RESEARCH ARTICLE Indian Journal of Agricultural Research, Volume 55 Issue 1: 23-32 (February 2021)

An Approach to Mapping Groundwater Recharge Potential Zones using Geospatial Techniques in Kayadhu River Basin, Maharashtra

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10.18805/IJARe.A-5477

ABSTRACT

Rapid increase in population, agricultural expansion and ongoing development projects in the region. However, the region is facing water scarcity because of seasonal precipitation and inadequate surface water resources. Therefore, groundwater resources are gaining much more attention mainly in Kayadhu river basin to fulfil drinkable water requirements in the area. To maintain the long-term sustainability of water resources artificial recharge is expected to become frequently necessary in future as the growing population requires more water and consequently, more storage is required to conserve water for use in the times of shortage. Geospatial techniques are used in the field of hydrology and water resources management. One of the chief advantages of this techniques for hydrological investigation and observe its ability to generate data in spatial and temporal fields, which plays vital role for fruitful analysis, estimation and authentication. The suitable zones for artificial recharge were identified by overlaying thematic layers such as land use/land cover, lineament density, slope, drainage density, lithology, geomorphology, rainfall and soil characteristics are integrated with recharge potential factors. The result reveals that 79% area of Kayadhu river basin is most effective for high to moderate artificial recharge potential zone.

Key words: Geographic information system, Groundwater recharge, Kayadhu river, Weighted overlay.

INTRODUCTION

According to Freeze and Cherry (1979) groundwater is defined as subsurface water that fills all the openings in the soil and rock formations below the water table. Groundwater flows through the aquifer towards the point of discharge such as springs, wells, rivers, lakes and the ocean. Ground water conditions are largely controlled by the prevalence and orientation of primary and secondary porosity. The depletion of groundwater levels is not a new account in Maharashtra, India, however, it has continued for last two decades, while annual water demand increased for agricultural, industrial activities and semi-arid situations in the Kayadhu river basin of Deccan Basaltic Province (DBP). The state is facing severe shortage of groundwater in spite of receiving a high annual rainfall (Raju, 1998). There are many influencing parameters that affects groundwater recharge potential in the area such as land use/land cover, lineament density, slope, drainage density, geology, geomorphology, rainfall and soil characteristics. Modern remote sensing techniques enable demarcation of suitable areas for groundwater renewal by taking into account the diversity of factors that control groundwater recharge. Satellite remote sensing has emerged as a useful tool for watershed characterization, conservation, planning and management in recent times (Aher and Sharma, 2014). Various studies have been carried out throughout the world to identify the groundwater recharge potential zones by employing remote sensing and GIS techniques were frequently employed in these studies for the preparation of required thematic layers. Moreover, existing maps, aerial photographs and ûeld data inputs have been commonly used (Krishnamurthy and Srinivas 1995; Krishnamurthy *et al*. 1996; Saraf and Choudhury 1997; Saraf and Choudhury 1998; Murthy 2000; Shahid *et al*. 2000, Krishnamurthy *et al*. 1996; Sener *et al*. 2005; Sree Devi 2003; Shaban *et al*. 2006; Solomon and Quiel, 2006; Tweed *et al*. 2007; Jasrotia and Kumar 2007; Ghayoumian *et al*. 2007; Yeh *et al*. 2009; Nagarajan and Singh 2009; Chenini *et al*. 2010, Subagunasekar and Sashikkumar 2012; Senanayake *et al*. 2016). 2009; Riad *et al*., 2011b). Most of these studies were built on knowledge-based approach and integrating diverse thematic layers such as land use/land cover, geology, geomorphology, lineament density, drainage density, slope, soil *etc*. with GIS techniques. Artificial recharge is a controlled recharge where surface water is

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How to cite this article: Ghute, B.B. and Babar, S.M. (2021). An Approach to Mapping Groundwater Recharge Potential Zones using Geospatial Techniques in Kayadhu River Basin, Maharashtra. Indian Journal of Agricultural Research. 55(1): 23-32. DOI: 10.18805/IJARe.A-5477.

Submitted: 09-12-2019 **Accepted:** 01-04-2020 **Online:** 18-06-2020

put on or in the ground for infiltration and consequently moves towards the aquifer to enhance the groundwater resources (Ta'any, 2011). It can be defined as the practice of increasing the amount of water entering to the subsurface reservoirs by artificial means (Bouwer 2002; Bhattacharya 2010). With Geographical Information System and satellite data, attempts were made to develop a suitable GIS based model, for mapping groundwater recharge potential zones by integrating different thematic layers which have direct control on ground water recharge in Kayadhu river basin, Maharashtra, India.

