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DECIPHERING THE GROUNDWATER POTENTIAL OF MADNUR AND JUKKAL MANDALS OF KAMAREDDY DISTRICT: A MULTI- CRITERIA ANALYSIS APPROACH

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Abstract

Groundwater is a crucial natural resource that sustains various human and ecological activities. However, the growing demand for water in Madnur and Jukkal Mandals of Kamareddy Districts, coupled with potential risks of groundwater depletion, necessitates a comprehensive assessment of groundwater potential for sustainable development. This research employs a multi-criteria analysis (MCA) approach to evaluate the groundwater potential in the study area.

The MCA integrates multiple factors affecting groundwater availability, including lithology, land use, soil characteristics, geomorphic units, slope, lineaments, hydrogeological conditions, and rainfall patterns. Geographic Information Systems (GIS) technology and remote sensing data are utilized to gather and analyze spatial information, enhancing the accuracy and efficiency of the assessment.

Considering diverse criteria, the study generates a comprehensive groundwater potential map, classifying areas into very high, high, moderate, low and very low potential zones. This spatial analysis facilitates a better understanding of the regional groundwater dynamics, identifying areas suitable for sustainable groundwater abstraction and those requiring conservation measures to prevent overexploitation.

The research's findings will be critical for developing effective water resource management strategies, promoting sustainable groundwater usage, and safeguarding the environment. The proposed multi-criteria analysis approach for deciphering groundwater potential can serve as a valuable model for similar studies in other regions facing water scarcity and resource management challenges. Ultimately, this research aims to contribute to the sustainable development and prudent utilization of groundwater resources in Madnur and Jukkal Mandals, ensuring their availability for future generations and fostering environmental conservation efforts.

Keywords: Groundwater potential, Multi-criteria analysis, Hydrogeological conditions, Geographic Information Systems, Water scarcity, Agricultural water management

1. Introduction

Groundwater plays a crucial role in meeting the water demands of communities, agriculture, and industries, especially in regions where surface water resources are limited or unreliable (Kamraju, M., & Ali, M. A. 2018). Prolonged overexploitation and inadequate water management practices have led to a precarious situation, prompting the urgent need for sustainable solutions to unlock the groundwater potential in these areas. This research paper endeavors to address the critical issue of groundwater depletion and its sustainable management in Madnur and Jukkal Mandals. Given how enormous the amount of groundwater is required for the people of the Mandals to earn their living from agriculture, the necessity of sustainable groundwater management and planning is required. The study aims to contribute to the creation of a resilient water supply system that can support the diverse needs of the local population and promote socio-economic development.

1.1 Background

The Mandals of Madnur and Jukkal, located in a semi-arid region, have been grappling with the pressing issue of water scarcity and declining groundwater levels (Smith et al., 2018; Sharma et al., 2020). The region heavily relies on groundwater as a primary water source due to limited access to surface water resources (Singh et al., 2019). However, prolonged overexploitation and inadequate water management practices have resulted in a precarious situation, with groundwater resources being depleted at an alarming rate (Patel et al., 2021).

The growing demand for water driven by population growth, agricultural expansion, and industrial development has placed tremendous stress on the groundwater reserves (Shah et al., 2017). Insufficient recharge mechanisms and unregulated extraction practices have exacerbated the problem, leading to declining water tables, drying wells, and an increasing number of areas experiencing acute water scarcity during periods of low rainfall (Kumar et al., 2018; Sharma et al., 2020).

Addressing the groundwater crisis in Madnur and Jukkal Mandals requires urgent attention and a comprehensive approach that encompasses scientific analysis, community participation, and effective policy interventions (Smith et al., 2018). By implementing sustainable groundwater management practices, the region can strive towards ensuring a reliable and sufficient water supply to meet the diverse needs of the local population and foster socio-economic development (Singh et al., 2019).

1.2 Research objectives

The present investigation is being carried out in Madnur and Jukkal Mandals to:

1. Evaluate the geographical factors influencing the groundwater course phenomenon
2. Uncover the very high, high, moderate, low and very low groundwater potential belts.

2. Study Area

The geographical locations of Madnur and Jukkal Mandals fall in the northwestern part of Kamareddy District of Telangana State. Figure 1 shows the research area extends from 77° 35 '52.301"E to 77° 42' 9.709"E longitudes and 18° 18 '32.322"N to 18° 32' 52.243"N latitudes. Survey of India Toposheets 56 F/10 and 56 F/11 covers the study area. It is drained by the Manjira River which forms the irrigation resource for cultivating the major crops like paddy, cotton, maize and soyabean alongside groundwater. Agriculture is the primary occupation and major livelihood for the population of Madnur and Jukkal Mandals. The administrative and agro-climatic zones of Madnur and Jukkal Mandals are Rajanna and North Telangana Zone (NTZ). Major Soils in Madnur include Black soils and Jukkal Mandal include Chalka soil. Rainfall ranges from 850 mm to 1000 mm. Deccan Traps of Cretaceous to Paleogene age form the geology.

