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DELINEATION OF POTENTIAL GROUNDWATER RECHARGE ZONES IN THE KUTCH REGION OF GUJARAT STATE USING RS, GIS AND MCDA TECHNIQUES

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ABSTRACT

The rapid increase in population and industrialization have led to heightened consumption of groundwater resources for domestic, drinking, agricultural and industrial purposes. The primary objective of this study is to develop groundwater recharge potential zone maps to facilitate the construction of artificial recharge structures in the Kutch region of Gujarat, India. To achieve this goal, an integrated approach using remote sensing (RS), geographical information system (GIS), and multi-criteria decision analysis (MCDA) were employed. Various parameters affecting groundwater availability including geology, soil, lineament density, slope, rainfall, land use/land cover, geomorphology, and drainage density were considered to delineate potential groundwater recharge zones. The influence factor for each parameter was determined using Satty's analytic hierarchy process (AHP) method. Sub-parameters were ranked according to the AHP scale and a weighted overlay analysis tool in ArcGIS software was utilized to map the potential groundwater recharge zones in the Kutch region. The results indicated that in the study area, the groundwater recharge potential was classified as Excellent (0.65%), Good (11.32%), Moderate (14.90%), Poor (54.18%), and Very Poor (18.95%) of the total area. These findings can aid in the efficient planning and management of groundwater resource development in the region.

Key words : GIS, Groundwater potential, MCDA, Remote sensing.

Introduction

Groundwater resources are complex and multifaceted. They are characterized by various factors such as their geographical location, temporal availability, quantity, physical and chemical properties, accessibility conditions, and the level of effort required to extract them. All these aspects must be assessed in relation to the demand for water, making groundwater management a dynamic and holistic process (Singh *et al*., 2011a). Groundwater plays a crucial role in global water supply, serving as a vital resource for approximately 1.5 billion people worldwide. Annual groundwater withdrawals are estimated at 600–700 billion cubic meters, accounting for around 20% of total global water usage (Gleick, 1993). This makes groundwater a significant contributor to meeting the growing demand for freshwater across the world studied by Shen *et al.* (2008). Arulbalaji (2019) studied the presence and movement of groundwater in a region are influenced by various factors, including topography, lithology, geological structures, depth of weathering, the extent of fractures, secondary porosity, slope, drainage patterns, landforms, land use and land cover, elevation, rainfall, and other climatic conditions. The interaction between these factors plays a key role in shaping groundwater dynamics.

Traditionally, groundwater potential zones were identified through ground surveys. However, with the advancement of technologies like remote sensing and

GIS, these tasks have become more efficient. Remote sensing and GIS have been widely used in numerous studies for the delineation of groundwater potential zones. Remote sensing and GIS have been utilized in numerous groundwater potential zonation studies, demonstrating an effective and economical method for groundwater prospecting and exploration. A substantial part of the area is conducive to groundwater recharge. Findings revealed that more than half of the study region falls into the categories of good and moderate recharge potential, indicating favourable conditions for groundwater replenishment Baria *et al.* (2024); Krishnamurthy and Srinivas (1995); Krishnamurthy *et al.* (1996); Murthy (2000); Jaiswal *et al.* (2003); Saraf *et al.* (2004); Jha *et al.* (2007); Chowdary *et al.* (2009); Chenini *et al.* (2010); Machiwal *et al.* (2011); Singh *et al.* (2011b)). Murugesan *et al*. (2012) conducted a groundwater investigation carried out in the Dindigul district of Kodaikanal Hill, located in the mountainous terrain of the Western Ghats, Tamil Nadu. Groundwater potential zones were delineated using remote sensing and GIS technologies. Thematic maps were developed using ResourceSat (IRS P6 LISS IV MX) data, and the Inverse Distance Weighting (IDW) model in GIS was utilized to assess the groundwater potential of the region. Different geomorphic units were assigned weight factors according to their ability to store groundwater. Singh *et al.* (2011) made quantitative modelling of groundwater in a part of Punjab using a weighted overlay approach. Ganapurama *et al.* (2009) have used DEM for mapping groundwater potential zones. GIS in groundwater studies has been used by Mukherjee *et al.* (2012); Jaiswal *et al.* (2003); Deepesh *et al.* (2011) etc. Recently a study by Machiwal *et al.* (2011) in the arid region of India was done using a principal component analysis approach to deciding the weight and ranking of the parameters controlling groundwater occurrence. The current study seeks to utilize an integrated approach combining remote sensing and GIS to create new thematic data layers alongside existing data for identifying potential groundwater zones. Eight thematic layers were considered for this delineation: lineament density, drainage density, slope steepness, land use and land cover (LULC), geomorphology, lithology, soil types, and average rainfall. These factors were meticulously analysed and integrated to generate a groundwater potential map for the study area. Additionally, an extensive analysis of these factors, along with rainfall data from the past 40 years (1981–2020), was conducted in this research.

Materials and Methods

Study area

Kutch is surrounded by the Gulf of Kutch and the Arabian Sea to the south and west, while the northern and eastern parts are surrounded by the Great and Little Rann (seasonal wetlands) of Kutch. It is also next to the border with Pakistan, a neighbouring country of India. The Kutch region is situated between 22° 51' N and 24° 53' N latitudes and 68° 4' E and 72° 8' E longitudes, covering a total geographical area of 43.16 lakh ha (Fig. 1). The average annual rainfall is around 978mm. The lowest temperature reached in January is about -2°C in Naliya. April and May are the hottest months with temperatures of about 44 to 50°C.