MATERIALS AND METHODS

The study area (Kayadhu river basin) is located in the eastern part of Deccan Basaltic Province (DBP), Maharashtra, India. The basin is confined between N19° 22″, E77° 40″ in the South East and N 20° 00″ E76° 40″ North West and total area of the basin is 2158.38 km^2. Out of the total area, around 1639.57 km^2 is covered with agriculture, 435.57 km^2 with waste land, 38.52 km^2 with settlements, 38.79 km^2 with forest and 5.92km^2 with water bodies. The Kayadhu river is seventh order and the major water source of this area and it originates from the Angarwadi village in Risod tauka of Washim district in Ajanta hill ranges with an elevation of 580 m. The drainage pattern in the study area is mostly dendritic as well as semi-dendritic. Climatologically, this area experiences semi-arid, sub-tropical condition characteristically hot summer with an annual rainfall ranging from 750 to 1244 mm and the temperature ranges between 12.7 and 41.7°C. The southwest monsoon is a major source of rainfall in the study area and it occurs during June to September (CGWB 2013). The population in the study area is around 5,00,000 and are distributed over 270 Panchayat villages and 4 townships (Fig 1).

For the present study, the methodology used is shown in the flow chart (Fig 2). In this study the spatial data base has been created using the topographic maps obtained from the Survey of India (SOI) 1:50000 scale, IRS P6 LISS IV MX satellite data, ASTER GDEM and field verification. Various thematic maps such as geology, drainage density, lineament density, rainfall data, soil, land-use/land cover, slope and geomorphology are prepared by using GIS and remote sensing. All of the map themes were presented in UTM Projection Zone 43 N, Datum WGS84 with 30 m resolution and converted to raster format.

Preparation of thematic layers

Geology

The type of rock exposed on the surface significantly affects the groundwater recharge (Shaban *et al*. 2006). According to El-Baz and Himida (1995) geology affects the groundwater recharge by controlling the percolation of water flow. While,

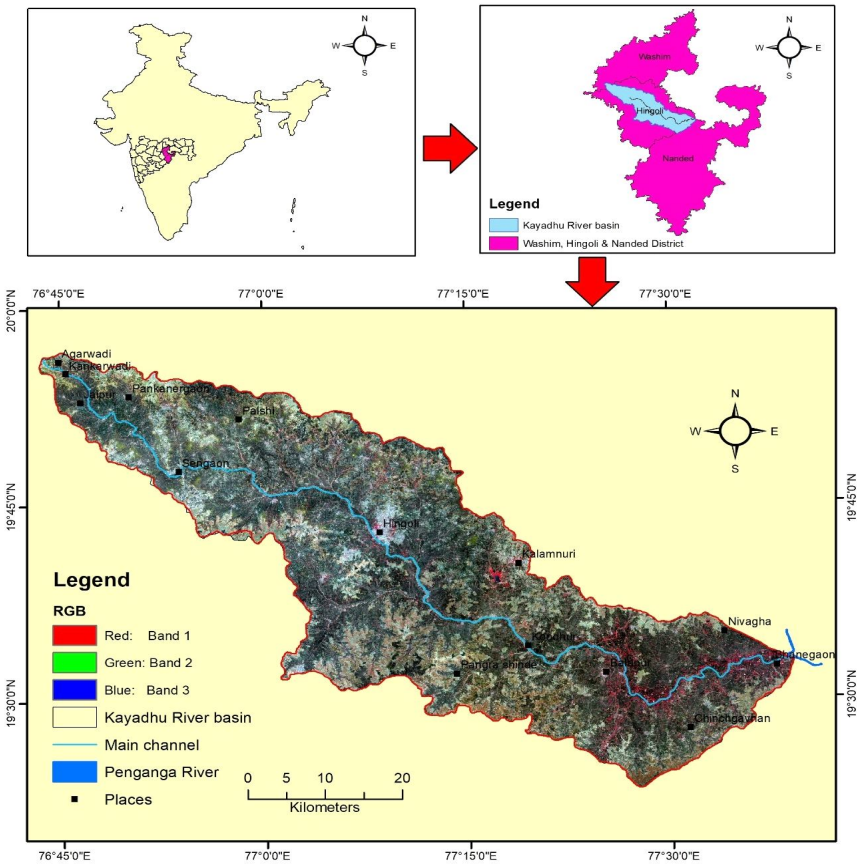


Fig 1: Location map of the study area.

