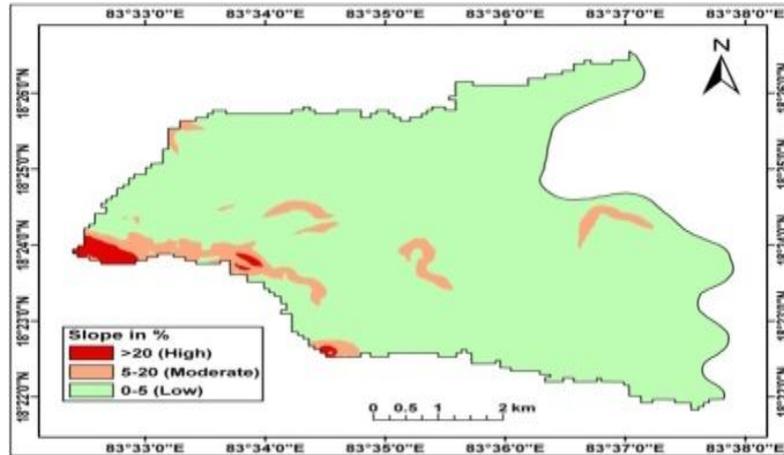


Fig. 10 Slope of the study area

4.6 Geomorphology

The study area is divided into two regions (Fig. 11) i.e. Denudational origin and Structural origin. Denudational origin is covered by an area of 50.20 km² [(98.4%) of the study area].

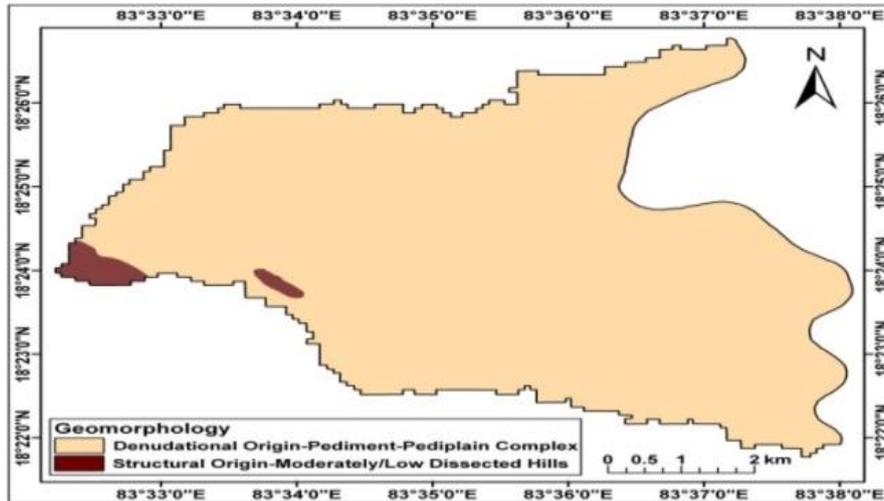


Fig.11 Geomorphology of the study area

4.7 Land Use / Land Cover

The land use classes are delineated from KOMPSAT image and field verification (Fig. 12). Around 86.8% of the total area is under cultivation, remaining are water bodies, scrub/waste land and built-up land covering an area of 5.8%, 3.8% and 3.6% respectively.

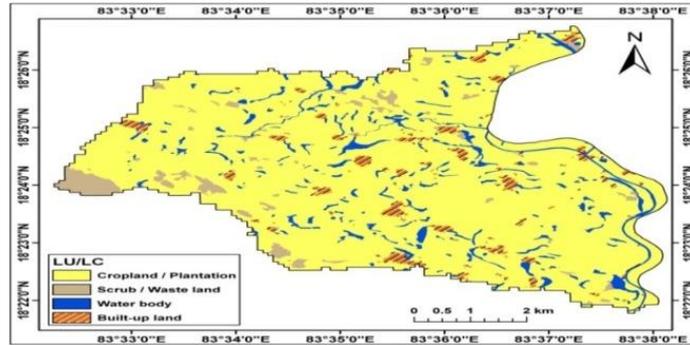


Fig. 12 Land use / Land cover of the study area

4.8 Geophysical survey

At 28 locations of the study area (Fig. 13), the geophysical survey has been conducted by electrical resistivity method to determine the subsurface layers as well the aquifer extent.