Data acquisition

Precipitation data spanning the years 1981 to 2020 were collected from various stations, with the data obtained through the State Data Centre in Gandhinagar and the Gujarat State Disaster Management Authority. Slope and drainage density thematic layers were created using open-source digital elevation data from the SRTM DEM, which was sourced from the Earth Explorer-USGS database. Geological and geomorphological maps were retrieved from the Bhukosh Geological Survey of

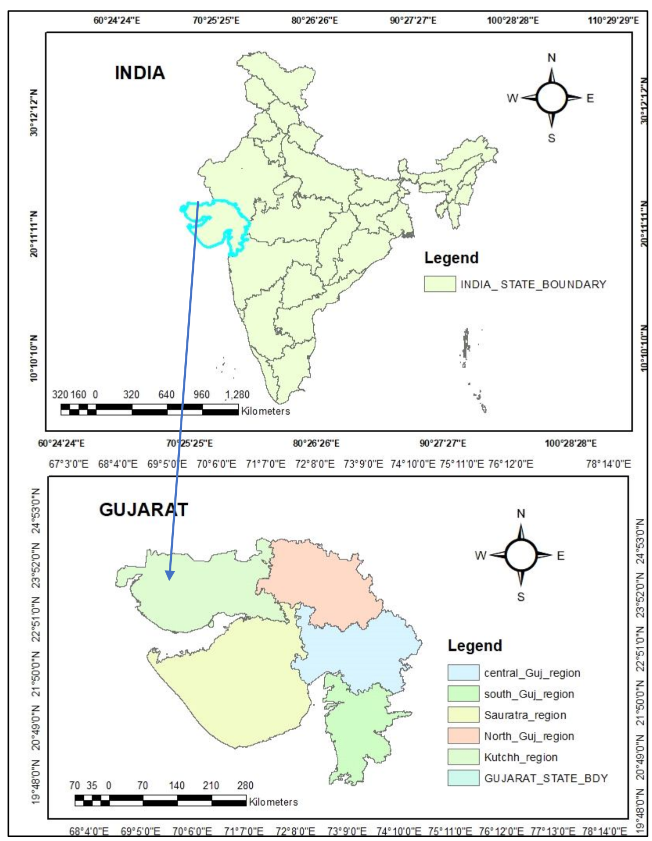

Fig. 1 : Study area map of Kutch region of Gujarat state generated by ArcGIS 10.4.1

India database. Additionally, the soil map, developed by the National Bureau of Soil Survey & Land Use Planning (NBSS&LUP), was provided by BISAG in Gandhinagar.

Demarcation of potential groundwater recharge zones

To identify the groundwater potential zone in the study area, thematic layers of geomorphology, lithology, lineament density, slope, land use/land cover, drainage density, soil and rainfall were generated using topographic maps, satellite image, existing maps and field data in GIS environment

Base map

The base map is the foundational representation, delineating the boundary of the North Gujarat Region watershed – the primary region of interest. It functions as the fundamental reference map for all subsequent thematic maps. The base map was created with 30 m spatial resolution using SRTM DEM data (Fig. 2). The mosaic tool was used to merge them. The Fill and Sink tools were used to remove defects in the DEM. Flow Direction, Flow Accumulation and streams were generated.

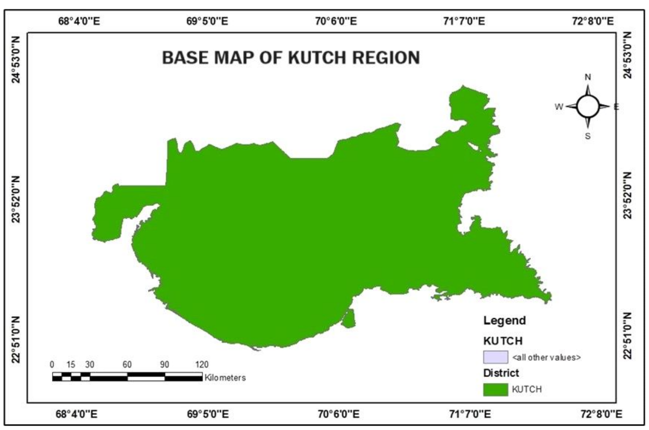

Fig. 2 : Base map of the Kutch region.

Geomorphology

The geomorphology of an area is one of the most important features in evaluating the groundwater potential and prospects. The geomorphology, as such, controls the surface water and subsurface movement of the groundwater. In this study, geomorphological data for Gujarat State, India, were obtained from open-source resources provided by the Bhukosh-Geological Survey of India. A Geomorphology Map for the Kutch Region was created in raster format using ArcGIS 10.4.1. To improve compatibility and clarity for subsequent analysis, the data were reclassified using the "classify tool" available in the spatial analyst function of ArcGIS 10.4.1.

Rainfall

Rainfall is a critical factor in the hydrological cycle and significantly impacts groundwater recharge. Infiltration rates vary based on rainfall intensity and duration, with heavy, short-duration rain causing more runoff and less infiltration, while lighter, prolonged rain enhances infiltration. This study utilized daily rainfall data from 1981 to 2020 to calculate average precipitation. The Thiessen polygon method was applied to determine the annual weighted rainfall for the area, dividing it into 7 polygons, each corresponding to a rainfall station. Additionally, a rainfall map for Kutch region was created using the Inverse Distance Weighted (IDW) interpolation method, where weights decrease with increasing distance from sampling points.

Slope

Slope is a vital terrain characteristic that reflects the steepness of the land surface and offers valuable information about geological and geodynamic processes at a regional scale. Slope plays a key role in influencing surface runoff and infiltration rates, with steeper slopes hindering groundwater recharge. On steep terrains, rainwater flows quickly, reducing the time available for infiltration into the saturated zone, while gentler slopes promote higher infiltration. In this study, DEM data was utilized to generate a slope map, and the slope tool in ArcGIS was used to create a raster file, representing the slope as a percentage.

Drainage Density

Drainage density, expressed in Km/Km^2, indicates the spacing of water channels and the properties of surface materials, providing a quantitative measure of the average stream length within a basin. Research across diverse geological and climatic settings reveals that low drainage density is typically found in areas with permeable subsoil, thick vegetation and low relief. Conversely, high drainage density is characteristic of regions with impermeable or weak subsurface materials, sparse vegetation and rugged terrain. Low drainage density creates a coarse drainage texture, while high density leads to a finer texture. As a key factor in surface runoff, lower drainage density suggests greater rainwater infiltration, increasing the potential for groundwater recharge. Thus, areas with low drainage density are more likely to support groundwater recharge and be potential groundwater zones.