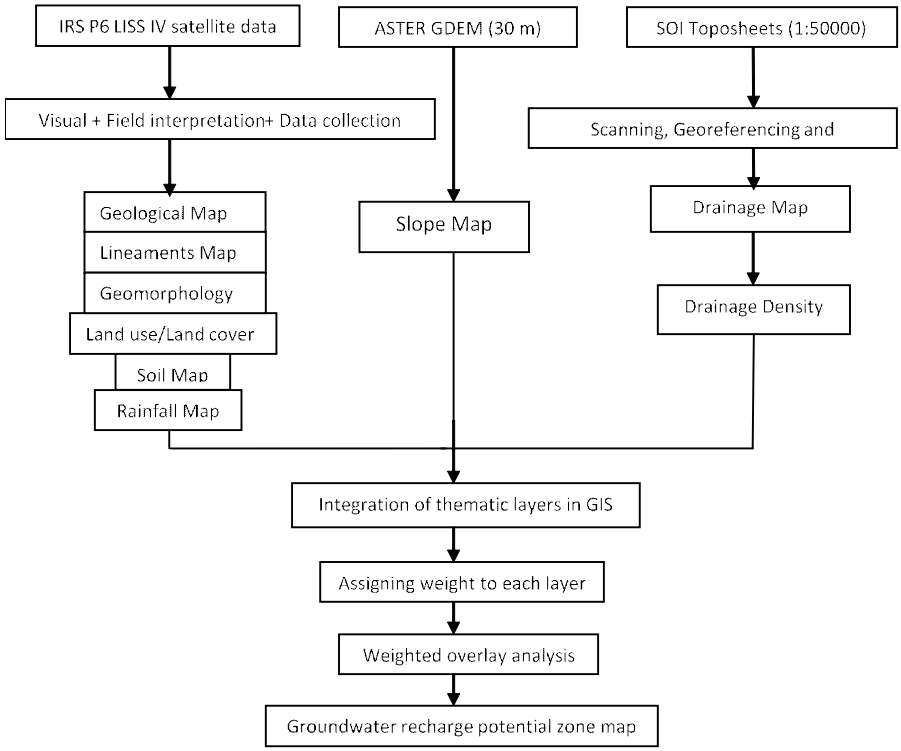


Fig 2: Flow chart showing methodology adopted in the study area to mapping groundwater recharge potential zone.

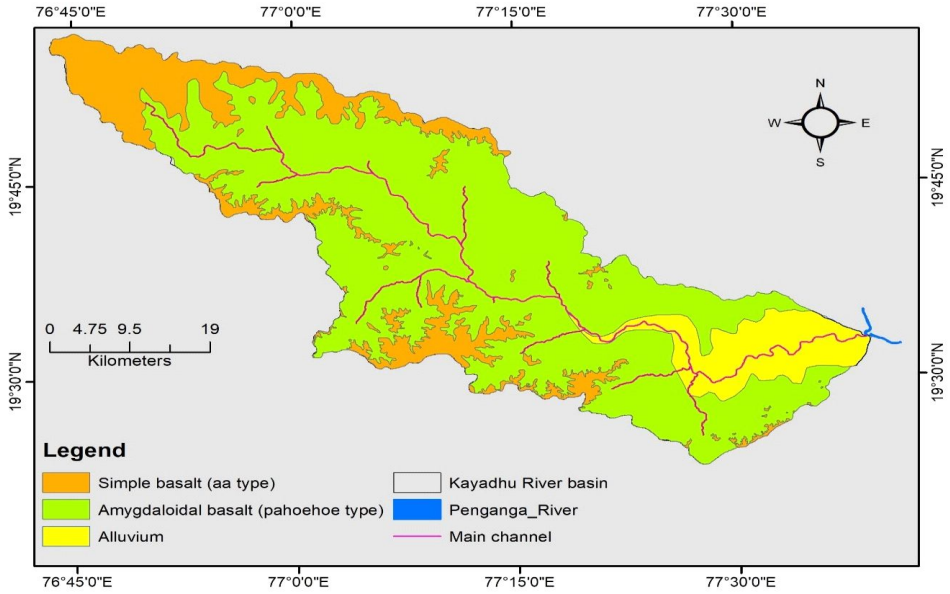


Fig 3: Geological map of Kayadhu river basin.

some researches have ignored this factor by regarding the lineaments and drainage features as a function of primary and secondary porosity, this study includes lithology to minimize uncertainty in determining lineaments and drainage.

