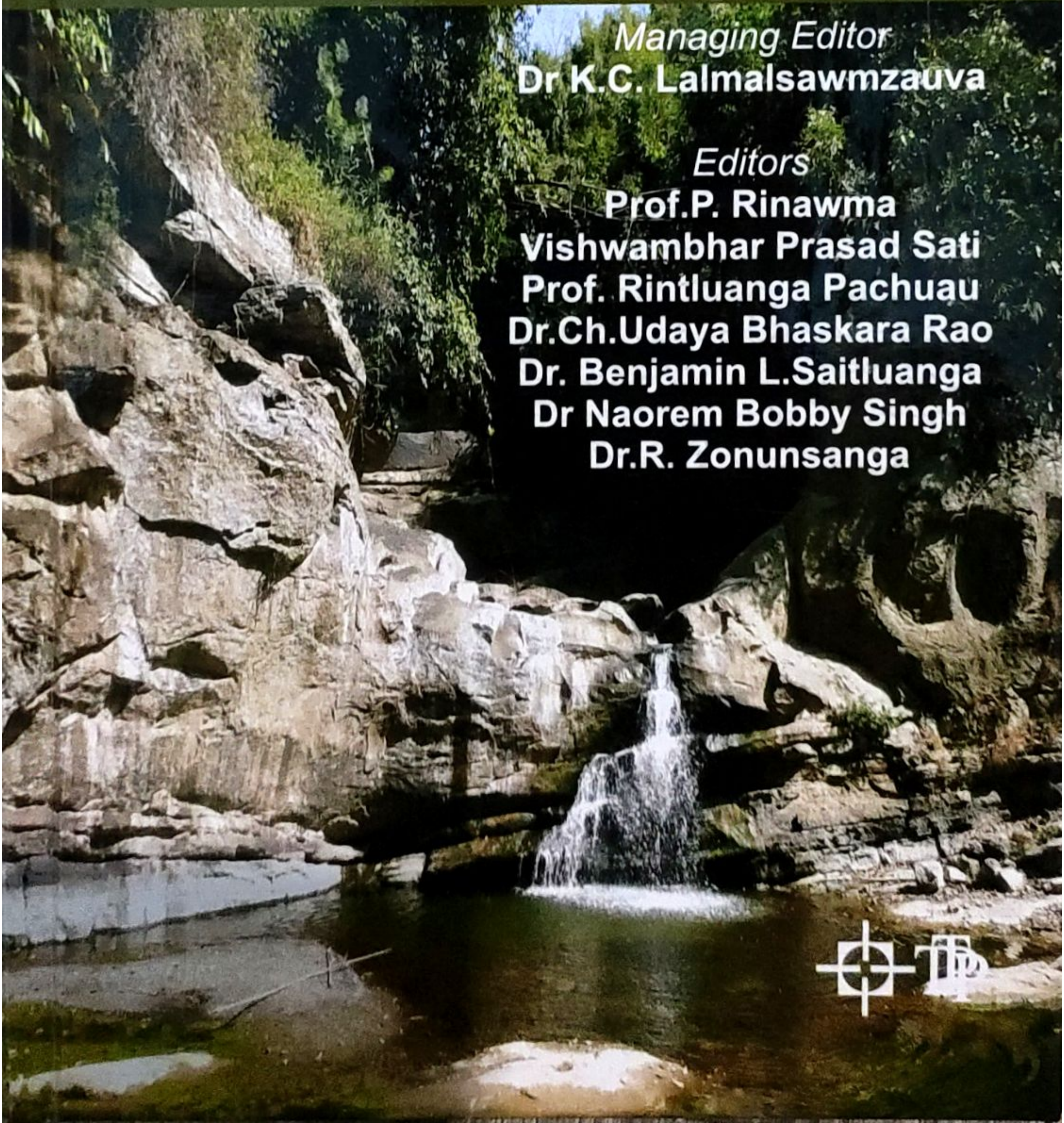
Natural Resource Management for Sustainable Development



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EVALUATION OF GROUNDWATER POTENTIAL IN MAT RIVER BASIN, MIZORAM THROUGH GIS ANALYSIS

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Abstract

Water is the most precious natural resource of the earth which supports all biophysical and human activities. Its identification and conservation are very expensive particularly, in a highly rugged predominant complex sedimentary terrain like Mizoram with steep slopes and high run-off. Groundwater is the substitute to surface water and its exploration is also expensive. The human and cattle population in the upper Mat river basin in Mizoram are experiencing severe water scarcity before the onset of regular monsoon. This paper is an attempt to identify the probable zones of groundwater occurrence in this area. The groundwater potential in the upper Mat drainage basin has been assessed using the major physical factors such as rainfall distribution, surface water bodies including springs, drainage density, slope, geology, landforms and lineament density using GIS software tools by weighted index multi-criteria analysis. The groundwater potential of the area has been classified into very good, good, moderate, low and very low zones based on the range of values obtained for integrated weighted raster. About 527.37 km^2 (89.26%) area is estimated to be moderate to a very good zone of groundwater with a small extent of 63.47 km^2 area mostly covered by medium to high range structural hills shows poor to very poor quantities.

Keywords: Rugged terrain, Mat river basin, groundwater potential, weighted index, multi-criteria analysis

Introduction

The occurrence of groundwater is subjected to rainfall incidence as it is the major input. Though Mizoram receives abundant rainfall during major part of the year, there is a scarcity of water due to the nature of the terrain which is composed of sedimentary rocks with steep slopes and high runoff. The physical factors like slope and lithology have strong control over groundwater accumulation and its movement. As it is difficult to collect surface water due to unfavourable terrain conditions by the presence of highly permeable sandstone, the only alternate source is groundwater. Groundwater occurrence depends upon the nature of bedrock material.