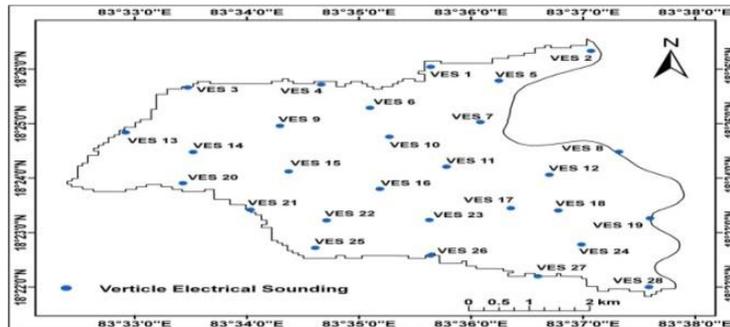


Fig. 13 Geophysical survey locations of the study area

4.8.1 Top soil thickness

Based on the top soil thickness, the study area is divided into two zones (Fig. 14) i.e minima (< 4m) and maxima (>4m). Minima zone occupies an area about 42.69 km² and maxima zone occupies an area about 8.33 km².

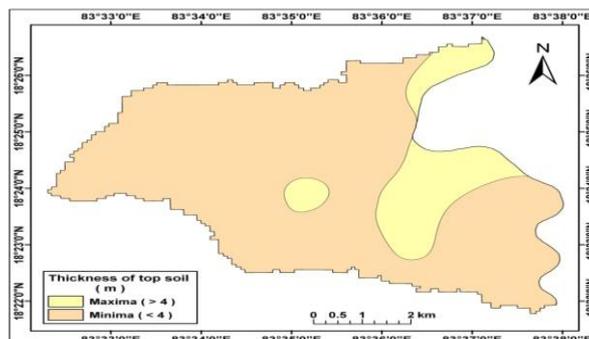


Fig.14 Top soil thickness of the study area

4.8.2 Weathered zone thickness

The study area has been divided into two zones (Fig.15) i.e minima (<15m) maxima (>15m). The minima zone covers an area of 44.76 km² and maxima zone covers an area of 6.26 km² of the study area.

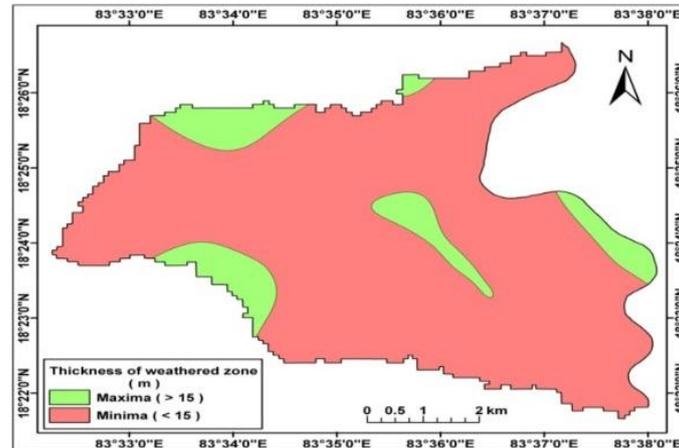


Fig. 15 Weathered zone thickness of the study area

4.8.3 Fractured zone thickness

Based on the thickness of the fractured zone the study area is divided into two zones (Fig. 16) i.e minima zone (<15 m) and maxima zone (>15m). Minima zone occupies an area of 13.48 km² and maxima zone occupies an area of 37.54 km².

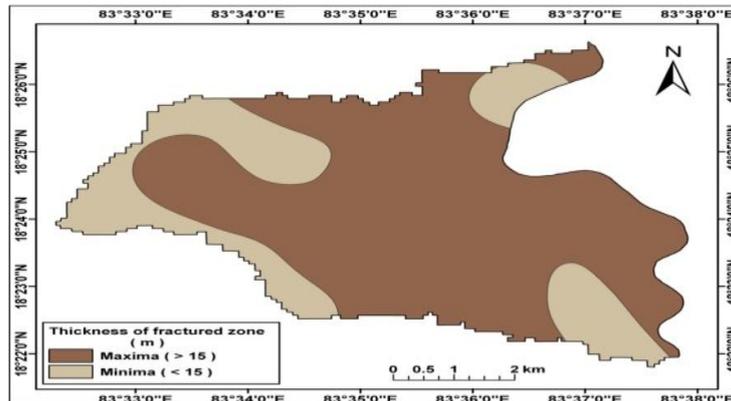


Fig. 16 Fractured zone thickness of the study area

4.9 well inventory data

Based on the mean annual water levels, the study area is divided into two zones (Fig. 17) i.e. maxima (>6 meters) and minima (<6 meters). Maxima zone occupies an area of 10.03 km² and minima zone occupies an area of 40.99 km² respectively.