Land use/cover

Land use /cover is an important indicator of the extent of groundwater requirements and groundwater utilization as well as important for selection of groundwater recharge. Satellite data LISS IV, topographic maps and field evidences were used as reference data. The different classes of land use /cover are identified on the basis of different tone in the satellite image such as barren land, water bodies, settlements, agriculture land and forest area.

Slope map

The study related with groundwater flow and storage the

slope is often neglected; mainly in the plain areas (Al Saud, 2010). The slope gradient is directly affecting the infiltration of surface runoff. High slope gradient produces small recharge and the area where slope is minimum it tends to water longer had a greater chance of infiltration and recharge during rainfall (Jasrotia *et al*. 2007; Yeh *et al*. 2016). The slope map was prepared from the ASTER GDEM in the GIS by using slope analysis function to assess the variation of the slope in the Kayadhu basin.

Lineaments

The term *lineament* is a commonly used in remote sensing studies in connection with fractures or weak zone. Lineaments are defined as mappable linear to slightly curvilinear subsurface features, which are differ distinctly from the adjacent feature and pattern, reflect subsurface information (O' Leary *et al*. 1976). The structural features usually related with joints, faults and lineaments may produce essentially straight rivers with minimum meandering (Twidale 2004). Lineaments are extracted from drainage pattern and vegetation shows prominent trends of feature observation on IRS P6 LISS IV satellite image. Lineaments in Kayadhu basin area were extracted through manual lineament extraction techniques (Weerasekara *et al*. 2014). Many non-geological structures, such as roads and channels, cause errors in the analysis of lineaments. These features are eliminated from the resultant layer.

Drainage density

The drainage density map of Kayadhu river (Fig 6) is the total length of all the streams in a drainage basin divided by the total area of the drainage basin. The structural analysis of a drainage network access the characteristics of a groundwater recharge zone. It is well known that the denser the denser the drainage network, the less recharge rate and vice versa. The percolation rate is also depending upon geology. According to Greenbaum (1985) is determined by an equation (1):

$$D_d = \frac{\sum_{i=1}^{i=n} Si}{A} \quad (1)$$

Where, $\sum_{i=1}^{i=n} Si$ denotes the total length of the drainage

On the basis of topographic maps drainage network is digitised and using density function in GIS, drainage density is calculated.

Soil types

The soil map of study area obtained from the National Atlas and Thematic Mapping Organization (2005) and subsequently georeferenced and digitized. Thickness of soil cover is less towards NW part of the basin where ground elevations are higher. Soil in central, southern and eastern regions of the basin near the banks of rivers are thicker. Here soil, ranging in depth from 1 to 2 m, are black and rich in plant nutrients (CGWB 2013). When assigning weights to each soil class, permeability of each soil type has been considered in this study, since inûltration and percolation rates is directly related to permeability Senanayak *et al.,* (2016).

Geomorphology

Geomorphologically, the study area is identified by various landforms such as older alluvial plain, present flood plain, pediments, pediplains, highly dissected plateau and denudational hills. Among these landforms older alluvial plain, present flood plain and pediplains have more potential for groundwater recharge, but the highly dissected plateau and denudational hills are not suitable for water augmentation because of the steep slope.

Rainfall

Rainfall is main source for groundwater recharge (Musa *et al*., 2000) and similarly for all hydrological process. The annual rainfall data collected from the Indian Meteorological Department (IMD) for annual rainfall measurements from rain gauge stations in the study region. The rainfall map has been categorized into three categories of rainfall zones each of 100 mm interval.

Subsequently, the thematic maps are used to analyse in overlay and ranks and weights are assigned for each thematic layer to evaluate the groundwater recharge potential zone as shown in Table 1 and Table 2. For identifying ground water recharge potential zones for an area following equation (2):

$$Pr = GL_wGL_r + DD_wDD_r + LC_wLC_r + LD_wLD_r + RF_wRF_r + GG_wGG_r + SG_wSG_r + SC_wSC_r \quad (2)$$

Where,

Pr is the groundwater recharge potential index, GL is the geology index DD drainage density index, LC land use land cover index, LD is lineament density, RF is rainfall index, GG is geomorphology, SG is slope gradient and SC is soil cover index. The subscript w and r represent the weight of a theme and the ranking of individual class of the theme respectively.