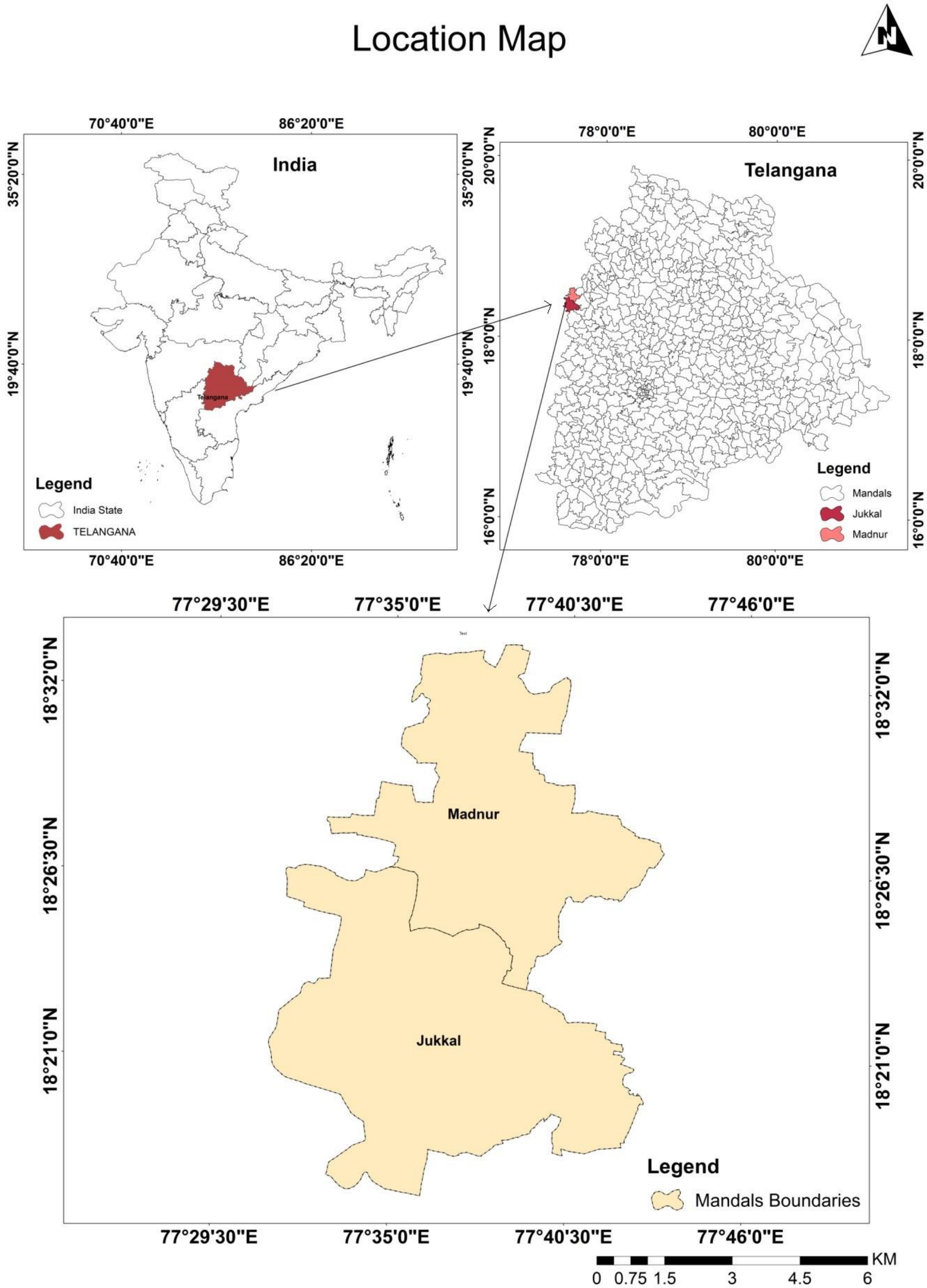

Figure. 1. Location Map of Madnur and Jukkal Mandals

3. Literature review

The literature review is a critical component of this research paper as it provides a comprehensive overview of existing studies, research findings, and relevant literature related to groundwater management, particularly in semi-arid regions. Through an extensive review of peer-reviewed articles, academic papers, reports, and case studies, this section aims to synthesize and analyze the knowledge accumulated on the subject. (Prathap, T. S., Ali, M. A., & Kamraju, M. 2019 a).

The literature review examines various aspects, including groundwater resources, challenges in groundwater management, sustainable groundwater management strategies, successful groundwater recharge projects, and policy frameworks. By assimilating the collective wisdom from previous studies, the literature review forms the foundation for the proposed comprehensive approach to unlock the groundwater potential of Madnur and Jukkal Mandals. It enables us to build upon the experiences and lessons learned from others' endeavors and identify gaps in current research, which guides the research objectives and contributes to the generation of innovative and effective solutions for addressing the pressing groundwater challenges in the study area. (Prathap, T. S., Ali, M. A., & Kamraju, M. 2019.b).

Several studies have emphasized the significance of groundwater as a vital water source for human consumption, agricultural irrigation, and industrial purposes (Gleeson et al., 2012; Famiglietti, 2014). These resources are often essential in regions facing water scarcity or unreliable surface water supplies.

Challenges related to groundwater management have also been extensively documented. Over Extraction of groundwater, driven by increasing demand and population growth, has led to declining water tables and the depletion of aquifers in many areas (Wada et al., 2010; Scanlon et al., 2012). Unregulated pumping practices exacerbate the problem, leading to significant environmental and socio-economic consequences (Braun et al., 2019).

Another critical challenge is the lack of integrated water resources management, which often results in conflicts among various stakeholders competing for limited groundwater resources (Araghi, 2015; Varis et al., 2018). Sustainable groundwater management requires cooperation and coordination among governments, local communities, and other stakeholders to ensure equitable and efficient water use.

The application of remote sensing and GIS techniques has emerged as a valuable tool for assessing groundwater resources and understanding recharge mechanisms (Foster and Chilton, 2017; Rajankar et al., 2018). These technologies aid in monitoring groundwater levels, identifying potential recharge zones, and guiding targeted interventions for sustainable groundwater management.

The literature review highlights the importance of groundwater resources in meeting water demands, particularly in arid and semi-arid regions. It also sheds light on the various challenges faced in managing groundwater sustainably. Implementing effective groundwater management practices requires a multifaceted approach that addresses over extraction, pollution, and promotes integrated water resources management. By integrating knowledge from existing studies, this research aims to propose a comprehensive approach to unlock the groundwater potential in specific regions and contribute to long-term water security and socio-economic development.

The research gaps identified in unlocking the groundwater potential of Madnur and Jukkal Mandals encompass several critical areas. Firstly, there is a need for local-specific studies that delve into the hydrogeological characteristics, groundwater availability, and recharge mechanisms in these regions to tailor management strategies accordingly. Secondly, community participation is essential for successful groundwater management, but its level and effectiveness remain underexplored. Integrating traditional knowledge can also provide valuable insights into sustainable water management practices.

4. Materials and Methodology

Deciphering the groundwater potential areas for a particular region requires a relevant research plan which includes ancillary and satellite data processed in GIS environment using the technique of Weighted Overlay Analysis (WOA). Sentinel-2A, CartoDEM *v3* of Cartosat-1, NBSS&LUP soil data and CHRS rainfall data were selected. CartoDEM *v3* is being processed to generate slope, stream network and lineament spatial layers in ArcGIS 10.2 software. Land Use Land Cover classes are generated in ERDAS IMAGINE 2015 software. Soil, geology and geomorphology map data was obtained from National Bureau of Soil Survey and Land Use Planning and Geological Survey of India (GSI) –Bhukosh Portal. Rainfall map is prepared from CHRS rainfall grid data of 0.04^o x 0.04^o by interpolation technique. The lulc layer is imported to ArcGIS 10.2. Drainage density is developed from stream networks and lineament density from lineaments. The layers of geomorphology, rainfall, drainage density, land use land cover, lineament density, soil, slope and geology are allotted relative influence percentage weight and ranks based on their impact on groundwater course phenomenon. All the above layers in vector format are raster converted and are overlaid and reclassified into very high, high, moderate, low and very low groundwater potential belts by weighted overlay analysis tool in ArcGIS 10.2 software.

5. Results and Discussion

5.1 Mapping and Data Analysis of Geographical Factors

Multiple geographical factors that control the groundwater course need to be ascertained to determine their relative influence weightage percentage.

Geomorphology

There are thirteen types of geomorphological landforms (Figure. 2) as disclosed from the geomorphology data downloaded from Bhukosh Portal which can be classified into four genetic classes viz., denudational, structural, anthropogenic and fluvial origin as per the NRSC geomorphological classification system (NRSC, 2010). Pediplain, pediment, pediment-corestone-tor composite, residual mound, upland (lateritic), plain (lateritic), Denori-pediment-pediplain complex and Denori- low dissected hills and valleys are the Denudational origin landforms that constitutes the major portion in the research area. Pediplain occupying the highest share i.e., 62.64% (219.72 sq.km) is extended across the study area except at the periphery of Jukkal Mandals. Pediments are spread in middle parts of Madnur Mandal and southern portion of Jukkal Mandal encompassing 49 sq.km. Low dissected hills and valleys are at the outer boundary of Jukkal Mandal. Remaining portion viz., 23.47 sq.km is spatially distributed by the upland (lateritic), residual mound, Denori-pediment-pediplain complex, pediment-corestone-tor composite and plain (lateritic) landforms. Structural origin landforms are dyke/sill ridge and plateau remnant which together occupy 42.11 sq.km (11.93%) and are mostly present in Jukkal Mandal. Channel bar forms the fluvial origin landforms in Manjira River main course. Dam and reservoir are of anthropogenic origin covering 3.56 sq.km.