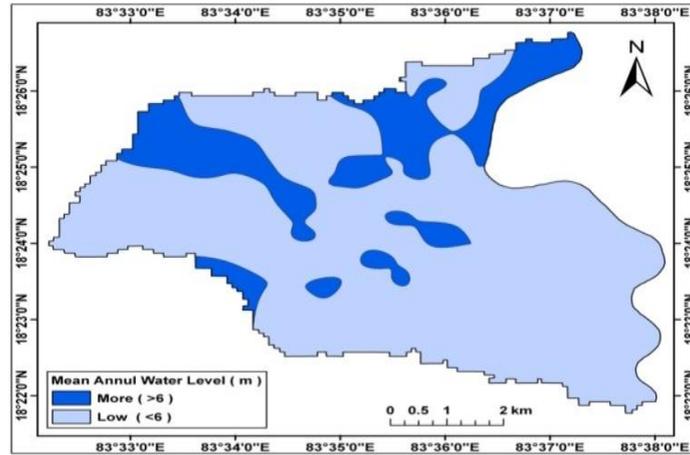


Fig. 17 Mean annual water level map of the study area

4.10 Integration of layers (4.2-4.8) for generating the favorable artificial recharge zones

The study area has been divided into three categories of favorable zones(Fig.18) for artificial recharge i.e high, moderate and poor, which occupies areas of 10.69 km² (20.9%), 1.37 km² (2.7%) and 38.96 km² (76.4%) respectively.

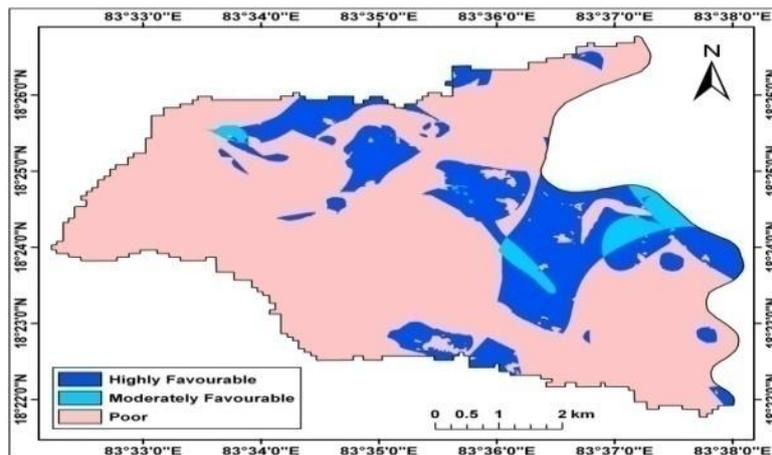


Fig. 18 Artificial recharge zones

4.11 Integration of layers (4.2-4.9) for generating the favorable artificial recharge zones

The study area has been divided into three categories of favorable zones (Fig.19) for artificial recharge i.e high, moderate and poor, which occupies areas of 1.09 km² (2.1%), 0.15 km² (0.3%) and 49.78 km² (97.6%) respectively.

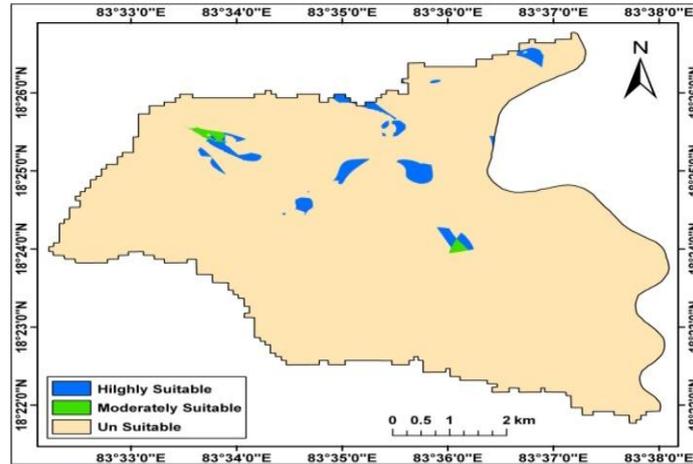


Fig. 19 Artificial recharge zones

4.12 Methods / Techniques used for artificial recharge

Based on the slope and drainage density the study area for artificial recharge has been divided into furrowing and flooding structures, check dams, recharge pits, percolation ponds and hydro-fractured areas.

4.12.1 Furrowing and flooding

These techniques are useful where the areas are having gentle slope and irregular topography. Since most of the study area is under null slope zone [19], there is no possibility to mark/identify the suitable zones.

4.12.2 Check dams

The study area comprises minimal drainage network and the major part is under null slope zone. Hence this area is not suitable for constructing check dams [20].

4.12.3 Recharge pits

The study area has been categorized into three favorable zones i.e high, moderate and poor (Fig. 20). These occupied the areas of 0.92 km² (1.8%), 0.15 km² (0.3%) and 49.95 km² (97.9%) respectively.