Table 1: Ranks assigned to themes. (Modified after Shahid *et al*. 2000; Jaiswal *et al*. 2003; Basavaraj and Nijagunappa 2011; Magesh *et al*. 2012; Sarup *et al*. 2011; Yeh *et al.,* 2016; Senanayak *et al.,* 2016).

Theme	Rank Assigned
Geology (GLr)	15
Geomorphology (GGr)	12
Land cover/ land use (LCr)	10
Lineament density (LDr)	13
Drainage density (DDr)	10
Rainfall (RFr)	15
Soil (SCr)	14
Slope (SGr)	11

Table 2: Weight assigned to each class of the theme (Modified after Shahid *et al.* 2000; Jaiswal *et al.* 2003; Basavaraj and Nijagunappa 2011; Magesh *et al.* 2012; Sarup *et al.* 2011; Yeh *et al.,* 2016; Senanayak *et al.,* 2016).

Theme	Classes	Weight assigned
Geomorphology	Present flood plain	3
	Older alluvial plain	4
	Pediments	6
	Pediplain	7
	Highly dissected plateau	2
	Denudational hill	1
Land use/Land cover	Agricultural land	6
	Waste land	2
	Forest	5
	Settlement	3
	Waterbody	8
Soil	Shallow black soil	2
	Medium Black soil	5
	Deep black soil	8
Geology	Simple Basalt	1
	Amygdaloidal basalt	4
	Alluvium	7
Slope (Degre)	0°-2°	10
	2°-4°	8
	4°-6°	4
	6°-8°	1
Drainage density (km/km2)	0.0-1.0	1
	1.0-2.0	2
	2.0-3.0	4
	3.0-4.0	6
Rainfall (mm)	<750	4
	750-850	5
	>850	6
Lineament density (km/km2)	0.0-3.0	1
	3.0-6.0	4
	6.0-9.0	6

RESULTS AND DISCUSSION

The geological map of area having three geological units such as Simple (aa type) basalt, compound (pahoehoe type) basalt and alluvial deposits in the study area (Fig 3). Simple aa type basalt covers 420.16 km^2 area having low porosity and permeability compared with compound pahoehoe type basalt 1531.73 km^2. Alluvium occupied 206.42 km^2 area of the study area. Land use /Land cover is one of the major governing factors in groundwater recharge processes. The different types of land use pattern identified in the study area, which includes agricultural land, waste land, settlements, forest and water bodies. Water bodies and agriculture land are good zones for groundwater recharge. Settlements and forest are moderate for groundwater recharge, whereas waste land having steep slope therefore low potential for groundwater recharge. The ranking potential distribution of land use and land cover (Fig 4) of the study area. The slope gradient has its own importance in affecting the runoff, recharge and movement of surface water. These are classified into four classes: (1) 0°-2°, (2) 2°-4°, (3) 4°-6° and (4) 6°-8°. It can be seen that the lowest slope (0°-2°). Slope is inversely proportional to recharge (Fig 5).

Lineaments density (Fig 6) and drainage density (Fig 7) are also important, more the density more will be the recharge. Soil map of the study area reveals three main soil categories (Fig 8). The study area is dominated by medium black soil (1479.64km^2) and shallow black soil (476.70km^2) with deep black soil present in relatively small areas (202.03 km^2) (NATMO 2005). Black soil is highly resistant for recharge because it having low permeability. Geomorphologically, the study area is identified by various geomorphic units such as older alluvial plain, present flood plain (17.75km^2), pediments (156.11 km^2), pediplains (1455.39 km^2), highly dissected plateau (457.55 km^2) and denudational hills (21.48 km^2) (Fig 9). A large part of the study area is covered with pediplain formation. A pediment