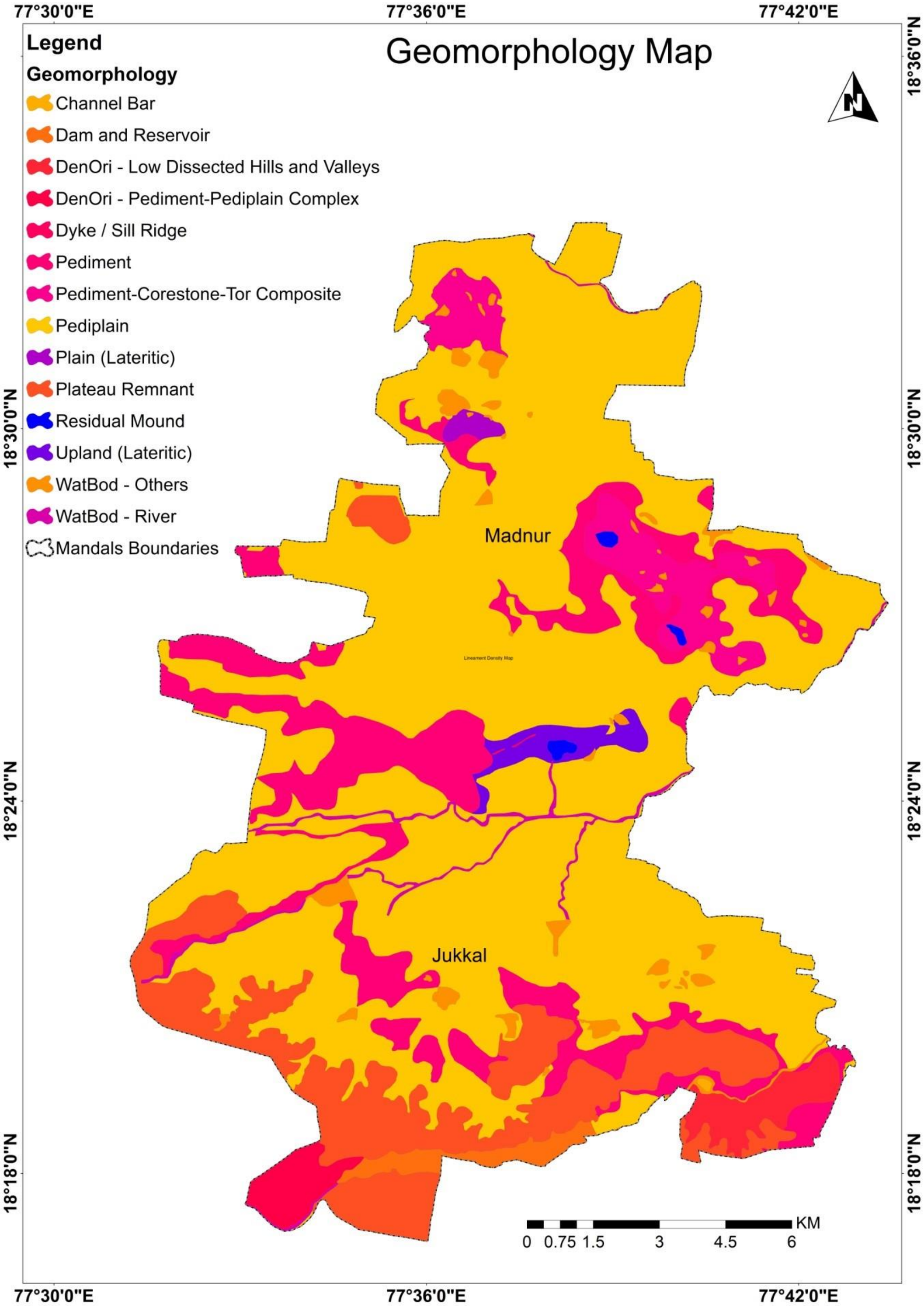

Figure. 2. Geomorphology Map

Geology

The geology map data of GSI available in Bhukosh Portal was extracted and added to ArcGIS 10.2 software. The geology map (Figure. 3) revealed basalt with infratrappeans and granite/gneiss variants together created the geology of Madnur and Jukkal Mandals. Pink biotite granite, basalt and alkali feldspar granite cover almost 95.67% approximately 337.77 sq.km of study area. Minor parts have the pink hornblende biotite granite, aplite, porphyritic granite, infratrappean, leuco granite, grey biotite granite and amphibolites of palaeoproterozoic, archaean-palaeoproterozoic and archaean age. They together makeup 4.33% of the study area.