Soil

Soil is a vital natural resource that plays a crucial role in identifying potential groundwater zones and is essential for agricultural productivity. It significantly influences groundwater recharge, as soil characteristics directly affect the movement of surface water into subsurface systems. These characteristics are closely linked to the rates of infiltration, percolation, and permeability, which in turn impact the soil's ability to retain and absorb water (Arulbalaji *at al*., 2019).

Lineament Density

Lineaments are straight, linear features visible on the Earth's surface, often referred to as "lines of landscape" (Hobbs, 1904). They typically reflect surface discontinuities resulting from geological or geomorphic processes (Clark and Wilson, 1994). Geological structures responsible for the formation of lineaments include faults, shear zones, fractures, dykes, veins, bedding planes, and stratigraphic boundaries. Geomorphic features that appear as lineaments on maps, aerial photographs and satellite images include streams, linear valleys and ridgelines.

Geology

The geological composition plays a significant role in determining the occurrence and groundwater flow within a particular area. The rock types in a specific area significantly influence the accessibility and replenishment of groundwater reserves (Horton, 1932). In this study, the resource map was scanned, rectified, and georeferenced using the Arc GIS 10.4.1 software, and the map of Geology for the North Gujarat Region River Basin was constructed. Geologically, the district features formations ranging from the Lower Jurassic to recent alluvial deposits. The northernmost region consists of the Great Saline Rann, while the southern coastal areas are characterized by recent alluvial formations. In the western part, Tertiary formations are observed in the Lakhpat and Abdasa talukas, with saline formations present in Rapar taluka. The central and southern areas are predominantly covered by basalt. The Kutch basin is filled with Mesozoic, Tertiary and Quaternary sediments, with thicknesses varying from less than 500 meters in the north to over 4,000 meters in the south, and from 200 meters in the east to more than 2,500 meters in the west. The landscape is marked by rugged uplands surrounded by lowlands. The uplands consist of hilly terrain exposing Mesozoic rocks, bordered by gently dipping Cenozoic rocks that form coastal plains. The lowlands include vast alluvial plains, mud and salt flats (Rann) and grassy undulations (Banni). The highlands are intersected by major east-west trending faults.

Land Use Land Cover (LULC)

Land use/land cover is a significant parameter in hydrogeological studies because it imparts major indication of the extent of groundwater necessity and usage, He *et al.* (2019). Land use involves various human activities and intentions on a specific land Top of Form. In contrast, land cover encompasses vegetation, water bodies, rocks/soil, artificial structures, and other features arising from land modifications (Arulbalaji *et al*., 2019).

Multi-criteria decision analysis using GIS techniques

AHP is used to demarcate the potential groundwater zones and this technique was proposed by Saaty (1990). In this study, the AHP pair-wise matrix was developed by input values of scale weights of themes and their features based on relative influence on groundwater occurrence and expert opinion (Table-1 and Table-2). Thereafter, a pair-wise comparison matrix was constructed using Saaty's analytical hierarchy process (Saaty, 1980) to calculate normalized weights for individual themes and their features. The AHP method allows assessing the geometric mean (Eq. 1), followed by allotting a normalized weight (Eq. 2) to various themes for finalizing the decision process. The normalized weights were assigned to various thematic layers which include lithology, geomorphology, lineament density, slope, land use/land cover, soil, drainage density, and elevation providing a certain clue for the groundwater potential. The pair-wise comparison for the eight layers was given based on the comparison between the layers and their relative importance towards groundwater prospects and an an8×8 matrix was formed. Based on the comparison matrix the following steps were carried out to calculate the normalized weight. In step 1 each thematic layer of the column was divided by the corresponding sum of the row to form the relative weight matrix. In step 2 the geometric mean was obtained by averaging across the rows and normalized weight was obtained by dividing each geometric mean thematic map with the sum of geometric mean is shown in Table 2. Geometric Mean The geometric mean is derived from the total sum of score of a specific parameter known as total scale weight divided by a total number of parameters; this is expressed as:

$$\text{Geometric Mean} = \frac{Total\ Scale\ weight}{Total\ number\ of\ parameter} \quad (1)$$

e normalized weight was derived from the assigned weight of a parameter feature class divided by the corresponding geometric mean. The formula is represented as:

$$\text{Normalized weight} = \frac{\dfrac{Assigned\ weight\ of\ a\ parameter}{featured\ class}}{Geometric\ mean} \quad (2)$$

Several thematic maps, representing various groups and their standardized weights, were integrated within the ArcGIS 10.4.1 platform. The Potential Groundwater Recharge Zone Index (PGWRZI) was calculated by combining all thematic layers in the GIS environment using the equation specified by Saaty (1980).

$$PGWRZI = \sum_{i}^{n}(X_A \times Y_B)$$

Where,

PGWRZI = Potential Groundwater Zones Index,

X_A - Denotes the weightage of the thematic layers, where A = 1, 2, 3, ………., X

Y_B - Signifies the rank of the thematic layers' subclass, where B = 1, 2, 3, …..., Y

Results and Discussion

Multi-criteria decision analysis using GIS techniques

The AHP pair-wise matrix was created by assigning scale weights to themes and features, considering their impact on groundwater occurrence. This involved synthesizing insights from literature reviews and expert opinions. A pair-wise comparison matrix, established in an 8 x 8 format using Saaty's analytical hierarchy process, determined influenced weights for each theme based on a rating scale. The consistency ratio of the assigned weights falls within the predefined range of (0.084 < 0.10); it can be concluded that the matrix is consistent, and the allocated weights are deemed acceptable shown in Table 1 which is self-explanatory.

The smaller the consistency index, the higher the consistency of the matrix. In the ideal case, CI = 0. The ideally consistent matrix is a rare case, even if the transitivity of its elements has been checked. The consistency degree of matrix P may be determined quantitatively by comparing the calculated consistency index of the matrix with a randomly generated consistency index (based on the scale 1-3-5-7-9) of the inverse symmetrical matrix of the same order shown in Table 2.