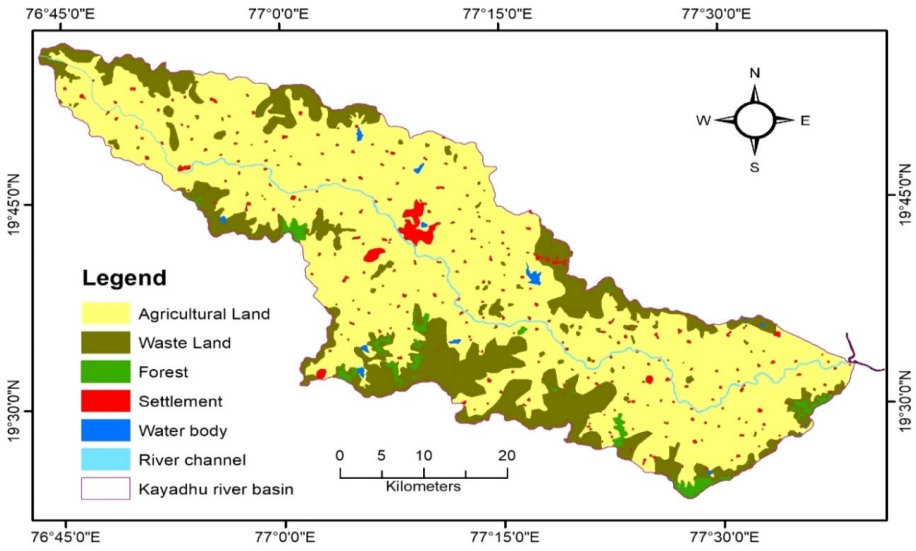


Fig 4: Land use land cover map of Kayadhu river basin.

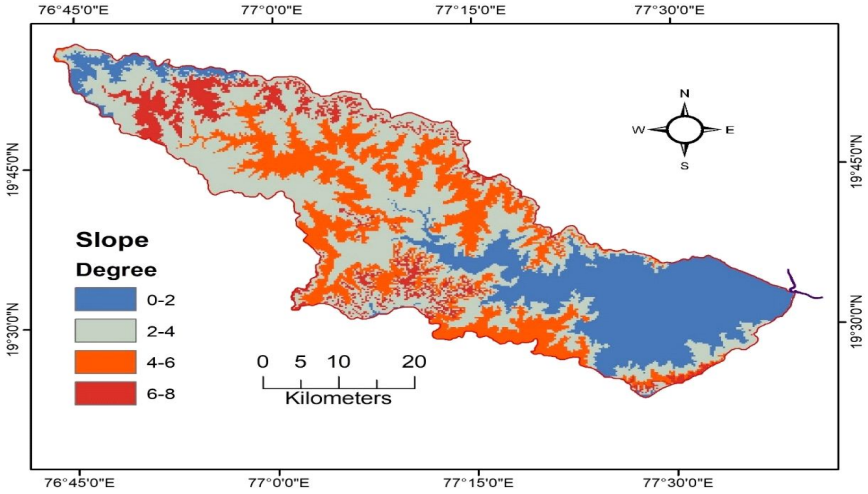


Fig 5: Slope map of Kayadhu river basin.

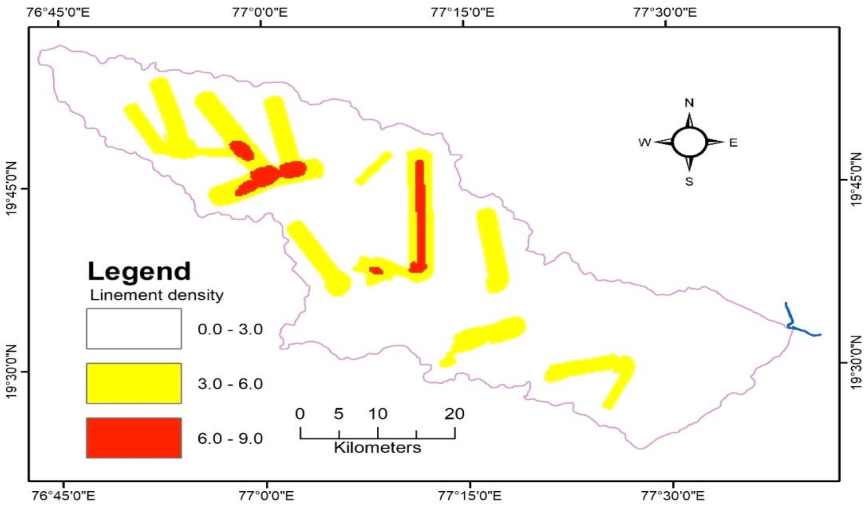


Fig 6: Lineament density map of Kayadhu river basin.