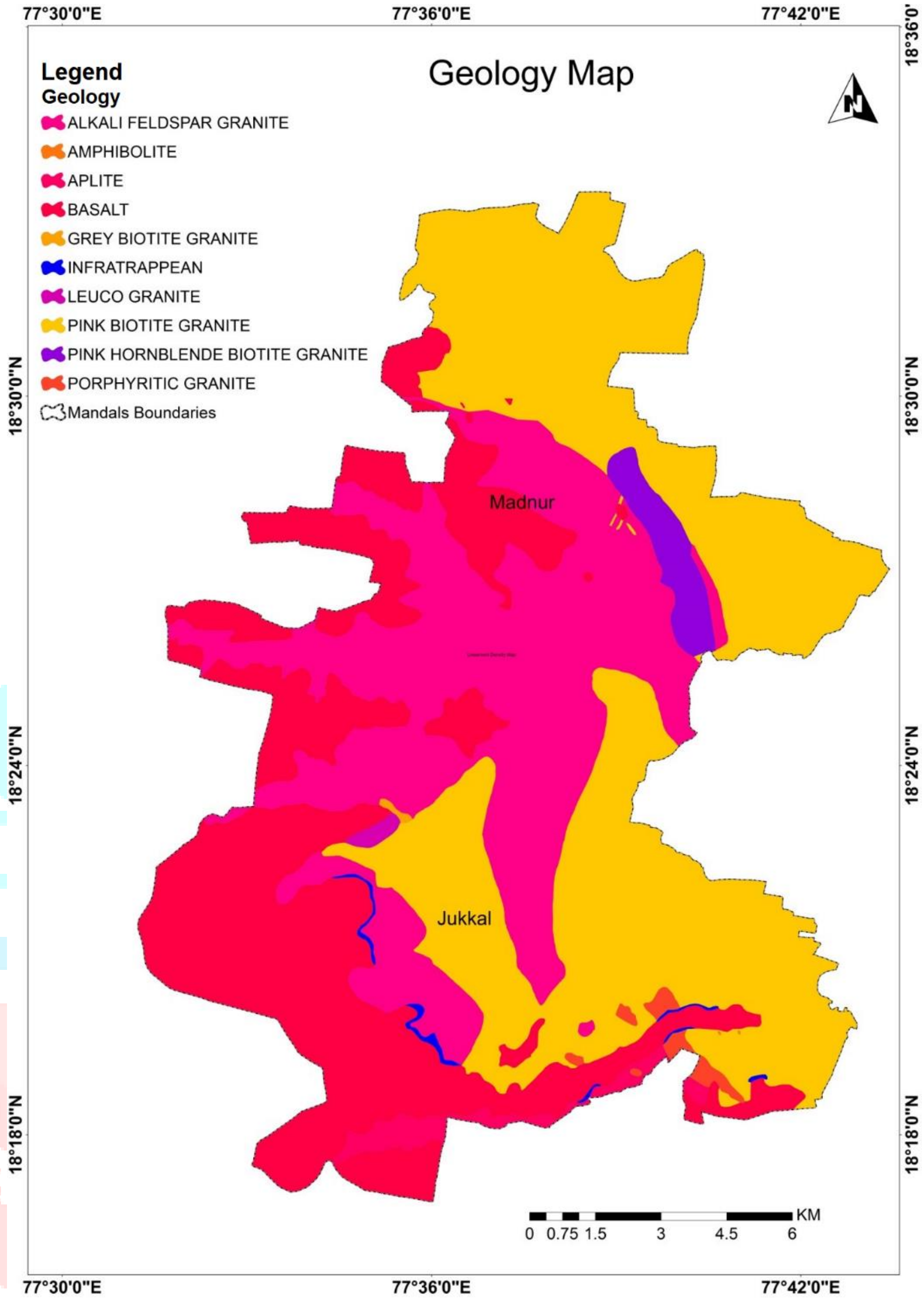

Figure. 3. Geology Map

Lineament Density

The presence of lineaments directly signifies the presence of porosity in the surface thus, allowing for the seepage of water beneath the surface into the aquifer. Lineament density is developed from the lineaments using a line density tool. Lineament density is classified into five types which are very high, high, moderate, low and very low as shown in figure 4. The very high and high lineament density belts are mostly concentrated in the southern portion of Jukkal Mandal and partly in the middle sections of the research area that indicates there were tectonic movements. As they cover only 1.89% they do not contribute much for groundwater augmentation and moreover they are present in the low dissected hills and valleys. Vast section is of very low lineament density which encompasses 61.45% i.e., 216.91 sq.km. It is followed by the low and moderate lineament density areas covering 129.45 sq.km.

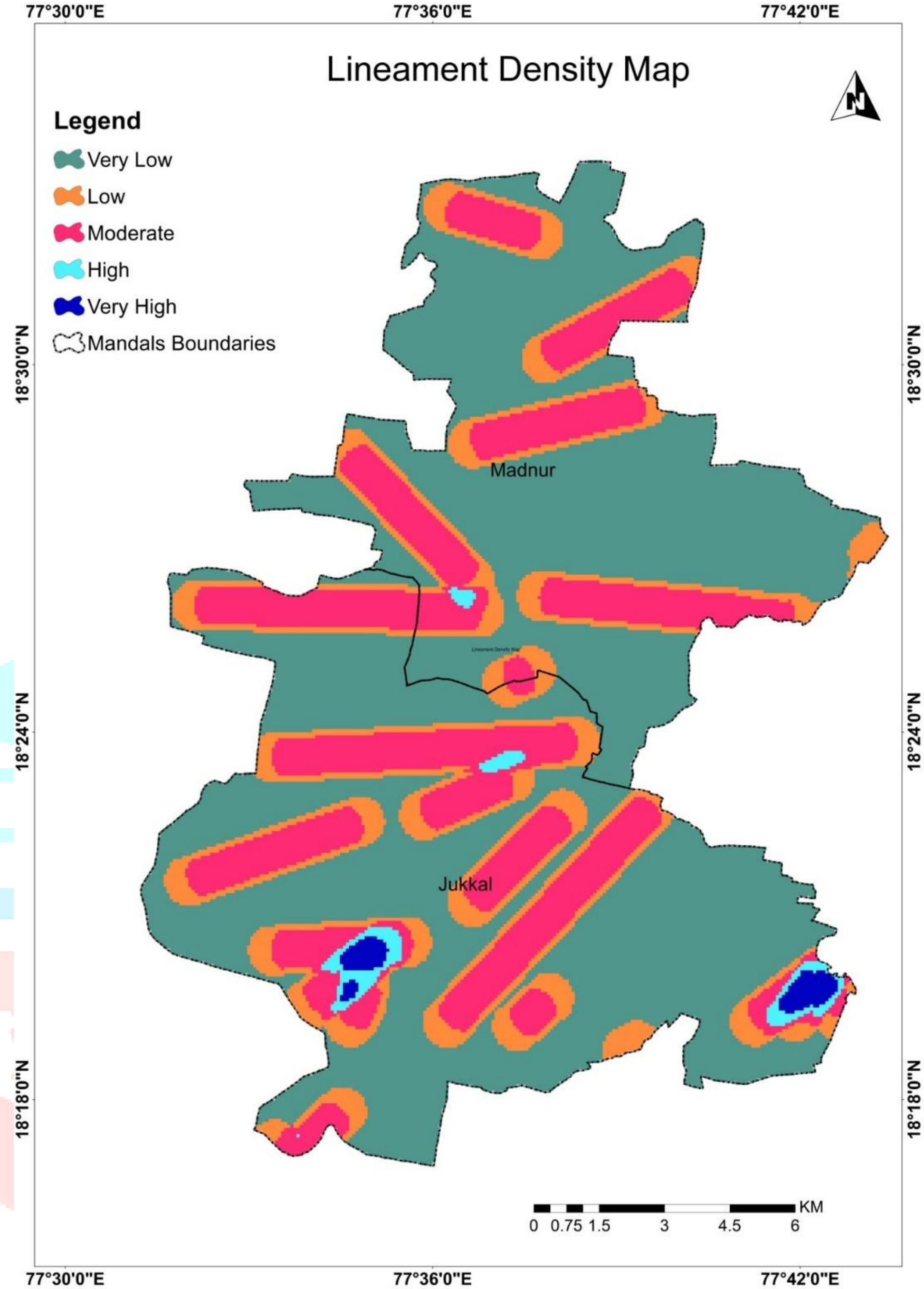

Figure. 4. Lineament Density Map

Land Use Land Cover

Sentinel-2A of 10m resolution is chosen and processed using digital image processing tools available in ERDAS IMAGINE 2015 software for segregating the land use and land cover into five classes i.e., agricultural land, vegetation, water bodies, built up and other lands. Largest segment is under agricultural land (88.55%) as the area is flat and occupied by pediplain. Vegetation is present in the south-east section of Jukkal Mandal that surrounds 14.92 sq.km (4.23%). Built-up land is sparsely distributed and mostly confined near the water bodies as depicted in figure 5 which together enclose 13.38 sq.km. Balance parcels are other lands (3.41%). The huge section of agricultural land shows the research unit may have moderate to good groundwater potential.