In general, well-sorted sediments such as sandstones, siltstones and shales have high porosity due to well sorting of the sediments which form good aquifers like gravel, sand and silt. In fact, siltstones have greater porosity than sandstones by about 5 %, but its permeability is lower than sandstones due to variation in grain size (Hiroko Kitajima *et al.*, 2017).

Though, there is limited scope for the accumulation of groundwater and maintain the water table at higher elevations due to nature of the rocks. There is a possibility for the formation of good aquifers in this area where siltstones and shales underlie sandstones. Substantial hydro-geological mapping has been done in different parts of the state (DG & MR, 2003 & 2004; CGWB,2013; Lalbiakmawia ,2015), In fact, its identification needs proper scientific techniques. A geographic information system is one of the powerful information technologies useful for mapping of the surface as well as groundwater resources. Groundwater identification and its quantification has been done globally in different terrains using the advanced tools of GIS software by weighted index multi-criteria evaluation (Shahid *et al.*, 2000; Jha et al., 2007; Bharadwaj Hutti and Nijagunappa, 2011; Bera and Bandopadhyay, 2012; Jhariya *et al.*,2015; Machiwal *et al.*,2011; Magesh *et al.*,(2012); Naveen Kumar *et al.*,2015; Pinto *et al.*, 2015; Savita *et al.*, 2018; Manjare, 2014).

The physical factors such as slope, lithology, rainfall distribution, drainage density, surface water bodies, landforms and lineament density are the themes selected for their integration in a GIS environment, expected to provide ample information in identifying probable concentrated zones of groundwater at appropriate locations in this highly rugged complex terrain.

Study area

The upper Mat drainage basin spreads in an area of about 590.84 km² between 92°44' 02" – 92°54'40" longitudes and 23°00'14" – 23°31'30" latitudes in parts of Aizawl and Serchhip districts of Mizoram (Fig.1).

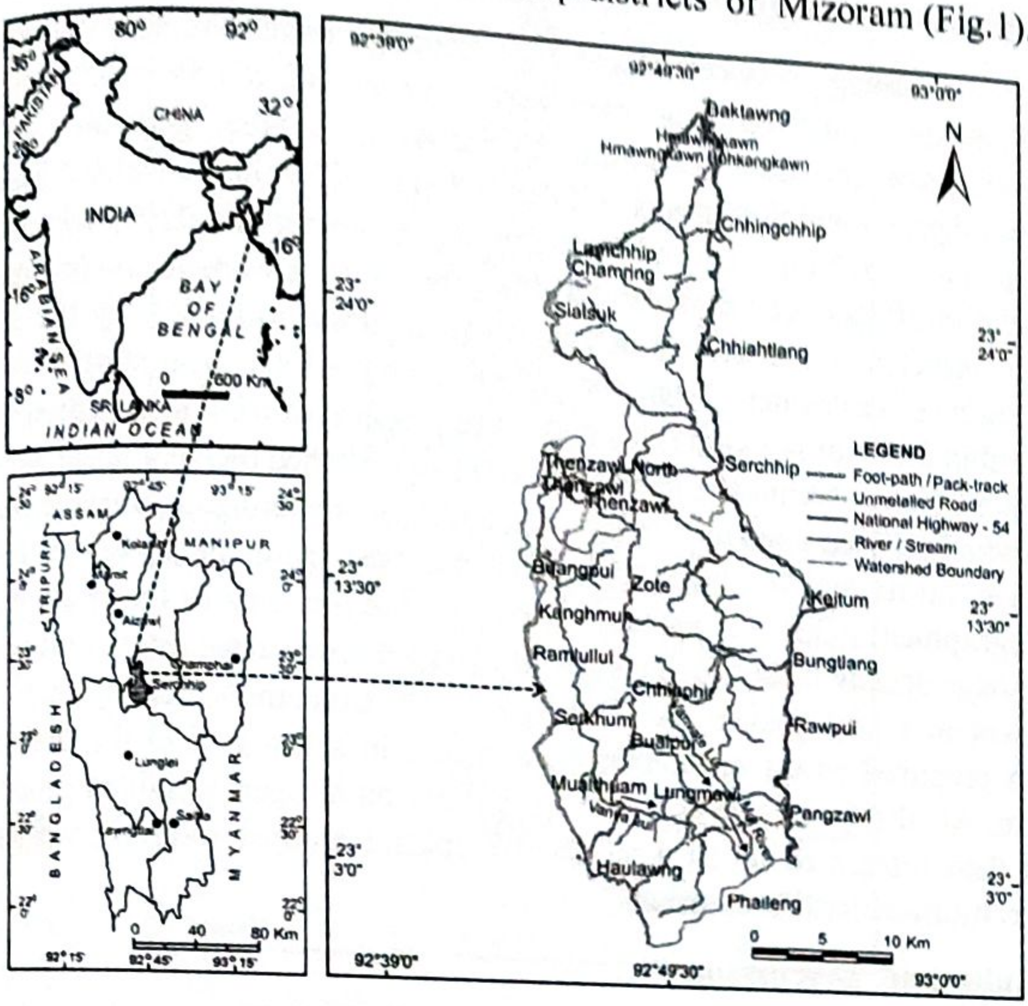

Fig.1 Location map the upper Mat river basin.

It is a north-south stretched elongated drainage basin. The river Mat is originated at an elevation of about 1160 m near Baktawng village in Aizawl district. It flows southward to join Kolodyne (Chimtuipui) the longest river in Mizoram. The minimum and maximum elevations in this drainage basin are 360 m and 1541 m, respectively. Humid sub-tropical hill zone type of agro-climate (Saxena,1989) exists with a mean annual rainfall of about 2476 mm in this area.

