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Development of Groundwater Potential Map for Lunglei Town, Mizoram, India

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Abstract: **The objective of this study was to create a groundwater potential map for localities between Zobawk in south Lunglei town to Pukpui locality in the north, Electric Veng locality in the east to Sazaikawn locality in the west which encompasses the modern Lunglei town in Mizoram, North East India. The lithology at Lunglei is primarily comprised of arenaceous and argillaceous rocks such as sandstones, shales and siltstones from the Middle Bhuban of the Surma Group, ranging in age from Upper Oligocene to Miocene. As the population and economic development rise, new sources of water and their management for safe and usable water in this hilly terrain have to be identified and developed for sustainable use. The Analysis Hierarchy Process (AHP) is used by the integration of various thematic layers to create the groundwater potential zones in the town of Lunglei in Mizoram. Slope, relief, geology, vegetation, runoff, drainage, lineament and land use/land cover are the thematic layers used for developing this groundwater potential map. The total area covered by the study is approximately 126.32 km^2, 11.47% of which falls in High potential areas and 2.08% in the Very High potential area.**

Index Terms: **ArcGIS 10.2, geology, Groundwater potential, Lunglei, Mizoram.**

I. INTRODUCTION

Groundwater is described as water that has occupied all of the voids and pores in the subsurface within the geologic formations, either directly or indirectly by runoff, snow, rivers, dams (Chapman, 1996). The hydrological cycle is an essential factor that makes up more than 97 percent of all on earth freshwater, excluding the glaciers and ice caps (Niu et al., 2014; Otieno et al., 2012). Groundwater contributes to the maintenance of life and habitat (Velis et al., 2017). Water, particularly groundwater, is a common asset for long-term sustainability, and we must take every precaution to protect it for future generations. And in the last 50 years the consumption of groundwater has multiplied (Shah, 2005). Many personnel employed Remote Sensing and Geographical Information Systems techniques to create and delineate groundwater potential maps (Anbazhagan and Jothibasu, 2016; Andualem and Demeke, 2019; Shimpi et al., 2019). In many areas of India and elsewhere across the world, due to increasing populations, farming, climate change, overflowing, water production, salinization, growth and development factors the groundwater decreases and water quality declines (Chakraborti et al., 2019; Garg and Hassan, 2007; Shah et al., 2001; Sharma et al., 2015). Women also suffer the most from water scarcity and water distribution system failures in rural communities in many areas. Strict rules and regulatory structure for groundwater governance in the world are required to handle this valuable resource properly (Kulkarni et al., 2015; Mechlem, 2016; Vaux, 2011). The rainfall in Mizoram from North East India has declined and the state witnesses water shortage every year and hydrological drought arrives at frequent intervals as compared to earlier years (Kumar et al., 2020; Saha et al., 2015). Owing to changes in weather conditions, climate change and the lack of sustainable water control, the natural water sources that were the main source for many families run dry frequenlty and there is a large market supply deficit each year (Biswas and Azyu, 2021). This is the main challenge that rural Mizoram villagers face each year with water shortages (Das, 2019; Goswami and Guha, 2011). Hilly rural residents in Lunglei district and nearby region of Mizoram are heavily dependent on the moonsoon fed rivers and springs for their crop, livestock and other livelihoods like many rural economies. Because of these reasons, it is important that Lunglei needs to have a new groundwater map to delineate the potential groundwater areas and to provide and meet every household water demand. Different researchers have successfully followed the AHP method to identify and delineate groundwater maps in many areas of India and the world (Agarwal et al., 2013; Arulbalaji et al., 2019; Kumar et al., 2020; Mallick et al., 2019; Rahmati et al., 2015; Shekhar and Pandey, 2015). This AHP technology was developed and successfully used by Thomas L. Saaty to create groundwater maps (Saaty, 1980). Using this AHP process, a groundwater potential map for the town of Lunglei in Mizoram is developed Fig.1.

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II. DESCRIPTION OF THE STUDY AREA

In general, Lunglei district of Mizoram is largest in the state, with a population of 57,011 according to the 2011 Census conducted by the Ministry of Home Affairs, Government of India.

It is a thriving modern town, with the district administrative headquarters located in Lunglei town. The research area is