The normalized matrix is derived from a pair-wise comparison matrix by adding the entries in each column of the comparison matrix and dividing each entry a_{jk} by the sum of the entries in the corresponding column Σa_{jk} of the comparison matrix. The sum of normalized entries in each column will equal one shown in Table 3.

Table 1 : A pair-wise matrix calculation determines the weight assigned to the thematic layers.

Layers	SL	GEOM	SO	GEO	LULC	DD	R	LD
GEOM	3	1	6	7	5	5	3	4
R	5	0.33	6	9	7	5	1	8
SL	1	0.33	3	7	5	2	0.20	6
DD	0.50	0.20	2	6	3	1	0.20	5
SO	0.33	0.16	1	5	2	0.5	0.16	3
LULC	0.20	0.20	0.5	3	1	0.33	0.14	2
LD	0.16	0.25	0.33	3	0.5	0.2	0.11	1
GEO	0.14	0.14	0.20	1	0.33	0.16	0.11	0.33
TOTAL	**10.34**	**2.62**	**19.03**	**41**	**23.83**	**14.20**	**4.93**	**29.33**

**Where, SL = Slope; GEOM = Geomorphology; SO = Soil; GEO= Geology; LU-LC = Land use / land cover; DD = Drainage Density; R = Rainfall; LD = Lineament Density.*

Table 2 : Parameters of AHP to check the consistency of weights assigned to thematic layers.

Parameter	Formula	Value
Consistency measures	$\frac{(A\ column\ of\ comparison\ Matrix) \times (Eigen\ Vector)}{Corresponding\ Eigen\ Vector\ of\ the\ row}$	70.66
Principal Eigen Value	$\lambda_{max} = \frac{70.63}{8} = 8.83$	8.83
Consistency Index (CI)	$\frac{\lambda_{max} - n}{n-1} = \frac{8.83-8}{8-1} = 0.119$	0.119
Consistency Ratio (CR)	$\frac{CI}{RCI} = \frac{0.119}{1.41} = 0.084$	0.084

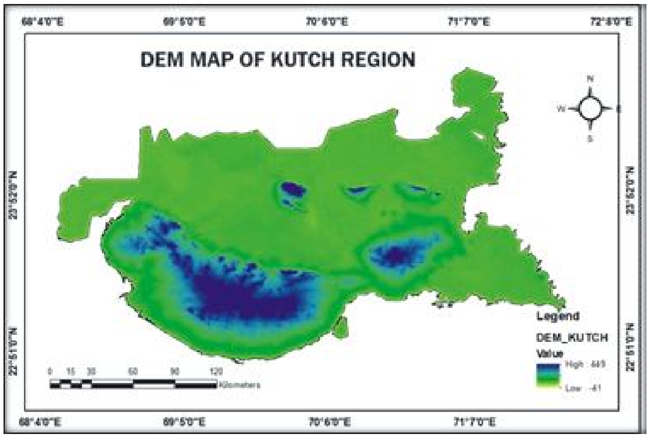

Fig. 3[A] : Elevation map (DEM).

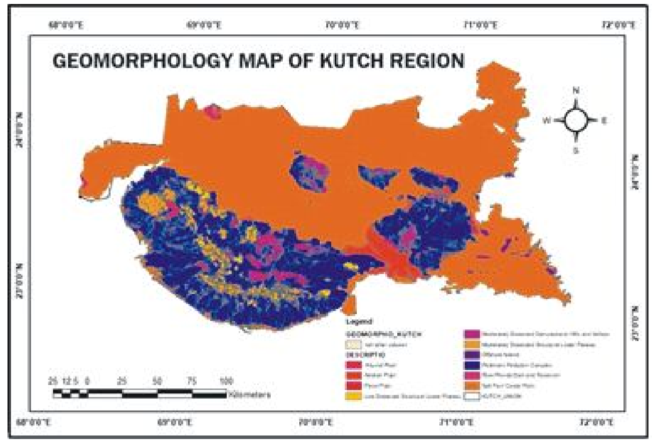

Fig. 3[B] : Geomorphology map.

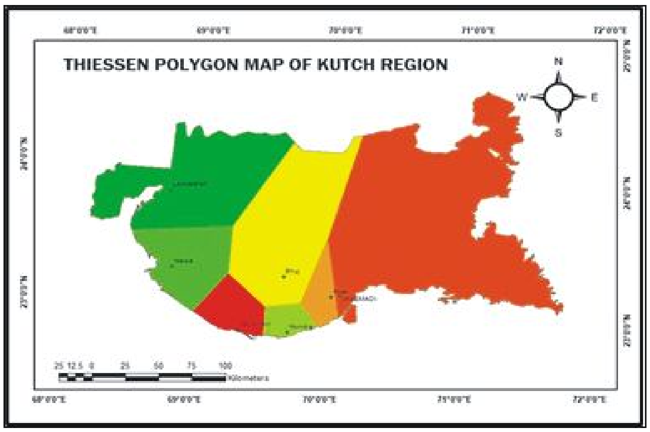

Fig. 3[C] : Thiessen Polygon map for rain gauge stations.

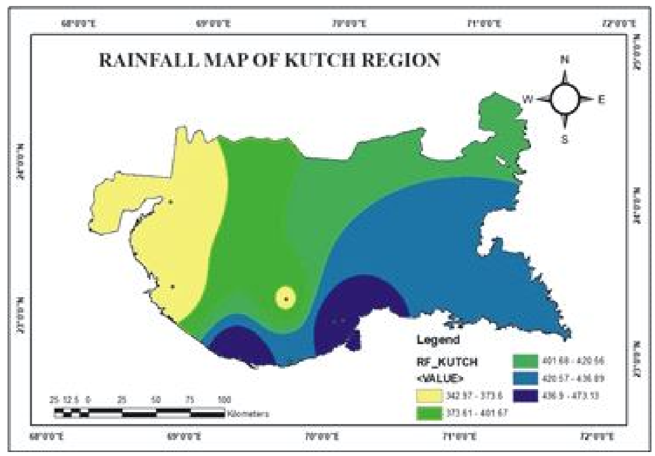

Fig. 3[D] : Rainfall map.