The area exhibits first-order topographic features with the remarkable landforms like high rise anticlinal hills and steep synclinal valleys (Ganju,1975). The Surma group of sedimentary rocks which belong to lower and upper Bhuban formations of Tertiary period spread extensively in the study area.

As the area falls under the influence of moist tropical climate with heavy rainfall, semi-evergreen type of forest propagates in this area. Temperature ranges between 6° C and 22° C during winter and varies from 22° C to 34° C during summer.

Materials and Methods

Drainage network of the Mat drainage basin has been delineated from the topographical maps prepared by Survey of India on 1:50,000 scale. Relief, slope and flow accumulation layers have been generated from global digital elevation model (GDEM) acquired by the Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) with 30 m resolution. It has been downloaded from the NASA website and processed with ArcGIS 9.3 spatial analyst. Rainfall data collected by the state agriculture department from the rain gauge stations located at Sialsuk, Serchhip and Haulawng has been used to prepare rainfall distribution map by interpolation technique. A geological map published by Geological Survey of India has been used to prepare lithology and structures. Surface water bodies, faults and fractures have been mapped from the survey of India topographical maps and updated with satellite imagery of the study area. Drainage density layer has been prepared based on the total length of streams present in a km^2 grid in the drainage basin. Lineament density map has been prepared based on their concentration in a km^{2}grid in the drainage basin. All the factors in the selected layers have been weighted properly and then integrated using ArcGIS 9.3 spatial analyst tools by weighted index multi-criteria evaluation.

Results and Discussion

The physical factors such as slope, rainfall distribution, lithology, drainage density, lineament density, landforms and surface water bodies have been selected for integration to find out probable zones of groundwater in the upper Mat drainage basin.

Slope

Slope is the most decisive factor of controlling surface runoff. The slope varies with a relief of the area as the slope is usually steep at higher altitudes. In fact, slope also varies with local lithology. Mizoram is composed of soft sedimentary rocks such as sandstones, siltstones and shales. It has been observed in Mizoram that slope is very steep due to strong relief, nature of the rocks and also by the ongoing tectonic activity. In the central and northwestern parts of the study area, a small extent of about 2.74 km^2 associated with the flood plain and hilltops, respectively, is gently sloping (Fig.2). Similarly, about 5.70 km^2 along the hill slopes at a higher elevation in western, central and northern parts are gently to moderate sloping. About 93.27 km^2 hill slopes in the middle parts throughout the watershed are moderately sloping. The remaining 489.13 km^2 (82.78%) of the watershed composed of hills is steep to very steep.

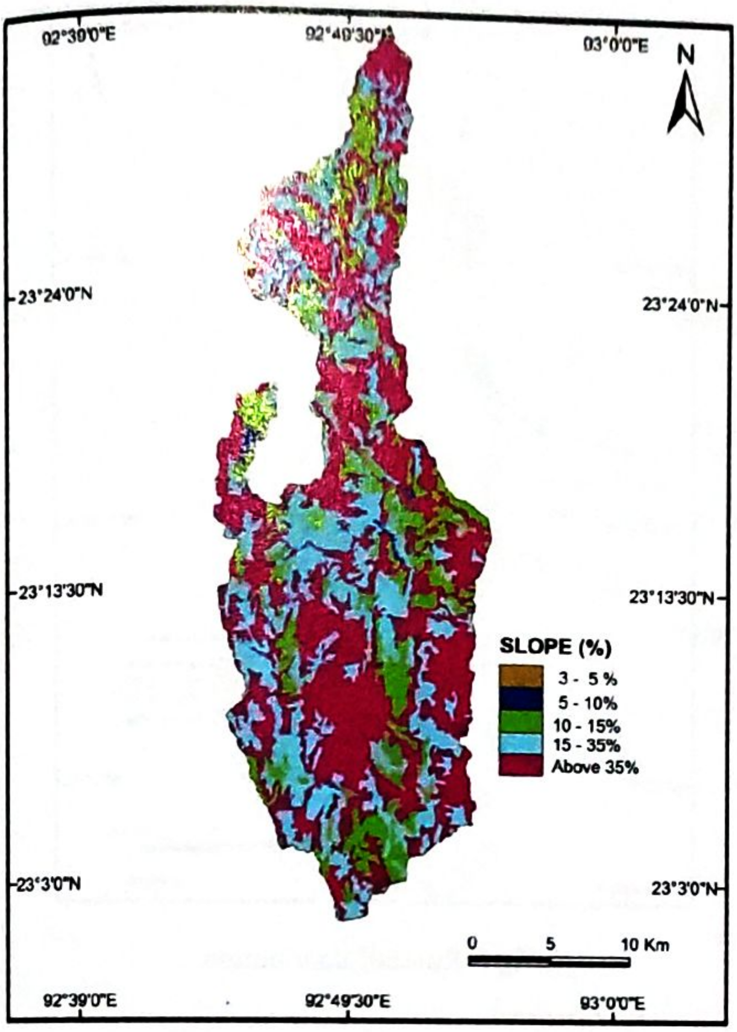

Fig.2 Distribution of slope in the study area.

Rainfall

Rainfallis the unique factor which alone determines the source of water to make up thegroundwater table seasonally. As thestudy area is influenced by the southwest monsoons, a major extent of theprecipitation is received during this period. The rainfall distribution in thestudy area is systematically showing an increasing trend from the southern partstowards the north. The southernmost parts of the watershed receive rainfall below2000mm while the western and northwestern parts receive more than 3000mm (Fig.3).In the central part, it ranges between 2000 mm and 2500 mm. The northern and a small extent in the western part of the watershed receive more than 2500 mm ofrainfall.