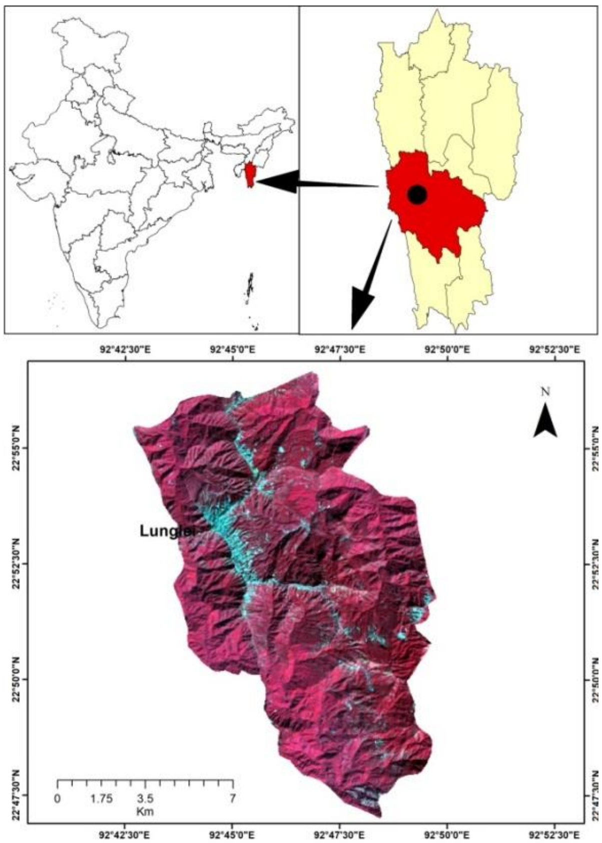

Fig. 1. Location map of modern Lunglei town, Mizoram.

located between 92^0 42″30' E, $22^0$55"0'N and $92^0$60"0'E, $22^0$55"0'N and is covered by Toposheet Nos. 84B/09 and 84B/13 prepared by the Survey of India. With the exponential development and rise in population, it is critical that water as a resource be sustainable for future generations. Mizoram is part of the Tripura – Mizoram depositional basin and is considered as the southern extension branch of the Surma Basin. This whole sedimentary basin is a continuous succession of arenaceous and argillaceous rocks of Palaeogene and Neogene ages having low to high relief (Ganju, 1975).

III. METHODOLOGY

Different thematic maps were created from remotely sensed data, traditional data, and a reconnaissance survey to create the groundwater potential map. This is accompanied by systematic geological fieldwork that covers the entire research area. The overall study definition entailed integrating slope, relief, geology, soil, rainfall, irrigation, lineament, and land use/ land cover thematic layers in a GIS environment. A toposheet map (at a scale of 1:50,000) from the Survey of India, as well as satellite images Landsat-8 and SRTM DEM data (30 m resolution) from the United States Geological Survey were used to create the necessary thematic layers to delineate potential groundwater areas using the *ERDAS IMAGINE 2014*, *Geomatica 2013*, and *ArcGIS 10.2* softwares.

The drainage density of the sample area was calculated using the stream network derived from the SRTM DEM. The research area's lineament was derived from a *Landsat-8* image using *Geomatica 2013* and the fracture line was analysed in *ArcGIS 10.2* to generate a lineament density map. For the validation of our generated lineament map, we compared with the earlier lineament maps from landslide susceptibility maps prepared for Lunglei town (Lallianthanga and Laltanpuia, 2013) (Lallianthanga and Laltanpuia, 2013). Using *ERDAS IMAGINE 2014* and *ArcGIS 10.2*, the land-use map was derived from Landsat-8 and translated into a thematic sheet. The slope and relative relief of the study area were created using the spatial analysis method in *ArcGIS 10.2* from SRTM DEM data with a cell size of 30 m resolution and pixel depth of 16 bit. The rainfall map was created using monthly rainfall data from 2010 to 2018. (Economics and Statistics, 2019). The rainfall distribution map was created by spatially interpolating these data using the Inverse Distance Weighted (IDW) procedure. Fieldwork was used to collect geological evidences. The soil chart that was obtained (Maji et al., 2001) was geo-referenced and digitised using the World Geographic System 84 (WGS84). The various thematic layer maps were then developed.

The created thematic layer maps were converted to raster format and used for overlay analysis. Using spatial analysis tools in *ArcGIS 10.2* and the weighted overlay analysis method, the groundwater potential zone for Lunglei town was generated. During weighted overlay analysis, a rank was allocated to each individual parameter for each thematic layer diagram, and weights were assigned based on the output using the MCDM (AHP) methodology, and the output map depicts the research area's possible groundwater zones. The technique used in this analysis is depicted in flowchart Fig.2.

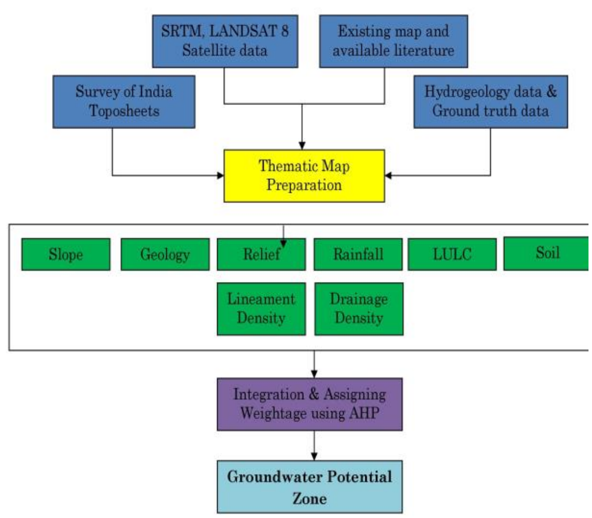

Fig.2. Flowchart representing methodologies of Lunglei Groundwater potential zonation map studies.