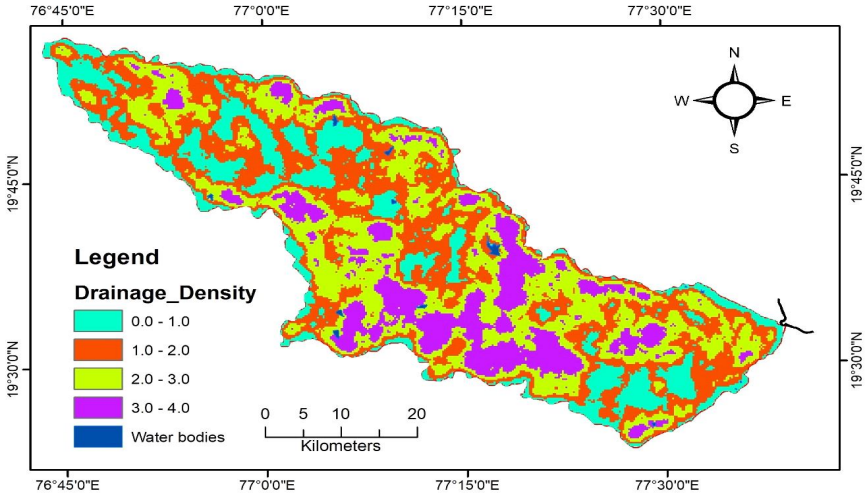


Fig 7: Drainage density map of Kayadhu river basin.

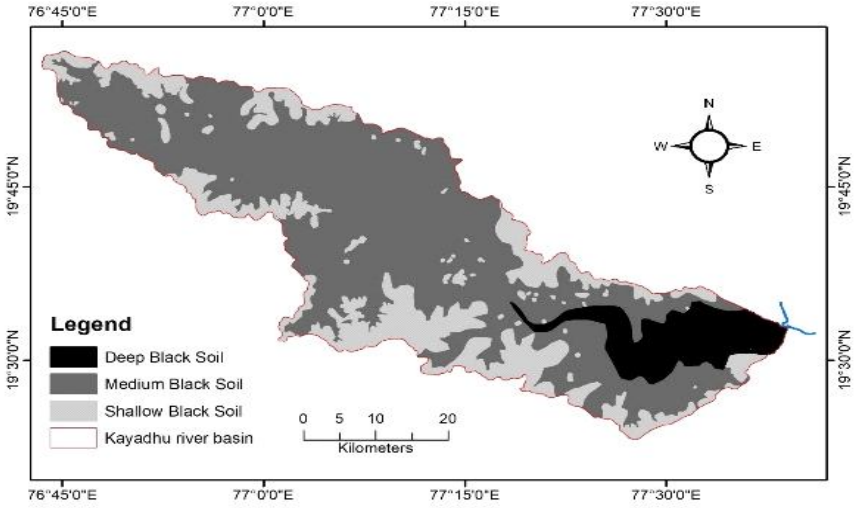


Fig 8: Soil map of Kayadhu river basin.

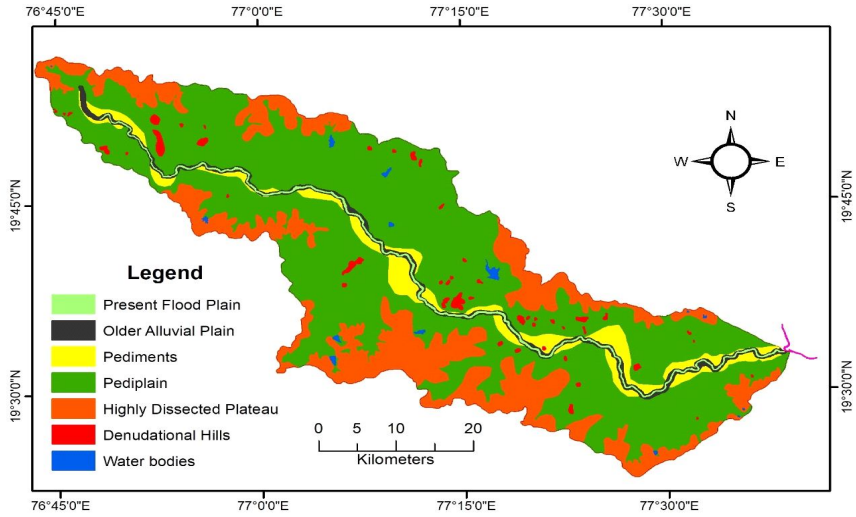


Fig 9: Geomorphological map of Kayadhu river basin.