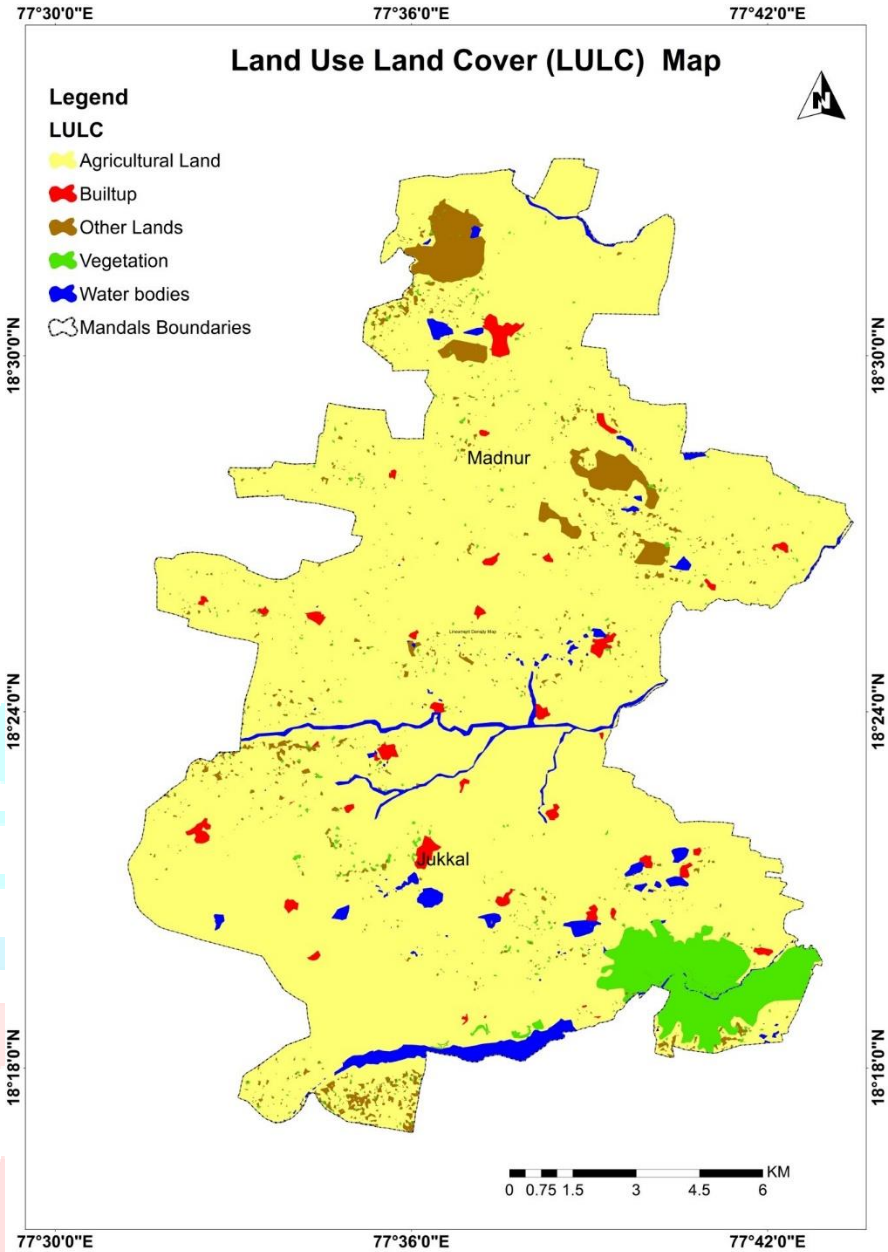

Figure. 5. Land Use Land Cover Map

Soils

Soils gauge the permeability of surface water. Soil map data procured from the National Bureau of Soil Survey and Land Use Planning display the presence of six soils (Figure. 6) that are clayey, clayey calcareous, cracking clay, cracking clay calcareous, gravelly clay and loamy. Cracking clay calcareous soil spread in half (50.78%) of study area is present in the northern and southern segments and is divided in between by cracking clay soil whose spatial extent is 39 sq.km. The central piece is enclosed by gravelly clay soil of 40.79 sq.km. Loamy soil is in the southern fringe of Jukkal Mandal and Clayey and clayey calcareous are at the edges. They together compose 94.02 sq.km.

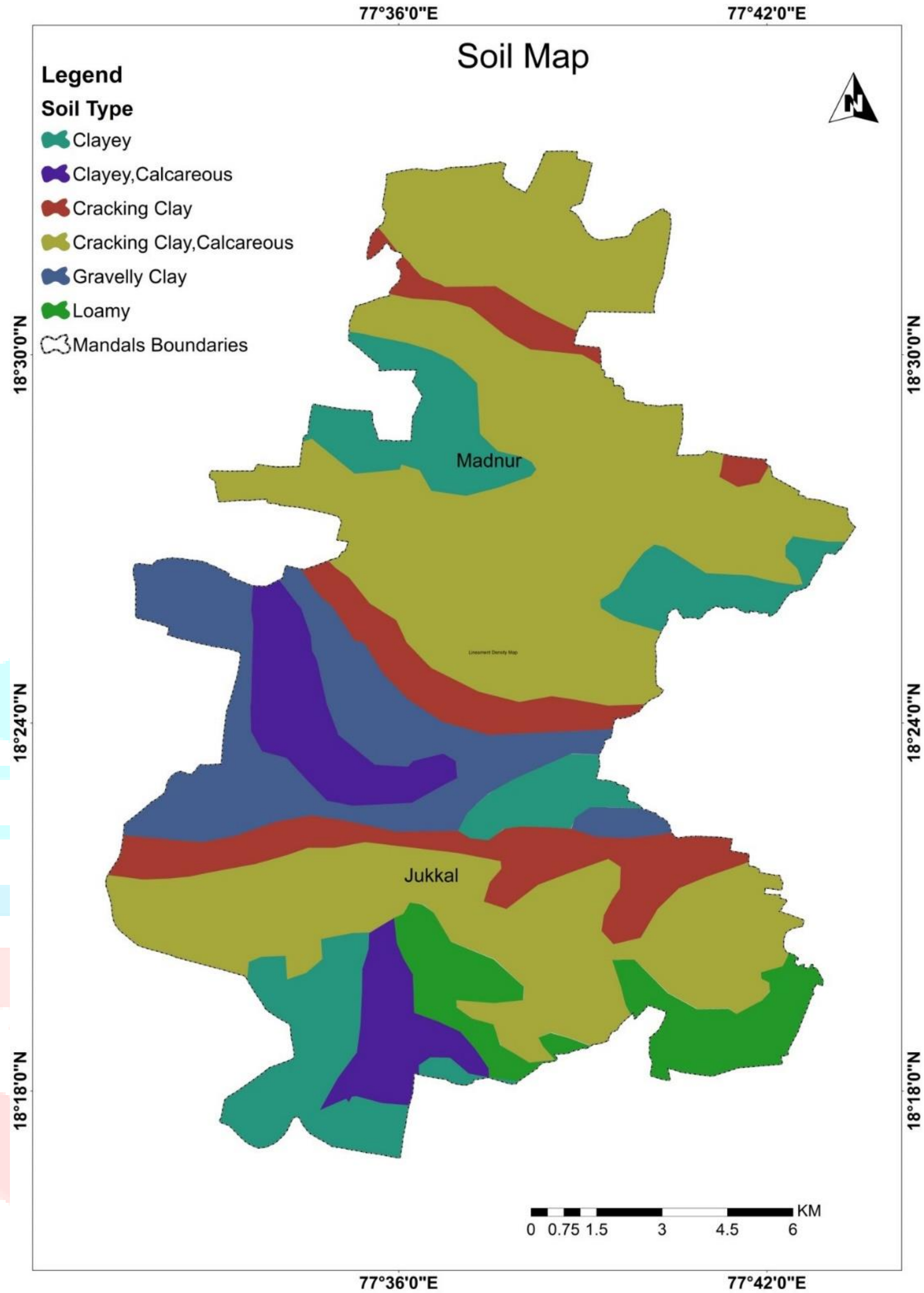

Figure. 6. Soil Map

Drainage Density

The spacing of the channels signals the rate of groundwater recharge. Stream network data was the input in creating the drainage density dataset using the line density tool available in ArcGIS 10.2 software. Figure 7 presents the drainage density is increasing from left boundary to the right boundary as the stream order increases. Very high and high drainage density is at 4th and 5th order streams that are spread in 20.94 sq.km. Low and moderate drainage density occurring at 2nd and 3rd order stream network is confined to 42.2 % of research area and surrounded by very low drainage density of 183.11 sq.km area.