IV. ANALYTICAL HIERARCHY PROCESS

The Analytic Hierarchy Process (AHP) developed by Thomas Saaty (Saaty, 1980) is an important method for dealing with complex decision making and can assist the decision maker in establishing goals and making the right decisions. It is a multiple-criteria decision-making technique that is commonly used for mapping groundwater potential zones. The AHP takes into account a variety of possible solutions. Table. I.

Table I. Evaluation criteria for AHP

Strength of significance	Explanation
1	Equal significance
3	Medium significance
5	Strong
7	Very strong significance
9	Maximum significance
2,4,6 and 8	Interim number between two adjacent numbers

A. *Strength of significance explanation*

The AHP assigns a weight to each assessment parameter based on pair-wise evaluations of the parameters by the decision maker. The quality ratio has been checked for accuracy. The table's consistency ratio will be verified using the equation CR=CI/RI. Where CI stands for Consistency Index and RI stands for Random Index.

$$Cl = \lambda\mathrm{max} - \mathrm{n}/\mathrm{n} - 1$$

Where λmax is the principle eigen value and n is the no. of

Table II. Random index for AHP

n	3	4	5	6	7	8	9	10
RI	0.58	0.89	1.12	1.24	1.32	1.41	1.45	1.49

comparisons**.**

V. RESULTS AND DISCUSSION

A. *Slope map*

Lunglei town landscape Table. III is characterized by a terrain ranging from Very Gentle slope to Escarpments or Cliffslopes. The Very Gentle slopes cover an area of 30.22 sq km which are slopes having slope angles < 15º. They contribute about 23.93% of the total area. The Gentle slopes vary from 16º-25º and they cover an area of 44.75 sq km which is the highest category. They contribute 35.42% of the total study area. A huge chunk of 34.43 sq km which is 27.25% is occupied by Moderately Steep slopes. While the Steep slopes of 36º-45º slope angle areas constitute about 15.08 sq km. The escarpments/cliffslope consist about 1.84 sq km of the total study area Fig.3.

Table III. Slope angles of Lunglei town according to Anbalagan, 1992

Slope Angle	Category	Area (sq km)	Percentage (%)
<15º	Very gentle slope	30.22	23.93
16º-25º	Gentle slope	44.75	35.42
26º-35º	Moderately steepslope	34.43	27.25
36º-45º	Steep slope	15.08	11.94
>45º	Escarpment/ cliffslope	1.84	1.46

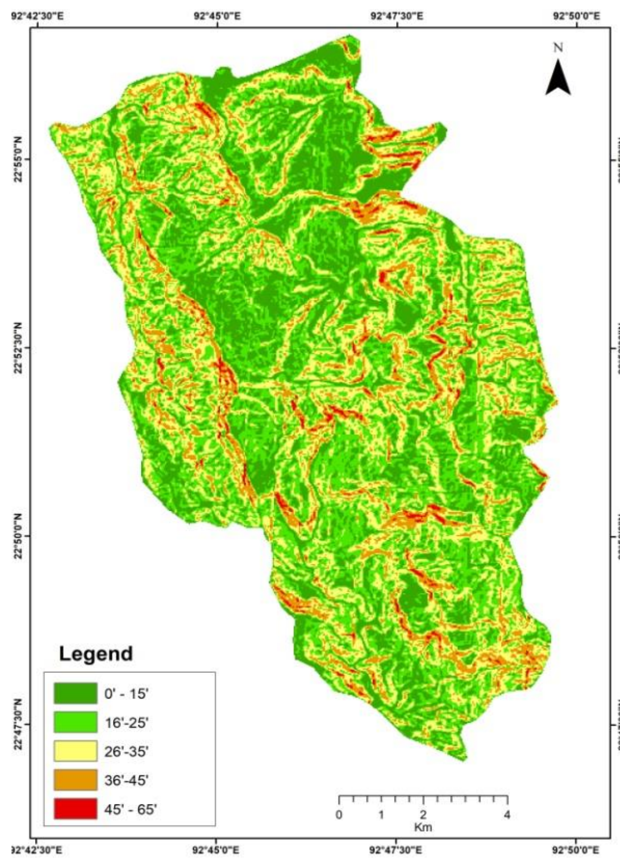

Fig. 3.Slope map of Lunglei

B. *Relief map*

The relative relief was calculated after (Anbalagan, 1992) method and areas of Low relief which are <100m classification is not found in the study area. While Medium relief having a relative relief of 101-300m occupying 1.24 sq km are present, they constitute 0.98% of the study area. In this hilly terrain, High relief areas where the relative relief is >300m constitute 125.04 sq km of the total area which is 99.02% of Lunglei town Fig.4. and Table.IV.