Fig. 3 : [A] Elevation map, [B] geomorphology map, [C] Thiessen polygon map, and [D] Rainfall map of Kutch region.

The Digital Elevation Model (DEM) for the Kutch region (Fig. 3A) shows an elevation range from a maximum of 449 m to a minimum of -41 m. The coastal plain and pediment-pediplain complex cover the largest area, spanning 37.22 lakh ha, which makes up 86.24% of the total region. In contrast, water bodies such as rivers, ponds, dams, and reservoirs cover 0.83 lakh ha, or 1.91% of the basin area (Fig. 3B, Table 4). To analyze rainfall, average precipitation was calculated using the Thiessen Polygon Method, with the IDW interpolation technique used to create a rainfall map. The highest recorded rainfall was 872.15 mm, while the lowest was 410.74 mm (Fig. 3C and D). Slope analysis indicates that the 0-4% slope range covers the largest area, totalling 37.67 lakh ha, or 87.28% of the total region. In contrast, slopes greater than 27.62% occupy just 0.11 lakh ha (Fig. 4A, Table 4).

Table 3 : Normalized Weights for thematic layer.

S. no.	Parameters	Value	Eigen Value	Normalized Weightage %
1	Geomorphology	High ↓ Low	0.307	31
2	Rainfall		0.283	28
3	Slope		0.143	14
4	Drainage density		0.097	10
5	Soil		0.065	7
6	Land use/landcover		0.044	4
7	Lineament Density		0.036	4
8	Geology		0.020	2
Total				100

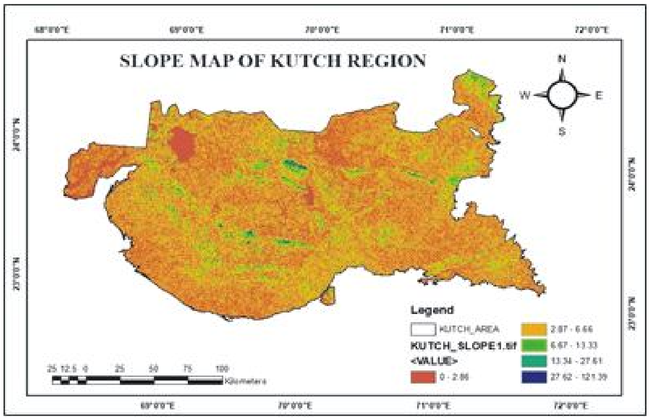

Fig. 4[A] : Slope map.

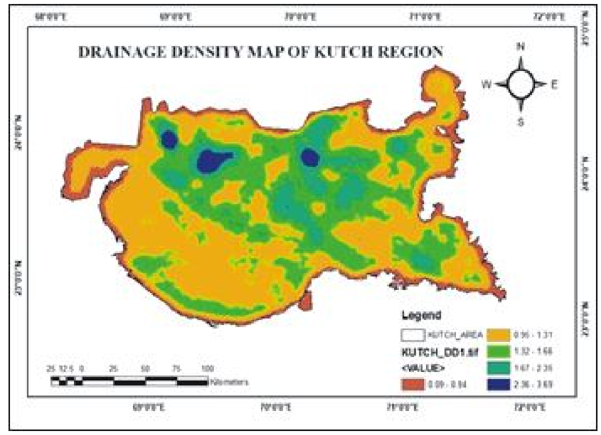

Fig. 4[B] : Drainage Density map.

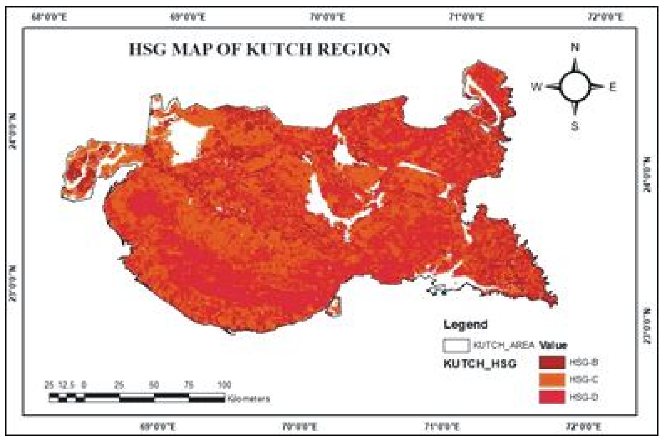

Fig. 4[C] : Soil map (HSG).

Figure 4. [A] Slope map, [B] Drainage map, [C] Drainage density map Soil map of the Kutch region.

Regarding drainage density, the 0.95-1.31 km/km² range represents the largest area, covering 20.25 km², which is 46.93% of the total. The highest drainage density range (2.36-3.69 km/km²) represents the smallest area, just 0.78 km², or 1.81% of the total (Fig. 4C, Table 4). Hydrologic soil group analysis shows that Group C dominates with 27.22 lakh ha, accounting for 63.08% of the total area, while Group D covers 10.63 lakh ha, representing 24.63% of the area (Fig. 4D, Table 4). In the Land Use Land Cover (LULC) categories, wastelands are the most extensive, covering 26.70 lakh ha (61.87% of the area), while forests cover the smallest area with 2.76 lakh ha (6.40%) (Fig. 5A, Table 4). The lineament density across the region ranges from 0 to 0.042 km/km² and is classified into five sub-classes. Generally, groundwater recharge potential increases with higher lineament density. The 0-0.04 km/km² range covers 19.21 lakh ha, or 44.50% of the total area, while the 0.26-0.42 km/km² range occupies only 1.54 lakh ha, or 3.57% of the region (Fig. 5B and C, Table 4). In geological terms, Quaternary Sand and Dunes cover the largest area, totalling 32.02 lakh ha or 74.18% of the total, while Tertiary Sedimentary Rocks cover the smallest area, measuring just 0.03 lakh ha or 0.06% of the total (Fig. 5D, Table 5).