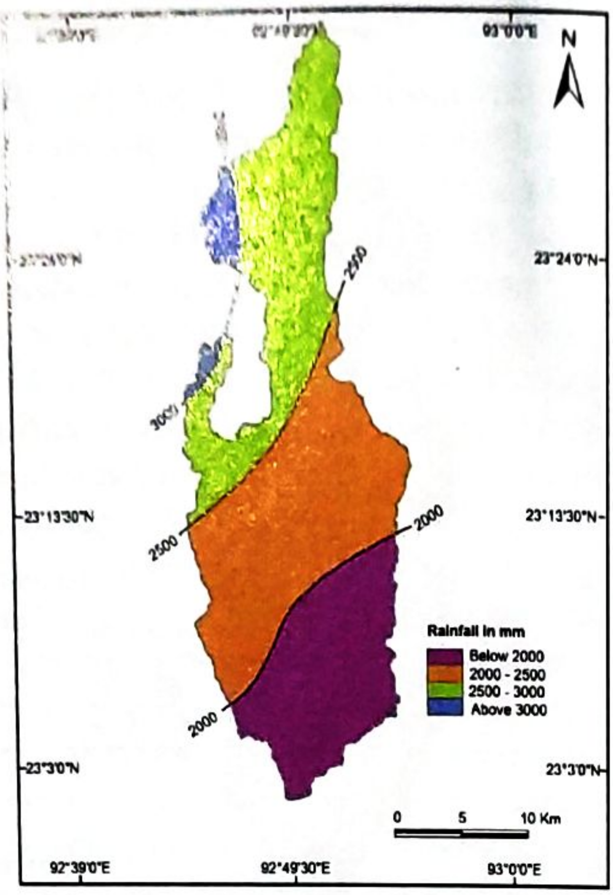

Fig.3 Rainfall distribution.

Lithology

Lithology is one of the dominant factors whichlargely control infiltration. It is high in sedimentary rocks due to highporosity and permeability. In Mizoram, rocks are a completely sedimentary typewhich favours the infiltration at a very high rate. At the same time, the surfacerunoff is also found to be very high. Though the infiltration is high, there are fewer chances for theformation of good confined aquifers due to lack of hard rock in the vicinity ofsedimentary rocks in this region. A number of faults and fractures are seen inthese litho units formed by the ongoing tectonic activity. These subsurfacefeatures help to recharge the groundwater. The major rocks found in the studyarea are medium-fine grained sandstone, siltstone and shales (Fig.4). The major part of the watershed of about393.57 km2 (66.61%) is covered by siltstone and shales.Medium-grained sandstones and shales arepredominant in the middle part of mostly along the main river course and adjoining partscovering an area of about 31.42% (185.64 km2). The fine-grainedsandstone is seen only in the western part of the watershed in the small extent ofabout 11.63 km2 (1.97%).

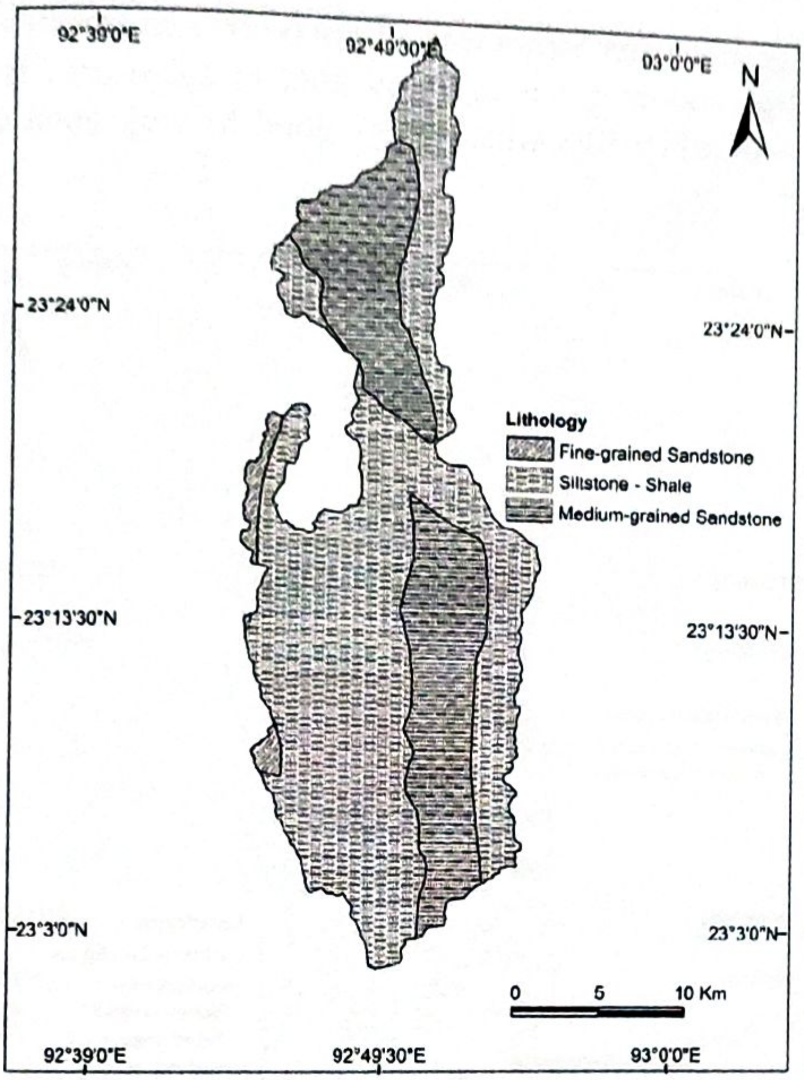

Fig. 4 Major litho-units in the study area.