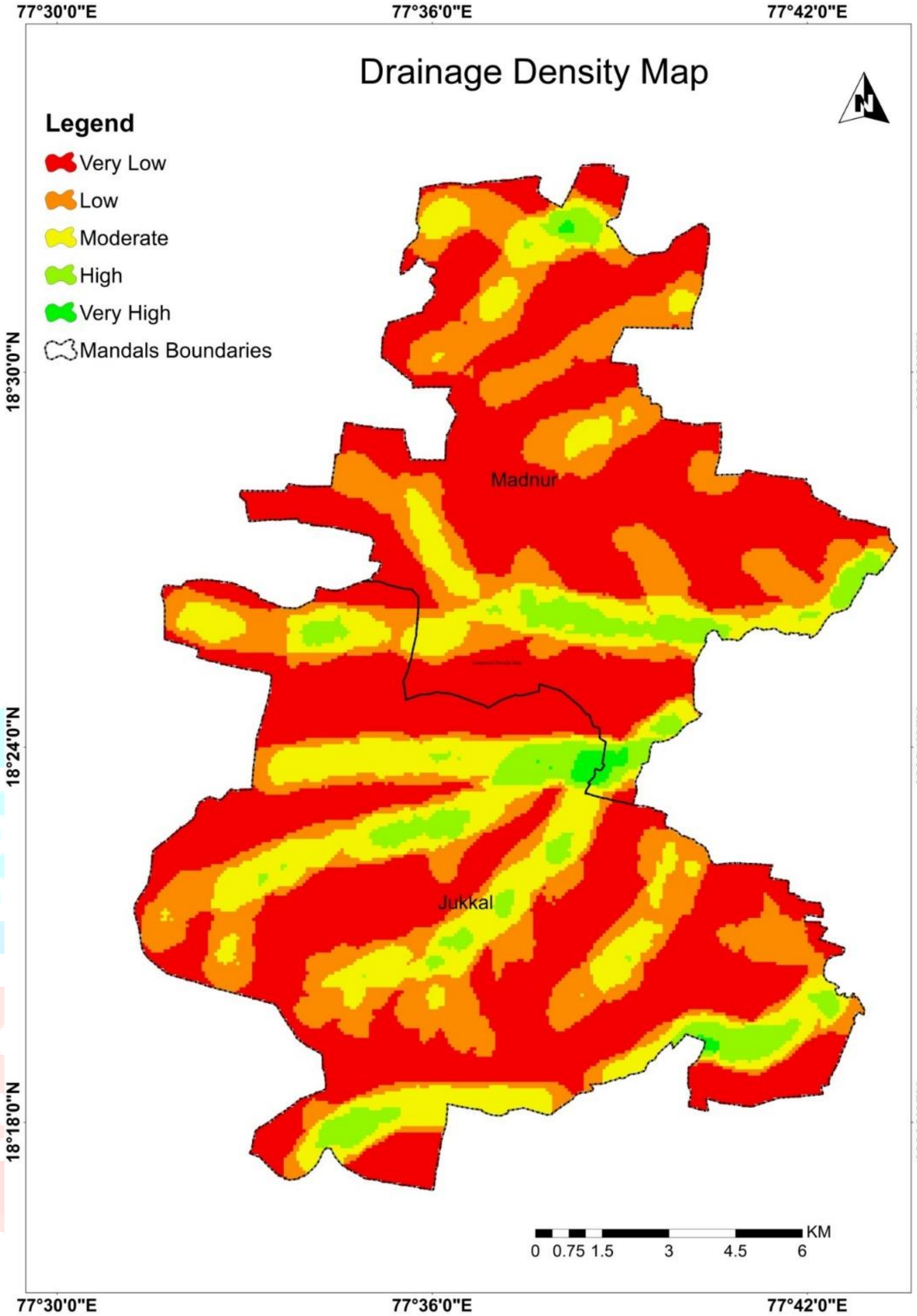

Figure. 7. Drainage Density Map

Rainfall

Rainfall is the primary recharge source in the semi-arid regions having granitic terrain. Kriging interpolation technique is employed for creating rainfall map from Center for Hydrometeorology and Remote Sensing (CHRS) rainfall raster data upon conversion to point data. Rainfall data of 2010 to 2020 was used to generate the average annual rainfall map (Figure. 8) that displays three categories of rainfall. The above map unfolds the fact that the rainfall increases from 449 mm to 485 mm from left to right but on contrary the spatial distribution was not same. Spatial distribution increases from rainfall class of 449mm -462 mm (123.83 sq.km) to 462 mm - 475 mm (204.32 sq.km) but abruptly decreases thereafter, in rainfall class 475 mm - 485 mm to 24.94 sq.km.