The Digital Elevation Model (DEM) for the Kutch region (Fig. 3A) shows an elevation range from a maximum of 449 m to a minimum of -41 m. The coastal plain and pediment-pediplain complex cover the largest area, spanning 37.22 lakh ha, which makes up 86.24% of the total region. In contrast, water bodies such as rivers, ponds, dams, and reservoirs cover 0.83 lakh ha, or 1.91% of the basin area (Fig. 3B, Table 4). To analyze rainfall, average precipitation was calculated using the Thiessen Polygon Method, with the IDW interpolation technique used to create a rainfall map. The highest recorded rainfall was 872.15 mm, while the lowest was 410.74 mm (Fig. 3C and D). Slope analysis indicates that the 0-4% slope range covers the largest area, totalling 37.67 lakh ha, or 87.28% of the total region. In contrast, slopes greater than 27.62% occupy just 0.11 lakh ha (Fig. 4A, Table 4). Regarding drainage density, the 0.95-1.31 km/km² range represents the largest area, covering 20.25 km², which is 46.93% of the total. The highest drainage density range (2.36-3.69 km/km²) represents the smallest area, just 0.78

Table 4 : Weightage allocation to various subclasses of the thematic layers.

Parameter	Parameter weight (%)	Sub-class	Potential Groundwater Recharge	Saaty's scale	Relative weight
Drainage Density (km/km^2)	10	0.09 - 0.94	Very high	9	36
		0.95 - 1.31	High	7	28
		1.32 - 1.66	Moderate	5	20
		1.67 - 2.35	Low	3	12
		2.36 - 3.69	Very low	1	4
		Total		25	100
Rainfall	28	436.9 - 473.13	Very high		
		420.57 - 436.89	High		
		401.68 - 420.56	Moderate		
		373.61 - 401.67	Low		
		342.97 - 373.6	Very low		
		Total		25	100
Geomorphology	31	Wetlands	Very high	9	24
		Waterbodies	High	9	24
		Agricultural Land	Moderate	7	19
		Forest	Low	5	14
		Wastelands/others	Low	3	8
		Natural/Semi-natural grassland and Grazing land	Low	3	8
		Build up	Very low	1	3
		Wetlands	Very high	9	24
		Waterbodies	High	9	24
		Agricultural Land	Moderate	7	19
		Total		43	100
Geology	2	Paleocene cretaceous rocks	Very high	9	22
		Cretacious sedimentary rocks	High	7	17
		Quarternary sediments	Moderate	5	12
		Neogene sedimentary rocks	Moderate	5	12
		Paleogene sedimentary rocks	Moderate	5	12
		Tertiary ignous rocks	Very low	3	7
		Tertiary sedimentry rocks	Very low	3	7
		Jurassic metamorphic and Sedimentary Rocks	Very low	3	7
		Quaternary sand and dunes	low	1	2
		Total		41	100
Lineament Density (km/km^2)	4	0.26 - 0.42	Very High	9	36
		0.18 - 0.25	High	7	28

Table 4 continued...

Table 4 continued...

		0.11 - 0.17	Moderate	5	20
		0.05 - 0.1	Low	3	12
		0 - 0.04	Very Low	1	4
		Total		25	100
Slope (%)	14	0 - 2.86	Very High	9	36
		2.87 - 6.66	High	7	28
		6.67 - 13.33	Moderate	5	20
		13.34 - 27.61	Low	3	12
		>27.61	Very Low	1	4
		Total		25	100
Landuse /land cover	4	Wetlands	Very high	9	24
		Waterbodies	High	9	24
		Agricultural Land	Moderate	7	19
		Forest	Low	5	14
		Wastelands/others	Low	3	8
		Natural/Semi-natural grassland and Grazing land	Low	3	8
		Build up	Very low	1	3
		Total		34	100
Soil (Acco. to HSG)	7	B	Very High	9	50
		C	High	7	39
		D	Very low	2	11
		Total		18	100

km², or 1.81% of the total (Fig. 4C, Table 4). Hydrologic soil group analysis shows that Group C dominates with 27.22 lakh ha, accounting for 63.08% of the total area, while Group D covers 10.63 lakh ha, representing 24.63% of the area (Fig. 4D, Table 4). In the Land Use Land Cover (LULC) categories, wastelands are the most extensive, covering 26.70 lakh ha (61.87% of the area), while forests cover the smallest area with 2.76 lakh ha (6.40%) (Fig. 5A, Table 4). The lineament density across the region ranges from 0 to 0.042 km/km² and is classified into five sub-classes. Generally, groundwater recharge potential increases with higher lineament density. The 0-0.04 km/km² range covers 19.21 lakh ha, or 44.50% of the total area, while the 0.26-0.42 km/km² range occupies only 1.54 lakh ha, or 3.57% of the region (Fig. 5B and C, Table 4). In geological terms, Quaternary Sand and Dunes cover the largest area, totalling 32.02 lakh ha or 74.18% of the total, while Tertiary Sedimentary Rocks cover the smallest area, measuring just 0.03 lakh ha or 0.06% of the total (Fig. 5D, Table 5).

Demarcation of potential groundwater recharge zones

Following the assignment of weights to the various thematic layers and their respective attributes, the next phase involved integrating these thematic maps using the ArcGIS platform. This integration was executed through the “weighted overlay” tool available in the spatial analyst module. The Potential Groundwater Recharge Zone Index (PGWRZI) was utilized to pinpoint and categorize areas based on their groundwater recharge capabilities. The overlay analysis results were classified into five distinct zones according to their recharge suitability: Very Poor, Poor, Moderate, Good, and Excellent (Fig. 6). This analysis emphasizes the potential groundwater recharge zones in the Kutch region. It was found that over half of the study area is categorized under good and moderate recharge potential, indicating conditions conducive to groundwater replenishment. Specifically, areas identified with excellent recharge potential account for 0.28 lakh ha (0.65%), while those classified as good potential cover 4.88 lakh ha (11.32%). The predominant classification is