Landforms

Landforms are the products of several geomorphicprocesses which reflect in the terrain. Groundwater potential can be quantifiedbased on the systematic analysis of landforms. The study area is composed ofmountains of structural origin which range elevation from 360 m to 1541 m(Fig.5). A majority of the hill ranges are narrowly crested along with a fewbroad crested in the northeastern part which is separated by narrow and deepstructural valleys. The hill ranges decrease their elevation from north tosouthern part of the study area i.e towards downstream. The occurrence of a number of faults and fractures guiding the main river and its tributaries signifies the intensity of tectonic activityin the study area. The structural hills in this area have been grouped intothree categories such as (i) low structural hills, (ii) medium structural hillsand (iii) high structural hills based on their relief and the groundwaterprospects. About 81.60% (482.12 km2) area is under the coverage ofstructural hills which shows moderate to poor potential of groundwater.Structural valleys occupy an area of about 102.03 km2 (17.27%) andthe remaining 6.69 km2 (1.13%) area is covered by floodplain and valley fills which show good to very good quantities of groundwater.

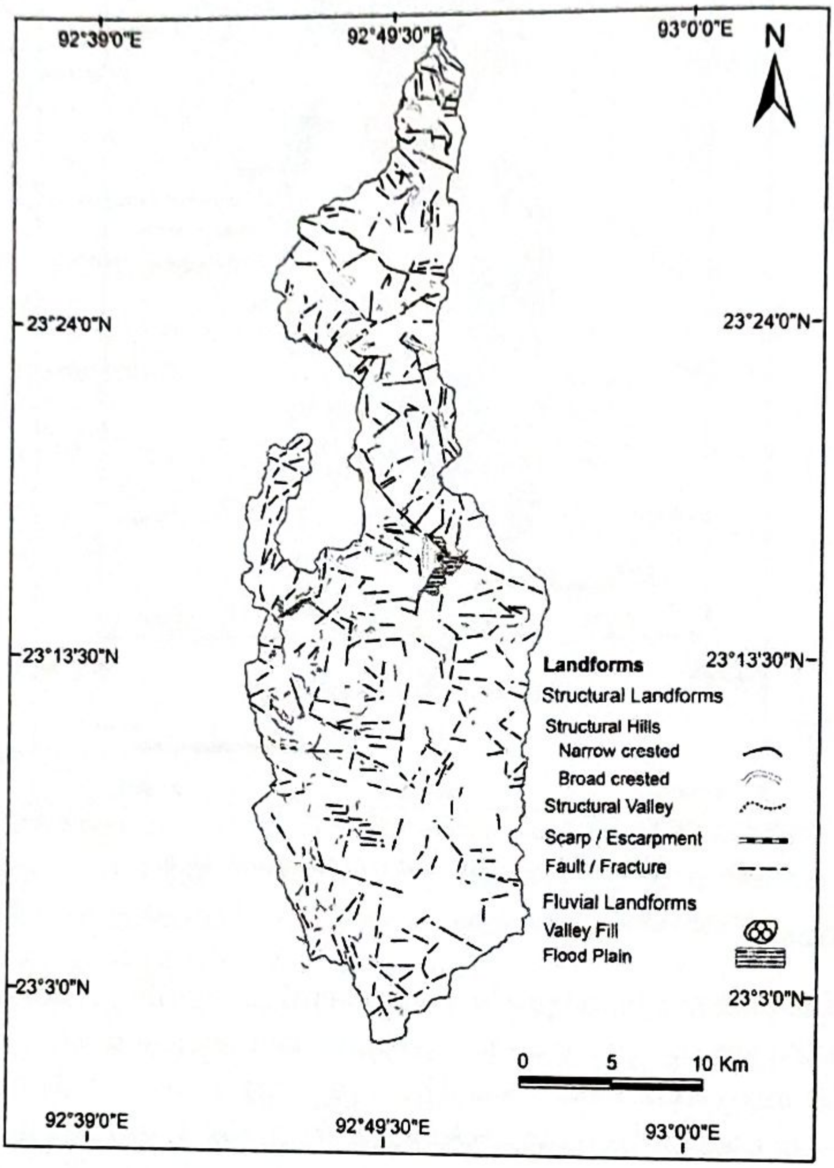

Fig.5 Major geomorphic features.

Surface water bodies

Perennialstreams are the only major source of surface water in the study area. These actas a good source for the surface as well as groundwater recharge. The total length ofthe perennial streams in the study area are 2437.57 km (Fig.6). Surface waterbodies have been considered as the most important factor in quantifying the surface and also the groundwaterresources in the study area.