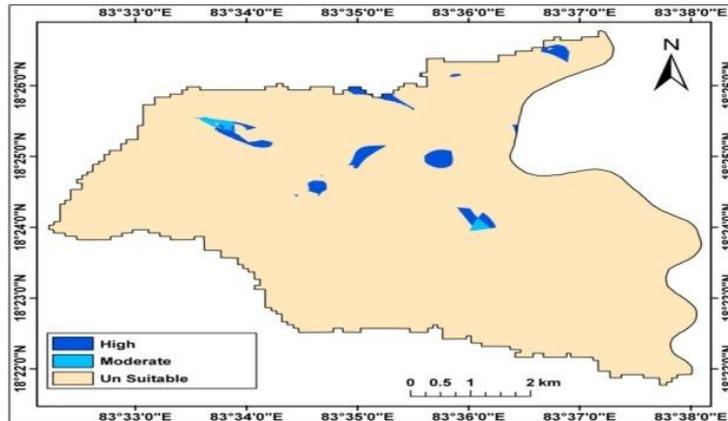


Fig. 20 Suitable locations for recharge pits

4.12.4 Percolation ponds

The investigations reveal that there is no coincidence of drainage convergence with good category zones for artificial recharge. As a consequence, construction of percolation ponds is not possible (Fig. 21).

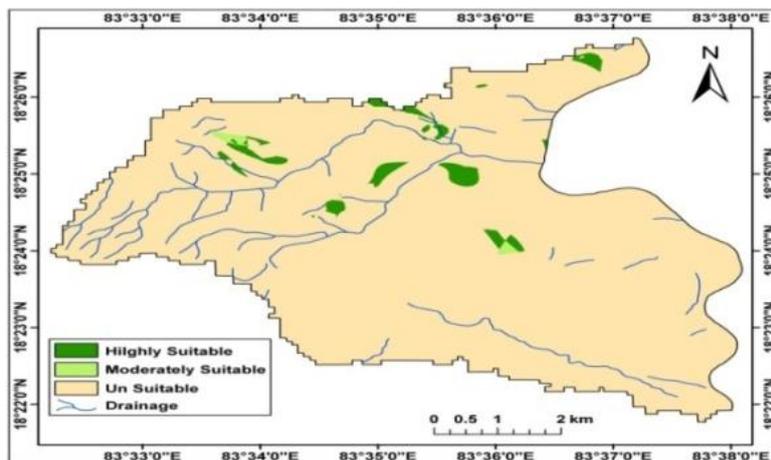


Fig. 21 Integration of drainage density and artificial recharge zones

4.12.5 Hydro-fracturing

It's the process wherein hydraulic pressure is applied for propagation of fractures and to extend the existing fractures. As per the methodology to mark suitable sites for hydro-fracturing in the study area, good zones of lineament frequency, density and intersections should coincide with final favorable artificial zones map. However, the present study indicates the coincidence of lineament frequency and density only with the favorable zones of artificial recharge, since intersections could not be identified i.e. out of the three parameters only two have been coincident with the favorable

zones of artificial recharge. Highly suitable sites for hydro-fracturing have occupied an area of 0.83 km² only (1.6%) and moderately suitable sites have occupied an area of 0.09 km² (0.2%) (Fig. 22).

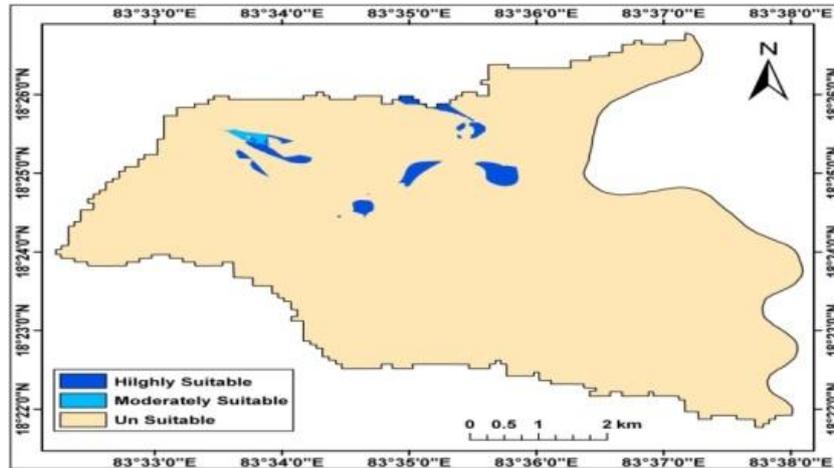


Fig. 22 Suitable locations for hydro-fracturing

CONCLUSION

The present study demonstrates the importance of ground water and the need for artificial recharge of ground water. Further, within the study area, we have identified the favorable locations for artificial recharge by using remote sensing, GIS & image processing techniques and recommended the suitable artificial recharge structures such as recharge pits and hydro-fracturing.

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