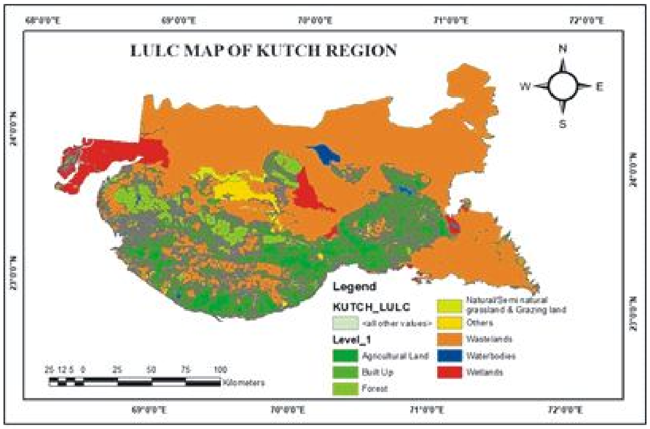

Fig. 5 [A] : Land use/ Land cover map.

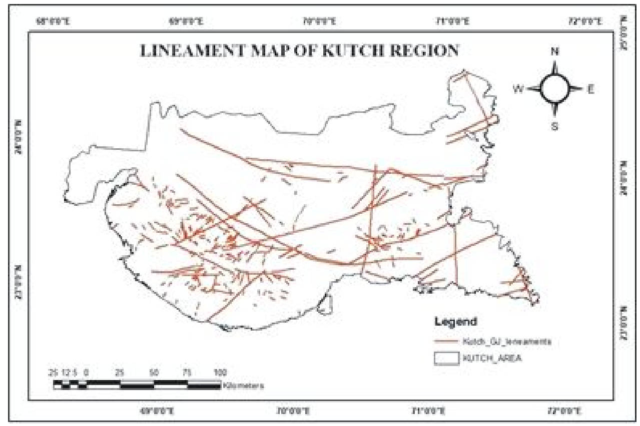

Fig. 5 [B] : Lineament map.

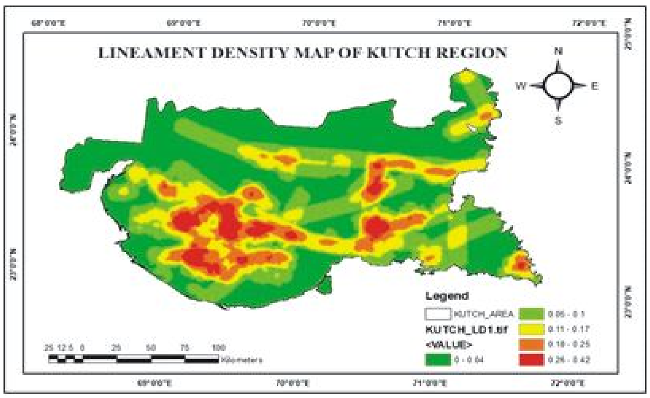

Fig. 5 [C] : Lineament Density map.

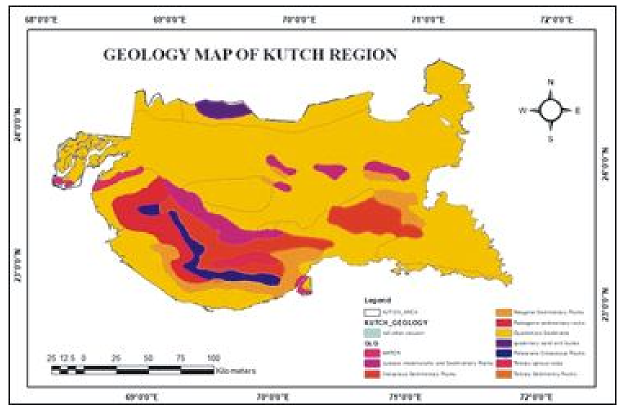

Fig. 5 [D] : Geology map.

Fig. 5 : [A] Land cover map, [B] Lineament map, [C] Lineament density map, and [D] Geology map of the Kutch region.

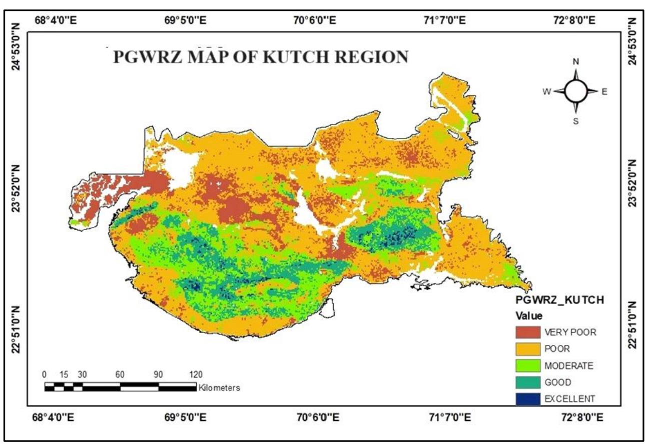

Fig. 6 : Potential groundwater recharge zones of the Kutch region.

moderate recharge potential, which encompasses 23.38 lakh ha (54.18%). Conversely, zones with moderate and very poor recharge potential collectively cover approximately 14.61 lakh ha (33.85%). Detailed spatial distribution of these recharge zones is presented in Table 6.

Future research should aim to explore various hydrological models to project potential scenarios for surface-water extraction in complex river basins, particularly in the face of climate change. Creating GIS-based hydrological models that factor in precipitation, evapotranspiration, land use, soil properties, topography and groundwater levels along with current and anticipated climate data for semi-arid and arid areas can facilitate the identification of appropriate, location-specific climate-resilient cropping systems. This will consider the water needs of different crops alongside groundwater availability over the next 30 years, ultimately enhancing the livelihood security of farmers.

Table 6 : Potential Groundwater Recharge Zones (PGWRZ) of the Kutch region.