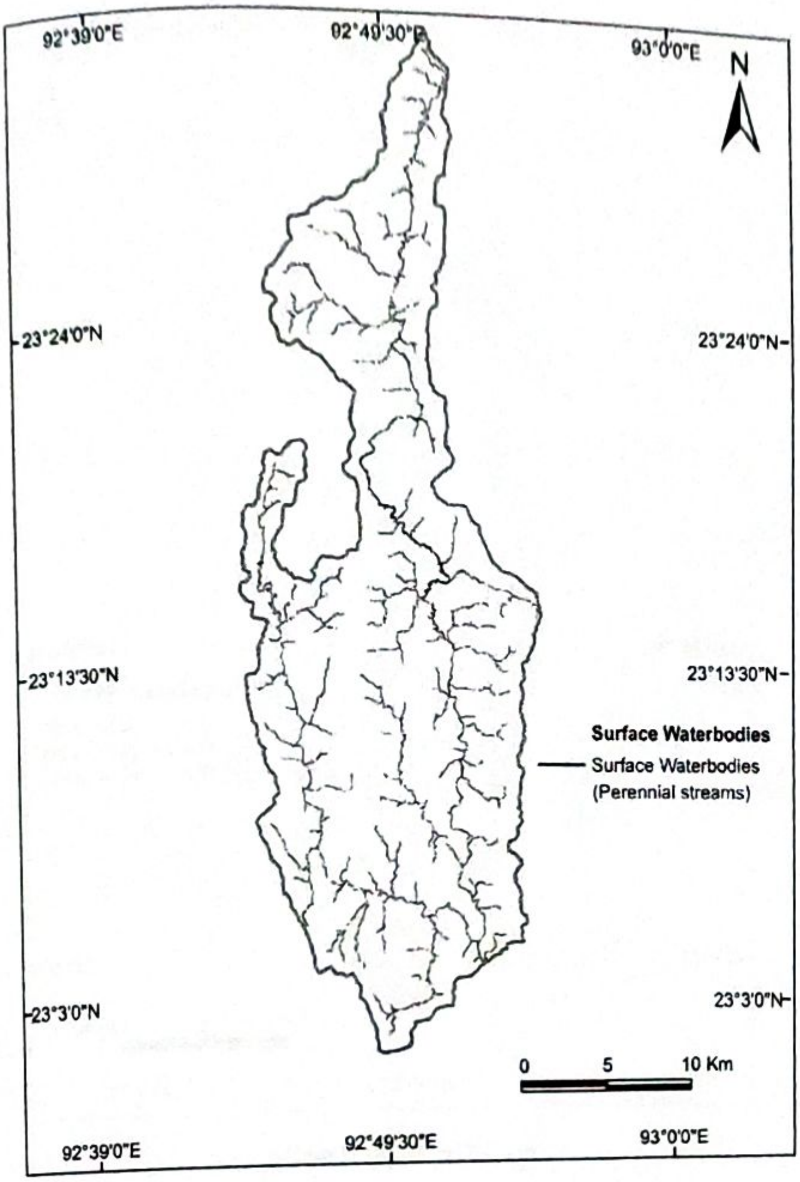

Fig.6 Surface water bodies.

Drainage density

Drainage density is one of the most importantphysical factors like rainfall, slope and lithology. An approximation can be made based ondrainage density as the presence of more number of channels indicate hugevolume of water provided ideal conditions exist. As a whole, the study area hasa good network of channels as seen on the drainage network map due to the presenceof soft sedimentary rock like sandstone. About 73.31% (433.16 km2) area falls under good to very gooddrainage network category and the remaining 157.68 km2 (26.69%) hasthe low drainage density (Fig.7). The low drainage density areas are mostlyephemeral nature.

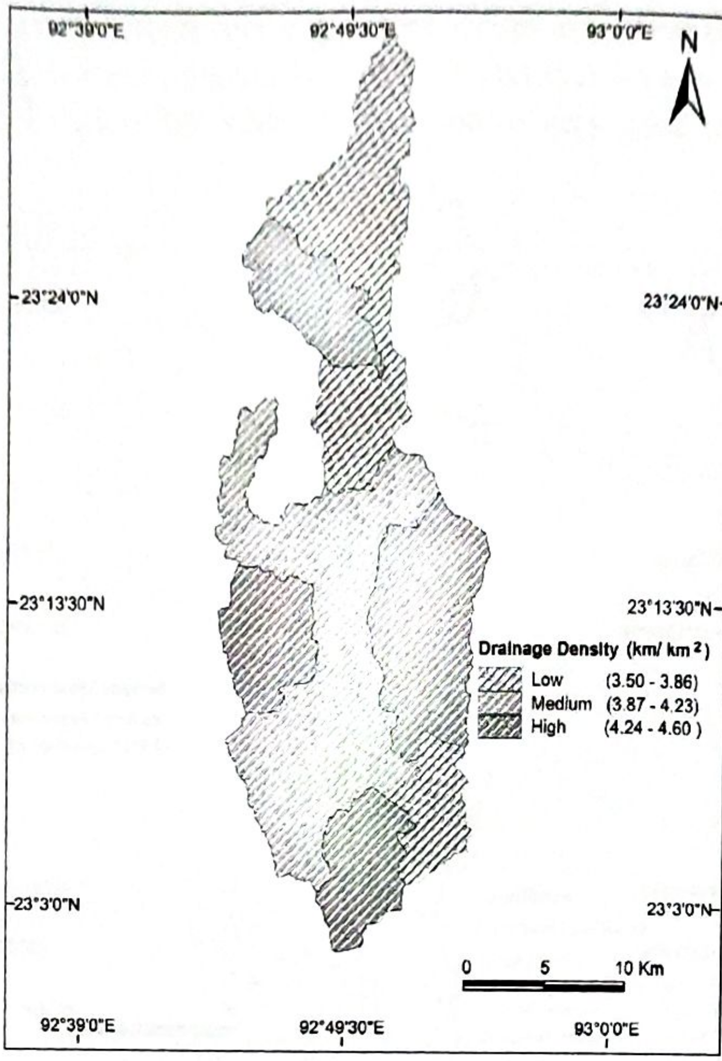

Fig. 7 Drainage density.

Lineament density

Lineaments are the most important geotectonicelements which indicate the nature of the tectonic activity. Lineaments are thepathways for water recharge and discharge to springs. In the study area, amajority of the perennial streams including Mat river are guided by theexisting faults, fractures and lineaments to a great extent. There are 317faults and fractures of various length with a total of 407.81 km. A majority of the lineaments are oriented in N-S, E-W and NW-SE directions. The prominent fault in NW-SE direction named after theriver Mat is the remarkable one in terms of strong tectonic activity. Medium to high lineament density is seen inthe middle and also in the northern half of the watershed covering an area ofabout 374.85 km2 (63.44%) (Fig.8). The southern half of the areacovering an area of about 215.99 km2 (36.56%) exhibits low lineamentdensity.