Table IV. Relative relief of Lunglei landscape

Relative Relief	Category	Area (sq km)	Percentage (%)
<100m	Low relief	-	-
101–300m	Medium relief	1.24	0.98
>300 m	High relief	125.04	99.02

Table V.

Rock Type (Lithology)	Area (in sq km)	Percentage (%)
Sandstone	8.95	7.08
Shale-Sandstone	38.14	30.15
Gravel and Silt	0.15	0.12
Crumpled Shale	1.28	1.01
Siltstone-Shale	77.96	61.64

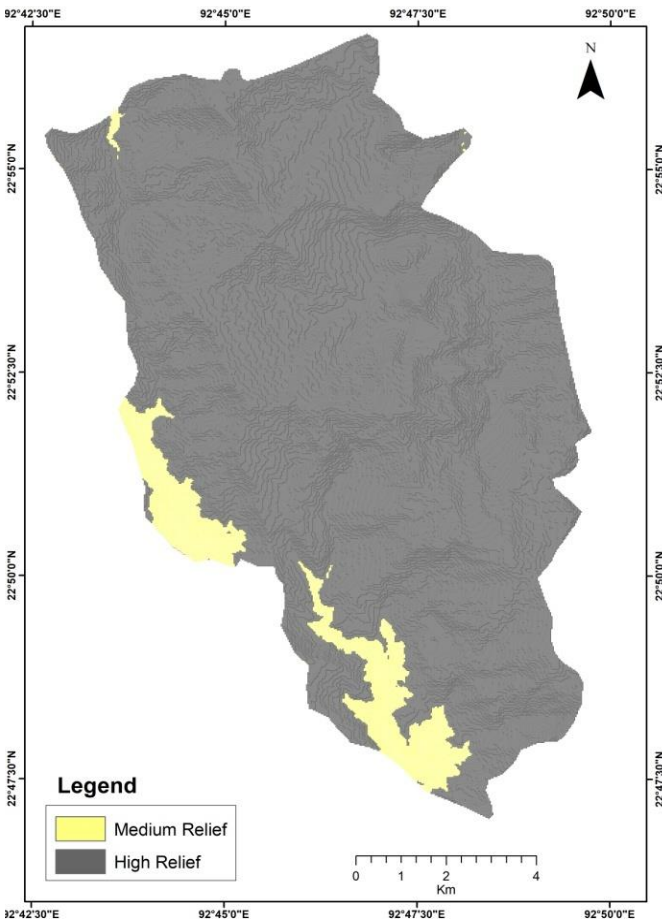

Fig. 4.Lunglei relief map

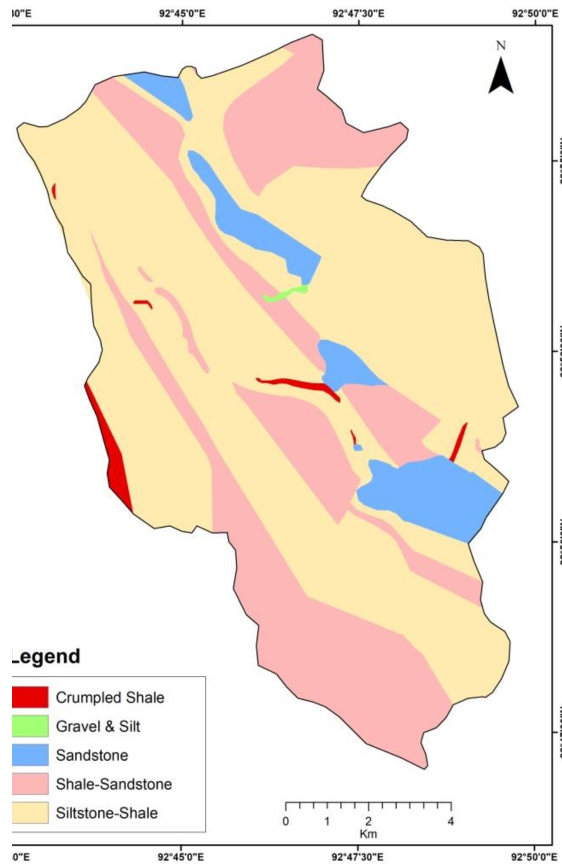

Fig. 5. Geology Map

C. *Geology map*

The lithology of Lunglei town is assigned as Middle Bhuban unit where siltstone-shales are the most dominant rocks Table. V. These are young sedimentary rocks with presence of fossils in some locations. In many places, the rocks are often associated with dip and parallel joints in them. Loose, unconsolidated rocks with soil mixture are commonly found in the study area. The shale-siltstone rocks constitute about 30.15% which is 38.14 sq km of Lunglei town. Sandstone rocks consist about 7.08% of the study area while the rest consist of crumpled shales, gravel and silt which is 1.13% of the lithology Fig.5.