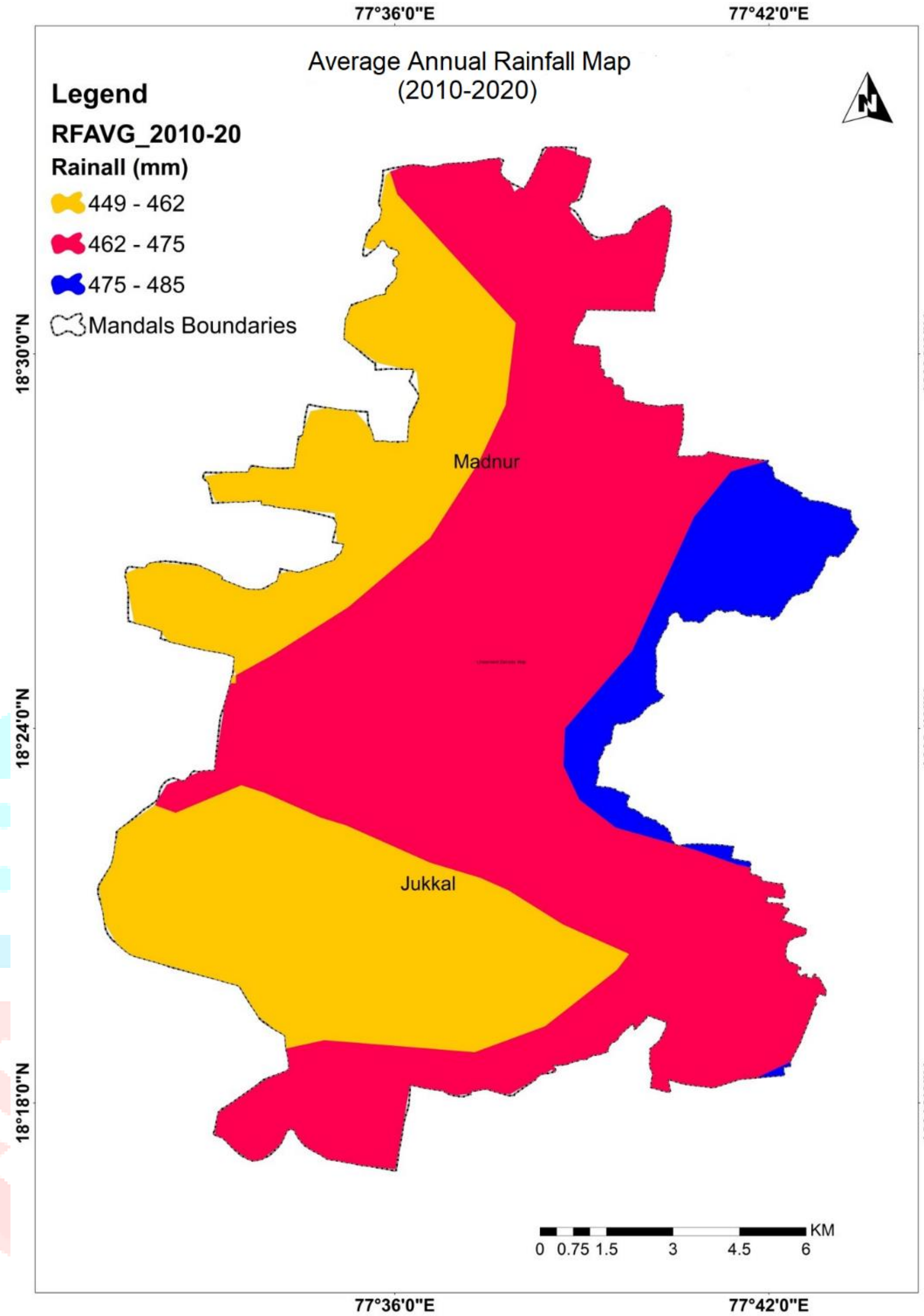

Figure. 8. Average Annual Rainfall Map (2010-2020)

Slope

Slope is developed from the CartoDEM *v*3 of Cartosat-1 satellite data available in ISRO's Bhuvan Portal using slope tool. It is the direct measuring index for rate of infiltration of surface water. Slope is classified into five categories which range in degrees from 0-2 to >15 deg. Figure 9 displays slope descends from the southern section to the northward because of low dissected hills in the south and flat pediplain area in the balanced segment. The Meagre area is of >15 deg slope and is at the southern boundary bordering 1.70 sq.km. Categories of 0-2 deg and 2-5 deg slope stretching the whole research area i.e., 89.31 % surround the 5-8 deg and 8-15 deg slope category that encompass 36.12 sq.km. Though the huge area is occupied by 0-2 deg and 2-5 deg slope category signaling the scope for high groundwater recharge the granitic terrain will obstruct the infiltration unless there are fractures in the surface.

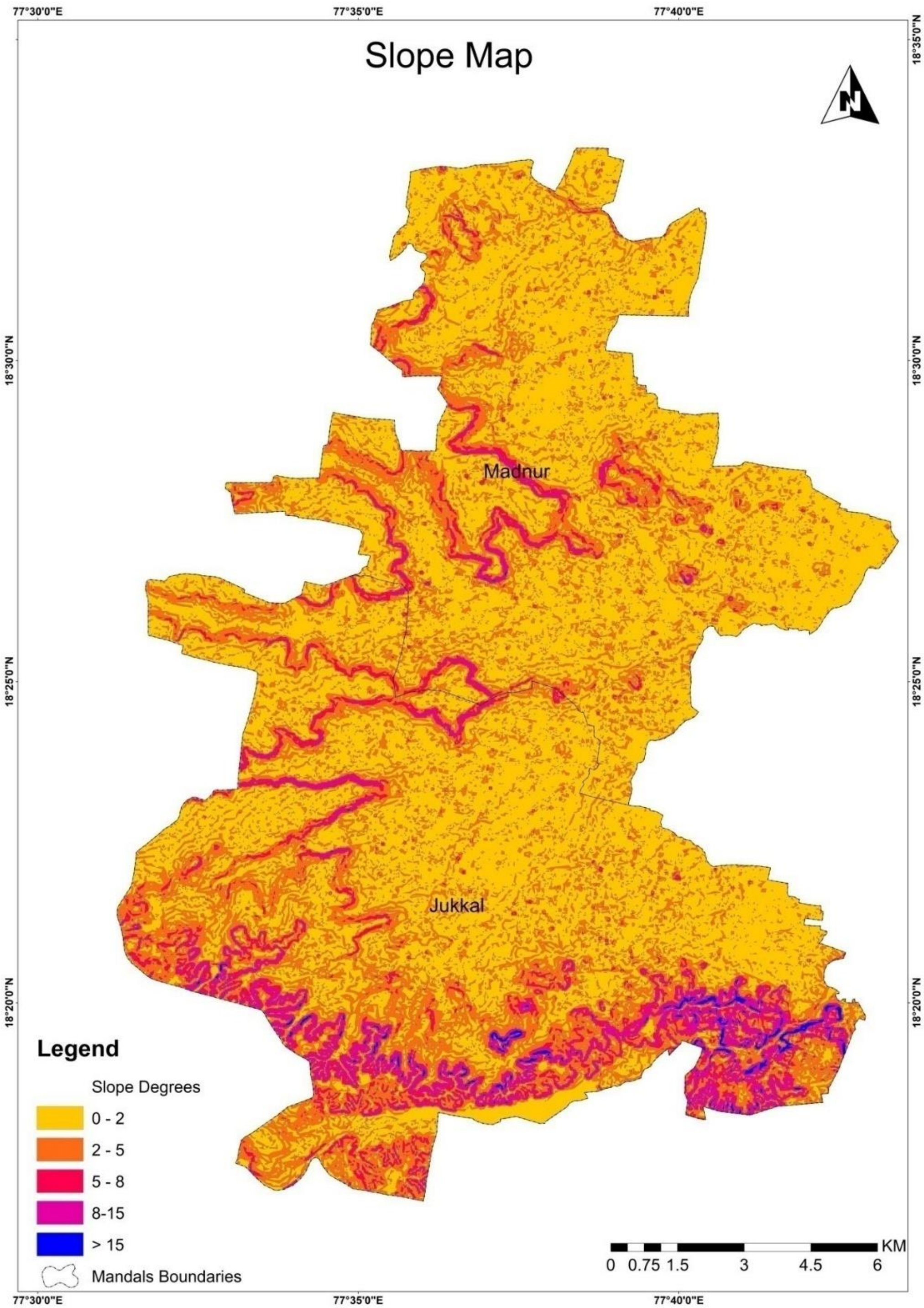

Figure. 9. Slope Map

5.2 Modelling of Groundwater Potential Zones

The multi-criteria decision-making approach involves human judgment with technical aspects. Weighted overlay is one such approach where the weights and ranks are assigned manually based on relative influence and results are produced technically. Groundwater potential zones map (Figure. 10) having five varying groundwater potential sections viz., very low, moderate, low, very high and high is deciphered by the weighted overlay analysis of geology, geomorphology, drainage density, lineament density, slope, land use land cover, soil and rainfall raster datasets. The weights and ranks assigned to the criteria is given in Table 1. The output of groundwater potential map of study area unfolds that the groundwater potential increases from the north-west and south-east to the eastern part. Moderate groundwater potential section stretches from north to south-east occupying the highest share which is of 32.62% (115.30 sq.km). In the next order comes the low groundwater potential segment and followed by high groundwater potential areas which together compose 193.22 sq.km and spatially distributed at north-west, south-west and central sections. Slight area is covered (7.09%) under very high groundwater potential segment present at eastern sector. Least portion of 19.91 sq.km is of very low groundwater potential section located at the edges of south-east and north-west boundaries.