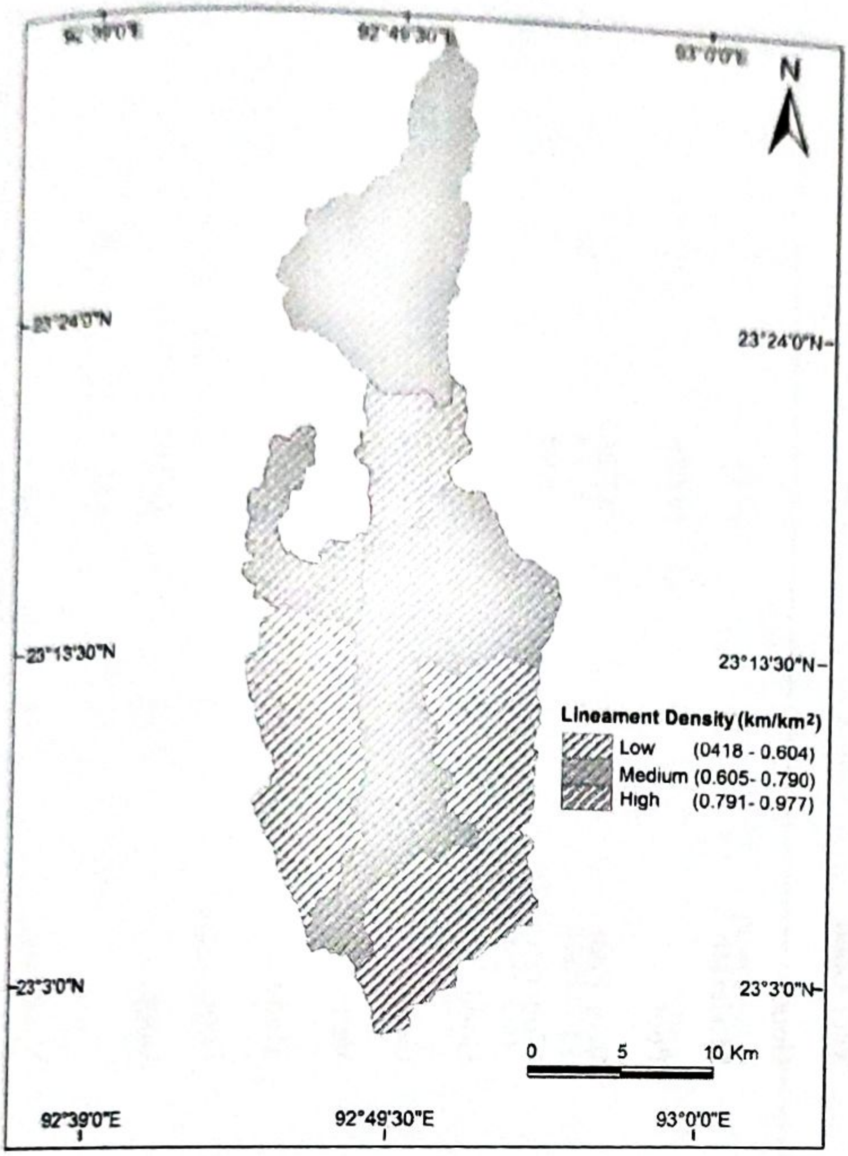

Fig.8 Lineament density.

The thematic units in each of these layers have been weighted according to their predicted contribution in groundwater accumulation and distribution in the area (Table.1).

The physical factor layers have been evaluated according to the total weight assigned to the individual themes.

Five zones of groundwater potential have been delineated in the upper Mat drainage basin based on the integration of the weighted multi-thematic layers (Fig.9 &Table 2). It has been observed in this study about 527.37 km^2 (89%) area shows moderate to very good quantities and the remaining 63.47 km^2 area of the watershed exhibits poor to very poor quantities of groundwater. It is clear from this study that the areas such as structural valleys, valley fills and flood plains, with low relief (360 m – 832 m), low slope (3 – 15%), medium to high drainage density (3.86 – 4.58),

Table 1: Ranking of physical factors.

Factor	Sub-Class	Category	Rank	Areal extent (km^2)	Theme Weight (%)
Slope (%)	1 – 5%	Very Good	1	2.74	20
	5 – 10 %	Good	2	5.70	
	10 – 15%	Moderate	3	93.27	
	15 – 35%	Poor	4	171.87	
	>35%	Very Poor	5	317.262	
Rainfall (mm)	< 2000	Moderate	3	150.97	15
	2000 - 2500	Good	2	225.85	
	2500 - 3000	Good	2	191.82	
	>3000	Very Good	1	22.20	
Lithology	Fine-grained sandstone and shale	Moderate	1	11.63	15
	Siltstone-shale	Poor	4	393.57	
	Medium-grained sandstone and shale	Good	1	185.64	
Landforms	Structural Hills			482.12	10
	Low (360 - 600m)	Moderate	3		
	Medium(600 – 1000 m)	Moderate to Poor	3		
	High (1000 – 1541 m)	Poor	4		

	Structural Valley	Very Good	1	102.03	
	Flood Plain	Good	2	2.71	
	Valley Fill	Good	2	3.98	
Surface Water bodies (km^2) or (km)	Perennial streams	Very Good	1	435.78	10
Drainage Density (km/km^2)	Low (3.5 – 3.86)	Moderate	3	157.68	10
	Medium (3.87– 4.23)	Good	2	202.62	
	High (4.24-4.60)	Very Good	1	230.54	
Lineament Density (km/km^2)	Low (0.418–0.604)	Moderate	3	215.99	10
	Medium(0.605–0.790)	Good	2	293.86	
	High (0.791-0.977)	Very Good	1	80.99	

high rainfall (2000 mm – 3500 mm), medium-grained sandstones, medium to high lineament density (0.604 – 0.976) and surface water bodies like perennial streams have shown good to very good groundwater potential.