D. *Soil map*

The Lunglei town is characterized by three types of soils (Maji et al., 2001) which are fine loamy soils constituting almost half of the total soils Table. VI. They occupy 60.40 sq km which is about 47.82% of the soils. This is followed by clayey skeletal soils, which is found in 58.21 sq km of the study area and they constitute about 46.09%. The rest 6.09% of the soils consist of loamy skeletal soils Fig.6. These soils are having moderate water infiltration properties.

Table VI. Soil types of Lunglei

Soil Type	Area (sq km)	Percentage (%)
Clayey skeletal Soil	58.21	46.09
Fine loamy Soil	60.40	47.82
Loamy skeletal Soil	7.69	6.09

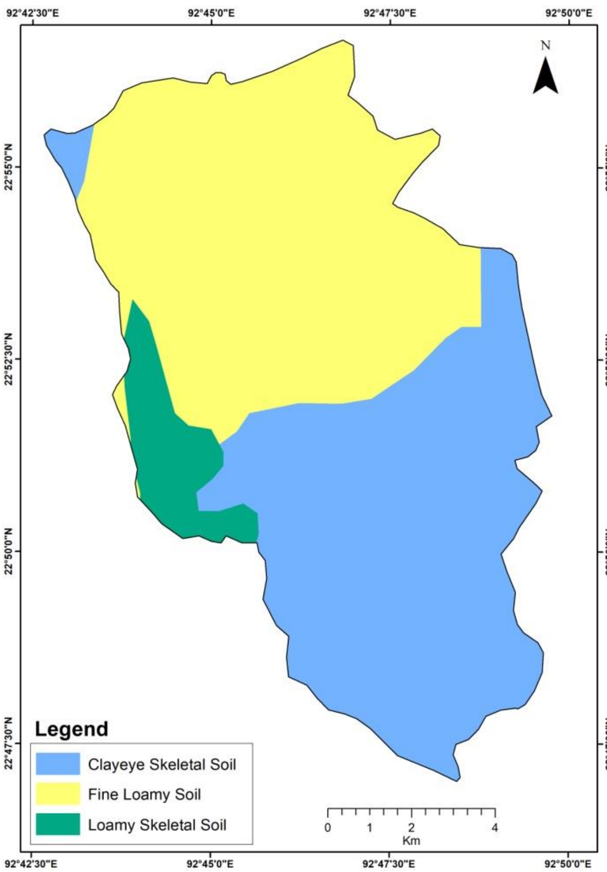

Fig. 6.Soil map of the study area

E. Rainfall map

Lunglei town is located in the south central part of Mizoram and it receives plenty of rainfall. Rainfall data from 2010-2018 was collected (Economics and Statistics, 2019). Lunglei received 1466mm to 1653mm of rainfall during the period Fig.7.

F. Drainage Density map

The drainage density is expressed by (km/km^2) and they represent the closeness of spacing of the stream channels Table. VII. The drainage density provide and measures the average length of stream channels within the watershed area. About 44.43 sq km have drainage density between (0-3.08 km/km2), and 29% of the study area have (3.08-6.36 km/km^2) drainage density which is about 36.55 sq km. About 29.49 sq km of Lunglei has drainage density of (6.36-9.91 km/km^2) which is about 23.43%. The rest 15.49 sq km has drainage density between (9.91-17.08 km/km^2). This drainage density was prepared in *ArcGIS* 10.2 platform Fig.8.

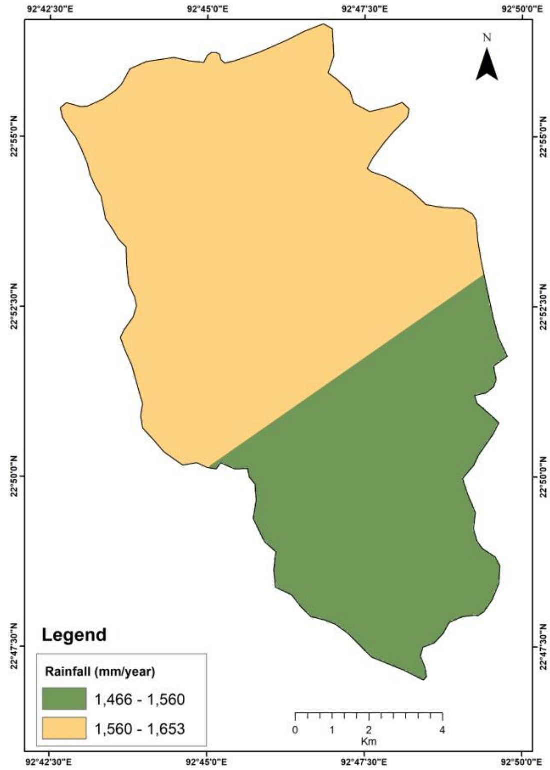

Fig. 7.Rainfall map for Lunglei 2010-2018

Table VII. Drainage density for Lunglei landscape

Density (km/km^2)	Area (sq km)	Percentage (%)
0 – 3.08	44.36	35.23
3.08 – 6.36	36.55	29.03
6.36 – 9.91	29.49	23.43
9.91 – 17.08	15.49	12.31