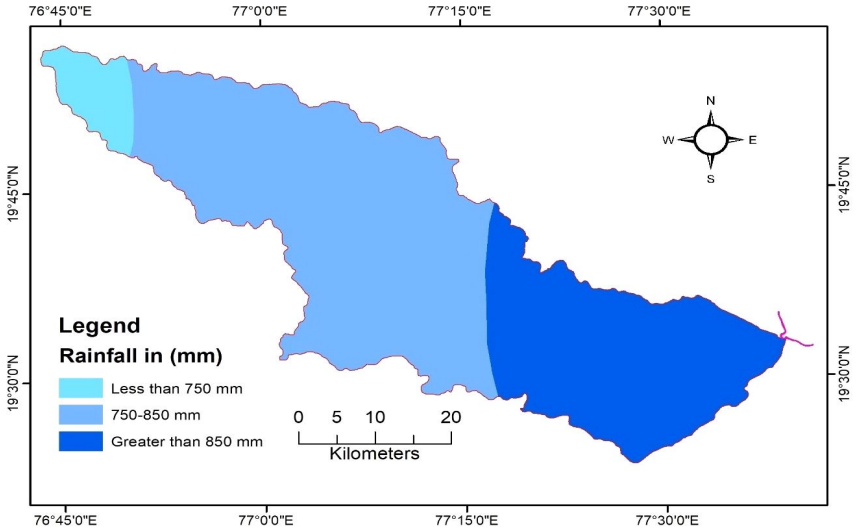


Fig 10: Rainfall map of Kayadhu river basin.

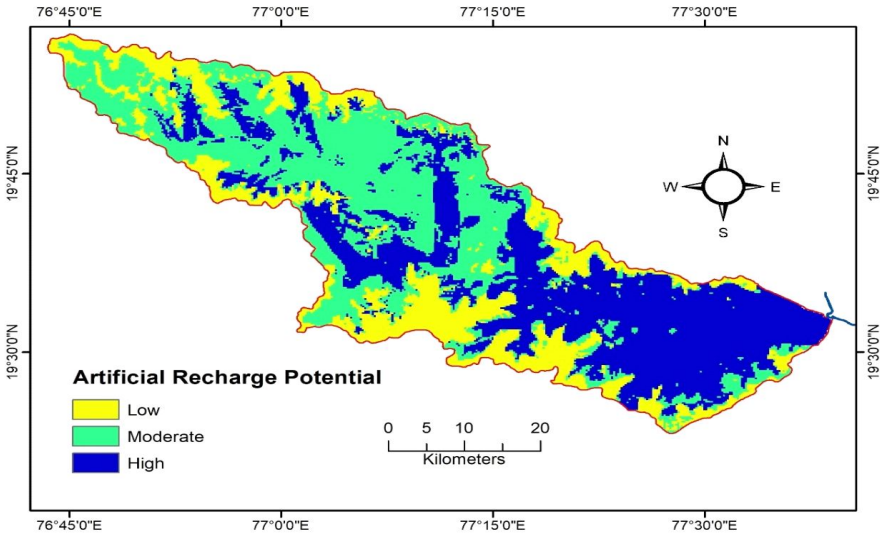


Fig 11: Groundwater recharge potential zone map of Kayadhu river basin.

is a gently sloping and transport and erode rock and connects eroding slopes to the areas of sediment deposition at lower levels (Oberlander, 1989). Among these geomorphic units alluvial plain, present flood plain and pediplains have more potential for groundwater recharge, but the highly dissected plateau and denudational hills are not suitable for effective groundwater recharge. Rainfall map of study area (Fig 10) shows a variation in the rainfall pattern in the Kayadhu river basin.

CONCLUSION

In order to demarcate the ground water recharge potential zones, different thematic layers have been prepared by utilizing GIS techniques, thus it provides an effective practice for saving extensive time, labour and cost. Thematic layers such as rainfall, lineament density, slope, drainage Density, land use/land cover, geology, geomorphology and soil cover map layers were integrated on a GIS platform using the raster calculator in overlay analysis method for classifying ideal artificial recharge zone (Fig 11) in Kayadhu river basin. Around 79% area was found to have high to moderate groundwater recharge potential zone, whereas only 21% area have a low artificial groundwater recharge potential. Moreover, the most effective recharge potential is found on regions of alluvium deposit. Whereas, the least effective recharge potential is in simple basalt formations. The resultant artificial recharge potential map and the technique used in this study will help as for sustainable use of groundwater resource for enhancing groundwater recharge by proper management and recommendation for artificial recharge structures such as percolation tanks, recharge basins, recharge wells, ridges and furrows, check dams, gully control/ stone wall structures, contour bunding, trenching, land fooding etc. This technique evaluates best qualitative approach for artificial recharge.

ACKNOWLEDGEMENT

The corresponding author is thankful to Swami Ramanand Teerth Marathwada University, Nanded for providing the financial support through research project File No. APDS/ Uni.MRP/Sci.andTech.-Geology/2017-18/2962.

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