Though, the drainage density is high at higher elevations due to the presence of more number of 1st and 2nd order streams and sandstone rocks, the groundwater potential appears to be poor as the slope is very steep which results in the high runoff than more infiltration elsewhere in Mizoram (Labiakmawia, 2015). Though, gentle to moderate sloping areas cover only 98.97 km² area, a major part (89%) of the basin falls under moderate to very good groundwater potential zone due to presence of sandstone with a number of faults and fractures even in moderate to steep sloping areas of low to medium structural hills and medium to low drainage density. As the area is tectonically active, the resultant structures act as conduits for the movement of groundwater from high altitudes to low lying areas. Moreover, many streams and valleys in this basin area structurally controlled. As a whole, the groundwater potential in the vicinity of valleys and perennial streams is found to be very good.

Table 2 : Groundwater potential zones

Groundwater potential zones	Range of values in integrated raster in km²	Groundwater probabilityclass	Areal extent	Areal extent in %
Zone 1	1.55 - 2.05	Very Poor	11.34	1.92
Zone 2	2.06 - 2.35	Poor	52.13	8.81
Zone 3	2.36 - 2.60	Moderate	146.63	24.78
Zone 4	2.61 - 2.85	Good	198.23	33.50
Zone 5	2.86 - 3.30	Very Good	182.51	30.84
			590.84	100.00

Conclusion

Asthe terrain of Mizoram is highly rugged with unfavourable lithological conditions, it is difficult to identify groundwater potential zones withoutproper scientific technique. GIS-based multi-criteria decision support systemis a very useful technique for delineation of groundwater as proved in thisstudy. It has been identified in theupper Mat river basin that about 527.37 km2 area out of 590.84 km2 the total area shows very good to moderate quantities of groundwater particularly,along structural valleys, valley fill, flood plains and also the gently slopinglow to medium relief hills

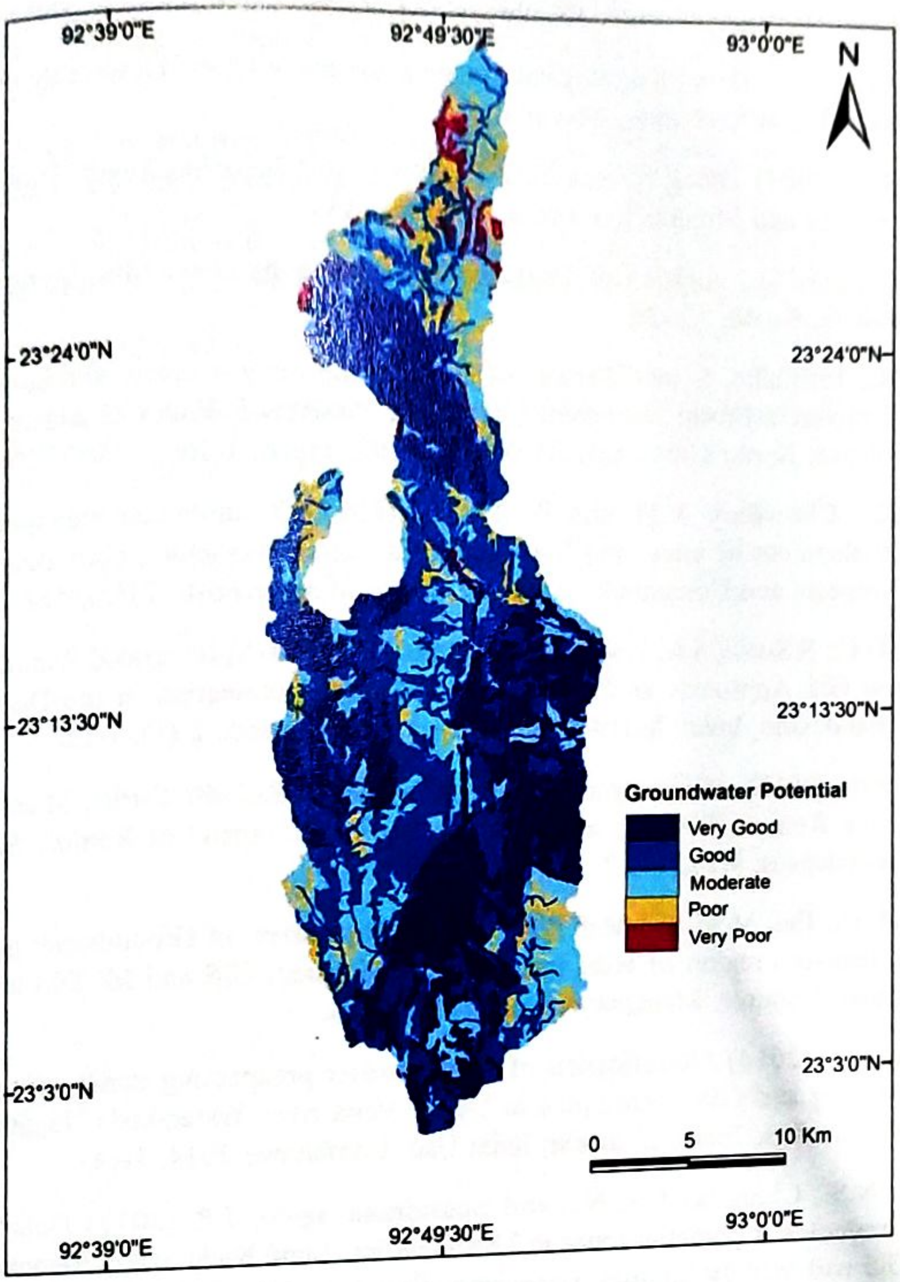

Fig.9 Probable groundwater zones.

composed ofsandstones. This technique can be applied to all other areas for identificationof groundwater probability where surface water scarcity is prevalent.

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