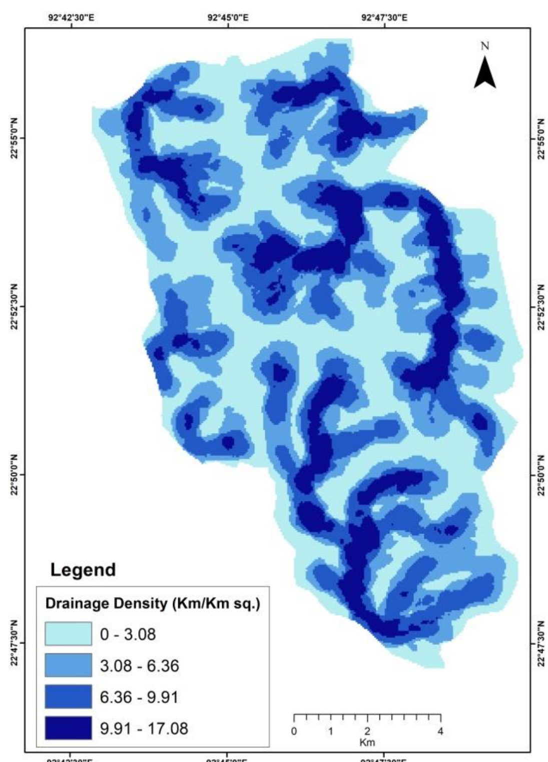

Fig. 8.Drainage density map for Lunglei town

G. Lineament Density map

In this study, the lineament density was categorized into three classes. Lineament with density 0-0.70 km/km^2 were dominating in the area, they encompass about 94.33 km^2 which is 76.75% of the area. Lineament densities having 0.70-2.37 km/km^2 cover 23.59 km^2 of the area and they represent 19.19%. The area having the least coverage in terms of lineament density is in the range 2.37-5.59 km/km^2 which is 4.06% of the total area representing 4.99 km^2 Fig. 9. and calculations in Table. VIII.

Table VIII. Lineament density of the study area

Density (km/km^2)	Area (sq km)	Percentage (%)
0 – 0.70	94.33	76.75
0.70 – 2.37	23.59	19.19
2.37 – 5.59	4.99	4.06

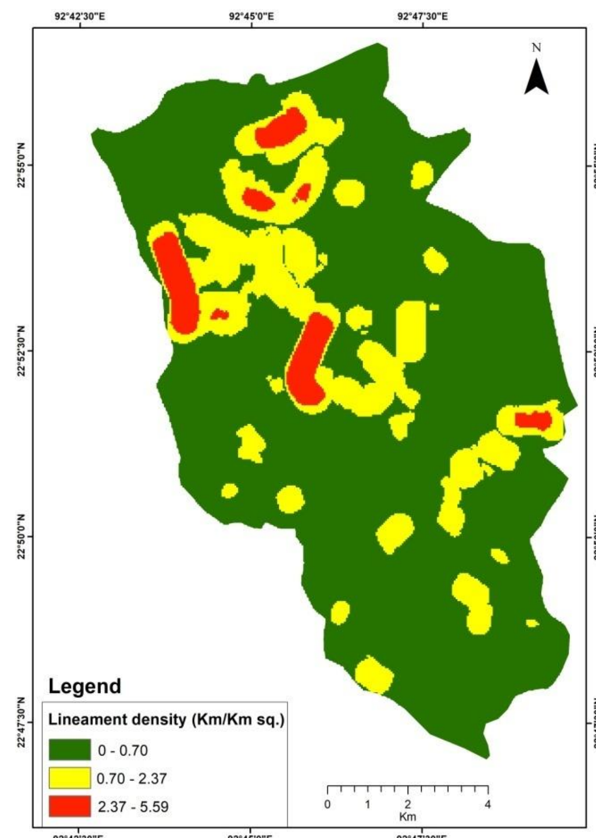

Fig. 9. Lineament density map for Lunglei

H. Land Use/ Land Cover

The study area consists of different land cover viz., built-up (urban), built-up (rural), heavy vegetation, light vegetation, barren land, agricultural land, shifting cultivation (jhum) and water bodies Fig.10. The major parts of the landscape were dominated by light vegetation and heavy vegetation which make up 101.55 km^2 which is 80.42% of the study area Table. IX.