Table. 1. Ranks of Features/Class and Percentage Influence of Influencing Factors

Sl. No	Influencing Factor	Feature/Class	Ranks	Percentage Influence (%)
1	*Rainfall*	449mm - 462 mm	3	25
		462mm - 475 mm	2	
		475 mm - 485 mm	1	
2	*Geomorphology*	Plateau remnant, Residual mound, Pediment-Corestone-Tor-Composite, Dyke/Sill Ridge and Upland (lateritic)	1	20
		Pediment, Pediment-Pediplain complex	2	
		Plain (lateritic), Pediplain and Low Dissected Hills and Valleys	3	
		Water body- River, Dam and Reservoir	4	
		Water bodies-others, Channel Bar	5	
3	*Lineament Density*	Very High	5	15
		High	4	
		Moderate	3	
		Low	2	
		Very Low	1	
4	*Slope*	0-2 deg	5	10
		2-5 deg	4	
		5-8 deg	3	
		8-15 deg	2	
		>15 deg	1	
5	*Geology*	Alkali feldspar granite, Pink hornblende biotite granite, Porphyritic Granite and Aplite	1	9
		Pink biotite granite, Grey biotite granite and Leuco granite	2	
		Infratrappean	3	
		Amphibolite	4	
		Basalt	5	
6	*Drainage Density*	Very High	1	9
		High	2	
		Moderate	3	
		Low	4	
		Very Low	5	
7	*Land Use Land Cover*	Water bodies	5	7
		Agricultural land	3	
		Vegetation	4	
		Other lands	3	
		Builtup land	1	
8	*Soil*	Clayey	1	5
		Clayey Calcareous	2	
		Cracking Clay	2	
		Cracking Clay Calcareous	3	

		Gravelly Clay	4	
		Loamy	5	

Source: Mondal et al., 2008; Dar et al., 2010, Jasmin and Mallikarjuna, 2011; Lone et al., 2013; Bagyaraj et al., 2013; Rajaveni et al., 2017;

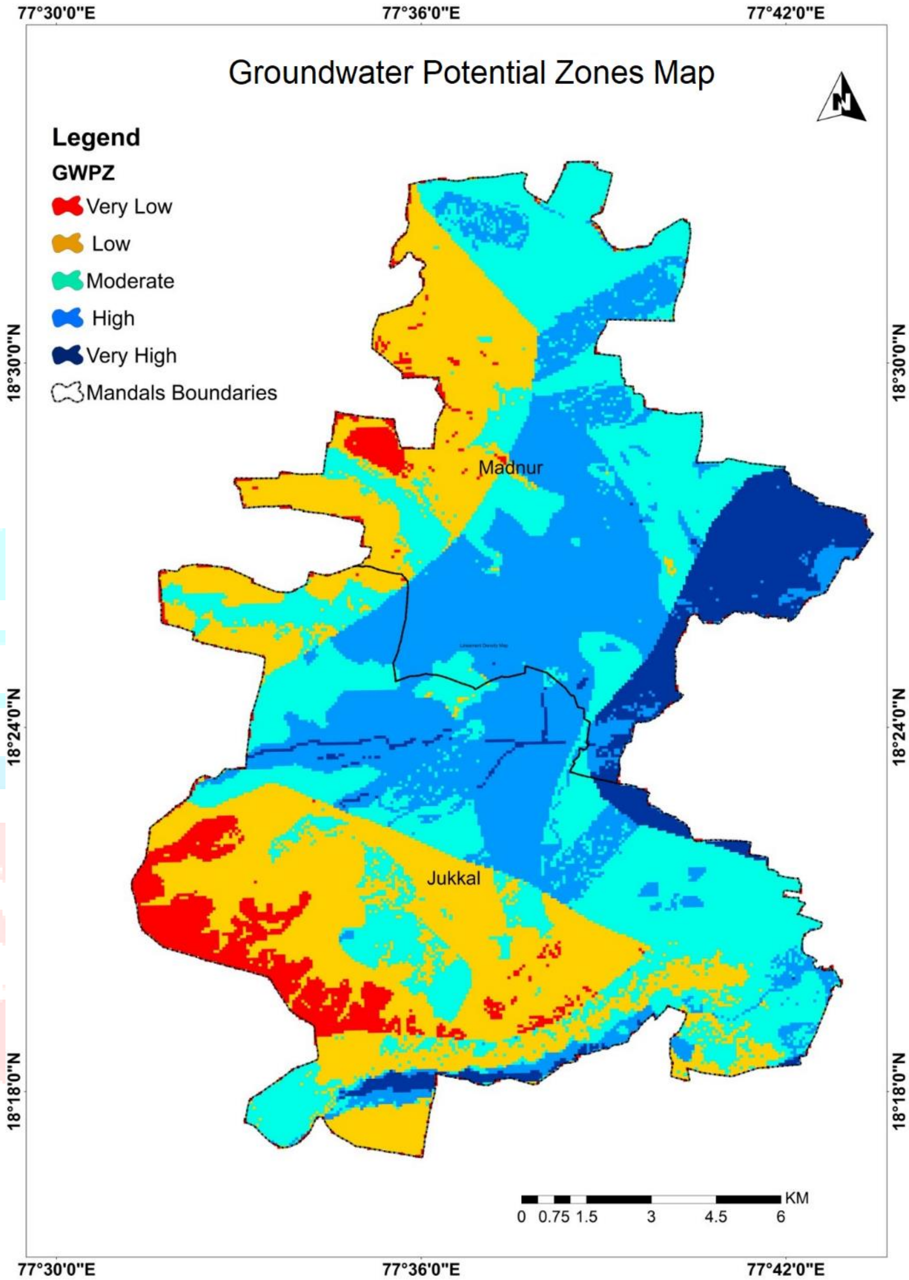

Figure. 10. Groundwater Potential Zones Map of Madnur and Jukkal Mandals

6. Conclusion

The extensive agriculture practiced in the wider area pulled for the higher demand of groundwater in the region which necessitated for the delineation of groundwater potential pockets. The multi-datasets of geology, geomorphology, rainfall, lineament density, soils, drainage density, land use land cover and slope enabled in the identification of groundwater potential areas by weighted overlay method. Thus, proving the adopted methodology is fruitful and allowed in the identification of vulnerable zones requiring immediate attention for sustainable groundwater development. This study forms the base for further studies in groundwater quality monitoring, watershed impact assessment, preparation of groundwater draft and in water supply management to both irrigation and households.

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