S. no.	PGWRZ	Area, lakh ha	Area (%)
1	Excellent	0.28	0.65
2	Good	4.88	11.32
3	Moderate	6.43	14.90
4	Poor	23.38	54.18
5	Very Poor	8.18	18.95

Conclusion

The integration of Remote Sensing and GIS technologies has proven to be an effective and economical method for groundwater exploration and assessment. A considerable portion of the area is conducive to groundwater recharge. However, it was observed that more than half of the study area is categorized under poor recharge potential, suggesting unfavorable conditions for groundwater replenishment. With proper planning, these less favorable areas can be transformed into suitable ones. Specifically, regions with excellent recharge potential cover 0.28 lakh ha (0.65%), while those identified as having good potential encompass 4.88 lakh ha (11.32%). Most of the area, totaling 15.31 lakh ha (50.27%), is classified as having moderate recharge potential. In contrast, zones with poor and very poor recharge potential collectively span about 31.56 lakh ha (73.13%). The spatial distribution of these recharge zones is presented in Table 6.

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References

Arulbalaji, P., Padmalal D. and Sreelash K. (2019). GIS and AHP techniques-based delineation of groundwater potential zones: A case study from southern Western Ghats, India. *Scientific Reports*, **9(1)**, 1–17. https://doi.org/10.1038/s41598-019-38567-x

Baria, S., Rank H., Limbasiya B.B., Gritesh A. and Satasiya R.M. (2024). Determining potential groundwater recharge zones in the North Gujarat region of Gujarat State using techniques of geoinformatics and multi-criteria decision analysis. *J. Geography, Environ. Earth Sci. Int.* **28**, 143–158. https://doi.org/10.9734/jgeesi/2024/v28i10831

Chenini, I., Mammou A.B. and May M.E. (2010). Groundwater recharge zone mapping using GIS-based multi-criteria analysis: A case study in central Tunisia (Maknassy basin). *Water Resources Management*, **24**, 921–939.

Chowdary, V.M., Ramakrishnan D., Srivastava Y.K., Chandran V. and Jeyaram A. (2009). Integrated water resource development plan for sustainable management of Mayurakshi Watershed, India using remote sensing and GIS. *Water Resources Management*, **23**, 1581–1602.

Clark, C.D. and Wilson C. (1994). Spatial analysis of lineaments. *Computers and Geosciences*, **20**, 1237–1258.

Deepesh, M., Jha M.K. and Bimal C. (2011). Assessment of groundwater potential in a semi-arid region of India using remote sensing, GIS, and MCDM techniques. *Water Resources Management*, **25**, 1359–1386.

Ganapurama, S., Kumar G.T.V., Krishna I.V.M., Kahya E. and Demirel M.C. (2009). Mapping of groundwater potential zones in the Musi basin using remote sensing data and GIS. *Advances in Engineering Software*, **40(7)**, 506–518.

Gleick, P.H. (1993). Water and conflict: Freshwater resources and international security. *International Security*, **18(1)**, 79–112.

He, X., Wu J. and Guo W. (2019). Karst spring protection for sustainable and healthy living: The examples of Niangziguan spring and Shuishentang spring in Shanxi, China. *Exposure and Health*, **11(2)**, 153–165. https://doi.org/10.1007/s12403-018-00295-4

Hobbs, W.H. (1904). Lineaments of the Atlantic border region. *Geological Soc. America Bull.*, **15**, 483–506.

Horton, R. (1932). Drainage basin characteristics. *American Geophysical Union Transactions*, **13**, 350–361.

Jaiswal, R.K., Mukherjee S., Krishnamurthy J. and Saxena R. (2003). Role of remote sensing and GIS techniques for generation of groundwater prospect zones towards rural development: An approach. *Int. J. Remote Sensing*, **24(5)**, 993–1008.

Krishnamurthy, J. and Srinivas G. (1995). Role of geological and geomorphological factors in groundwater exploration: A study using IRS LISS data. *Int. J. Remote Sensing*, **16(12)**, 2595–2618.

Krishnamurthy, J., Kumar N.V., Jayaraman V. and Manuvel M. (1996). An approach to demarcate groundwater potential zones through remote sensing and a geographical information system. *Int. J. Remote Sensing*, **17(10)**, 1867–1884.

Machiwal, D., Jha M.K. and Mal B.C. (2011). Assessment of groundwater potential in a semi-arid region of India using remote sensing, GIS and MCDM techniques. *Water Resources Management*, **25**, 1359–1386.

Murthy, K.S.R. (2000). Groundwater potential in a semi-arid region of Andhra Pradesh: A geographical information system approach. *Int. J. Remote Sensing*, **21(9)**, 1867–1884.

Murugesan, B., Thirunavukkarasu R., Senapathi V. and Balasubramanian G. (2012). Application of remote sensing and GIS analysis for groundwater potential zone in Kodaikanal Taluka, South India. *Earth Science*, **7(1)**, 65–75.

Mukherjee, P., Singh C.K. and Mukherjee S. (2012). Delineation of groundwater potential zones in arid region of India: A remote sensing and GIS approach. *Water Resources Management*, **26**, 2643–2672.

Saaty, T.L. (1980). The analytic hierarchy process. *McGraw Hill*, New York.

Saraf, A.K., Choudhury P.R., Roy B., Sarma B., Vijay S. and Choudhury S. (2004). GIS-based surface hydrological modeling in identification of groundwater recharge zones. *Int. J. Remote Sensing*, **25(24)**, 5759–5770.

Shen, Y., Oki T., Utsumi N., Kanae S. and Hanasaki N. (2008). Projection of future world water resources under SRES scenarios: Water withdrawal. *Hydrological Sci. J.*, **53(1)**, 11–33.

Singh, C.K., Shashtri S., Mukherjee S., Kumari R., Avatar R., Singh A. and Singh R.P. (2011a). Application of GWQI to assess the effect of land use change on groundwater quality in lower Shiwaliks of Punjab: Remote sensing & GIS-based approach. *Water Resources Management*, **25(7)**, 1881–1898.

Singh, C.K., Shashtri S., Singh A. and Mukherjee S. (2011b). Quantitative modeling of groundwater in Satluj River basin of Rupnagar district of Punjab using remote sensing and geographic information system. *Environ. Earth Sci.*, **62**, 871–881.