Table IX. Land Use/ Land Cover for Lunglei town

Land Use / Land Class	Area (km^2)	Percentage (%)
Built-up (urban)	6.31	4.99
Built-up (rural)	0.19	0.16
Heavy vegetation	47.80	37.86
Light vegetation	53.75	42.56
Barren land	9.14	7.23
Agricultural land	4.28	3.38
Shifting cultivation	4.83	3.82
Water bodies	0.002	0.002

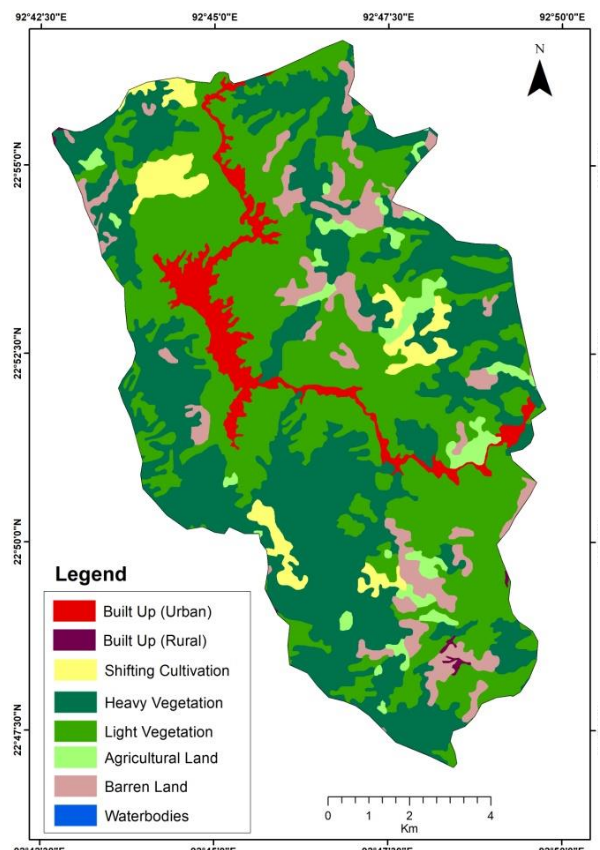

Fig. 10.Land Use/ Land Cover for Lunglei town

VI. OTHER RESULTS

A. Pairwise comparision matrix and normalized weight

From the different thematic maps consisting of drainage density, LULC, lineament density, geology, rainfall, slope, soil and relief maps, the normalized weight was calculated Tab.X.

Table X. Pairwise comparision matrix and normalized weight

THEMATIC MAPS	DRAINAGE DENSITY	LULC	LINEAMENT DENSITY	GEOLOGY	RAINFALL	SLOPE	SOIL	RELIEF	NORMALIZED WEIGHT
Drainage Density	1.00	0.25	5.00	0.14	0.33	0.50	0.50	2.00	0.07
LULC	3.00	1.00	3.00	0.33	0.33	0.25	0.33	3.00	0.08
Lineament Density	0.20	0.33	1.00	0.14	0.14	0.17	0.33	3.00	0.04
Geology	6.00	3.00	7.00	1.00	0.50	2.00	3.00	3.00	0.23
Rainfall	3.00	3.00	7.00	2.00	1.00	2.00	3.00	5.00	0.26
Slope	2.00	4.00	5.00	0.50	0.50	1.00	2.00	5.00	0.17
Soil	2.00	3.00	3.00	0.33	0.33	0.50	1.00	3.00	0.11
Relief	0.50	0.33	0.50	0.33	0.20	0.20	0.33	1.00	0.04
Sum	17.70	14.9	31.5	4.77	3.33	6.62	10.49	25.0	1

B. Consistency Ratio

The Consistency Ratio 'CR' is calculated as

$$CR = CI/RI \quad \text{and} \quad Cl = \lambda\text{max} - \text{n}/\text{n} - 1$$

$$\lambda\text{max} = 8.45\ , \quad CI = 0.06, \quad RI = 1.41$$

$$CR = 0.04\ which\ is < 0.1$$

Hence the consistency ratio is<0.1 and which is significant and the assigned weightage value is acceptable. Aggregated weight for each parameters Table. XI.

Table XI. Consistency Ratio

Drainage Density	0.07
LULC	0.08
Lineament Density	0.04
Geology	0.23
Rainfall	0.26
Slope	0.17
Soil	0.11
Relief	0.04

C. Groundwater Potential Index

All the above said parameters were prepared as thematic layers. Further it is weighted and ranked depending on its influence nature. Weightage has been given by using AHP Technique. Ranking is given based on its priorities Table.XII. The weighted and ranked layers were integrated in the GIS environment of *ArcGIS 10.2* software. The weightage and rank were given in the Table XII. Groundwater Potential index were calculated as:

$$\begin{aligned} WPI = (Ws * Rs) + (Wg * Rg) + (Wrf * Rrf) \\ + (Wld * Rld) + (Wdd * Rdd) \\ + (Wt * Rt) + (Wlu * Rlu) + (Wr * Rr) \end{aligned}$$

Where, W = Weightage, R= Rank, s = Slope, g = Geology,
rf = Geomorphology, ld = Lineament Density, r = Rainfall,
dd = Drainage Density, t = Soil Texture, lu = LULC.

Table XII. Groundwater Potential Index

Factor	Weight	Rank
Drainage Density (km/km^2)		
0 – 3.08		4
0.08 – 6.36	7	3
6.36 – 9.91		2
9.91 – 17.08		1
LULC		
Built-up (Urban)		1
Built-up (Rural)		2
Heavy Vegetation	8	4
Light Vegetation		4
Agricultural Land		4
Jhum Cultivation		2
Barren Land		2
Water bodies		5
Lineament Density (km/km^2)		
0 - 0.70		1
0.70 – 2.37	4	2
2.37 – 5.59		4
Geology		
Crumpled Shale		5
Gravel & Silt	23	4
Sandstone		2
Shale-Sandstone		3
Siltstone-Shale		3
Rainfall (mm/year)		
1466 -1560	26	4
1560 - 1653		5
Slope		
Very gentle slope		4
Gentle slope		3
Moderately slope	17	2
Steep slope		1
Cliff		1
Soil		
Clayey Skeletal Soil		1
Fine Loamy Soil		2
Loamy Skeletal Soil	11	2
Relief		
Medium Relief		2
High Relief	4	1

VII. GROUNDWATER POTENTIAL ZONES

The measured Potential Index can be used to delineate groundwater potential areas of Lunglei town and nearby areas. The added Potential index is divided into five ranges based on its sum total values: Very High, High, Moderate, Poor, and Very Poor. The resulting map depicts the Lunglei groundwater watershed's potential areas. The study revealed that approximately 2% of the research region has Very high potential, 11% of the area has High potential, 28% has moderate, 33% for Poor, and 24% has Very poor potential for groundwater development. Table XIII contains a diagram of possible zones and a classification of them..

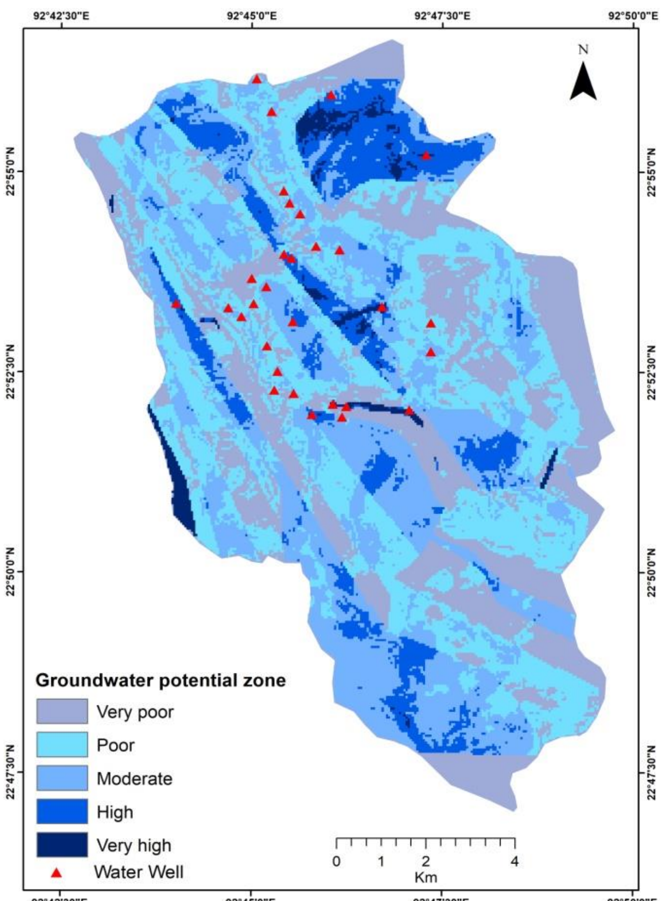

Fig. 11.Groundwater Potential map for Lunglei town

Table XIII. Categorization of Potential zones

Categories	Area (sq km)	Percentage (%)
Very poor	29.953242	24.61
Poor	40.257244	33.07
Moderate	35.027625	28.77
High	13.95983	11.47
Very high	2.533103	2.08

DISCUSSION AND CONCLUSIONS

The groundwater potential map for Lunglei has shown that the north-east of the landscape has the greatest potential for developmental practices for groundwater resources. These regions are categorised as Very High for possible areas of groundwater. Furthermore, this group includes other regions in the North, middle, West and South West landscape areas. This category has been assessed and is 2.53 km^2 in size. In this Very High Groundwater Potential Region, therefore, various groundwater production activities can be carried out. The High Potential Zone category with a surface area of 13.95 km^2 is also likely to increase groundwater productivity. The development of this map will go a long way to address the growing inadequacy of Lunglei's water suppliesThe siltstone-shales which are the most dominant rock can serve as good recharges for groundwater, especially in the unconsolidated areas. Since quartz is the most dominant mineral in sandstones which is found the least of all the rock types, the study area is very good for groundwater recharge. Lunglei town is receiving more than 1400mm of rainfall. poor drainage course network is obtained in the high drainage density areas due to high permeable sedimentary rocks.The groundwater recharge will be higher in the areas of high lineament density areas as they allow water to percolate down in the soil. Since the heavy and light vegetated areas made up most of the rural areas of the study area, the water infiltration rate will be very high in these areas since they are covered by thick forest in many places.

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