DRASTIC model developed with lineament density to map groundwater susceptibility: a case study in part of Coimbatore district, Tamilnadu, India

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Abstract

Due to rapid and often unplanned urbanisation, industrial, and agricultural growth, groundwater has never been relied on as much as it has been in parts of Coimbatore in the last two decades. This paper aims to provide local and regional planning authorities with a succinct groundwater vulnerability assessment of the part of Coimbatore region in order to guarantee more maintainable growth in the area. The Part of Coimbatore region, which covers Pollachi, Sulur and Coimbatore south in eastern part of Tamilnadu, is the study's focal point. The conventional DRASTIC model is used to map the initial groundwater vulnerability assessment. It is then altered by adding "lineament density index" to the original seven DRASTIC features, due to the previously established high correlation between groundwater flow and yield and lineament. The final drastic index map was classed into five categories: very low, low, medium, high, and very high vulnerability, with each covering an area of 840.26, 732.58, 583.46, 183.17, and 167.13 km^2. The modified drastic index defined the same five groups, with 965.35, 880.14, 399.21, 158.29, and 103.54 km^2 of land covered in each. Alanthurai, Thodamuthur, Pichanur, and Pollachi are among the most susceptible places in the state. This groundwater vulnerability map will be used to aid in groundwater pollution management and planning.

Introduction

Groundwater is the most significant source of water supply since it is abundant and less prone to contamination than surface water. A safe and reliable water supply is essential for people's lives and the country's long-term progress (Saha et al., 2018). The physical, chemical, and biological qualities of water determine its appropriateness, which can be altered by natural and human activity. Geology, chemical weathering of different rocks, recharge water quality, and the interaction of rock and water all have an influence on groundwater quality (Bodrud-Doza et al., 2019). Anthropogenic activities like as industrial pollution, wastewater discharge, waste disposal, agricultural runoff, and a variety of others, on the other hand, have a significant influence on groundwater quality (Saha and Rahman, 2020; Kumar 2013).

Furthermore, groundwater vulnerability assessments based on vulnerability maps are thought to be a additional time and cost-effective way of avoiding or minimising pollution than remediating contaminated groundwater or exploring alternate water sources (Wang et al. 2015). Aller et al. (1987) invented the DRASTIC methodology, which is widely recognised as the most extensively used, time-saving, and cost-effective overlay and index-based method. Many authors have attempted to link DRASTIC to other pollution parameters, either by adding new ones or ignoring old ones, such as land use (Kumar et al. 2014), lineament (Sener et al. 2009), groundwater velocity (Huan et al. 2012), and soil exchange capacity (Herlinger Jr and Viero 2007), and/or by using sensitivity analysis to control the evaluation (Javadi et al. 2011). Others have removed topography and hydraulic conductivity from the original DRASTIC model due to their higher reliance or lower spatial variability in the studied area (Wu et al. 2014).

The influencing factors that play a significant role in selecting specific techniques to assess groundwater vulnerability of an area are the geological conditions of the area, as special attention may be required to some rock formations, and data availability, as a lack of data can be detrimental to any vulnerability assessment (Mendoza and Barmen 2006). Scientists have attempted to include geology factors into groundwater vulnerability evaluations because geologic variables can have a significant influence on the vulnerability of highly fragmented locations (Barbulescu 2020). In a research conducted in Nicaragua, Mendoza and Barmen (2006) created a lineament index map based on the density, connectedness, and length of the lineament. The lineament index map was then handed to the remaining seven. As a result, the DRASTIC parameter maps were revised. The DRASTIC map gives a more accurate pollutant assessment in regions with a lot of fractures. Lineaments can be seen as linear features in satellite images, aerial photography, and digital elevation models (DEM). They're almost probably caused or caused by a geological structure, and earlier research has discovered a relationship between the presence and density of these structures and groundwater supply and flow (Al-Rawabdeh et al. 2014). Higher lineament density might indicate a larger risk of groundwater contamination (Abdullah et al. 2015).

The goal of this study is to create a map for a portion of the Coimbatore district lineament density and utilise it as an additional component in the DRASTIC model to predict groundwater contamination vulnerability. Using a range of GIS and remote sensing approaches, lineament maps were produced from satellite data from the Operational Land Imager (OLI).

Study Area

The study region part of Coimbatore district covers a taluk of Sulur, Pollachi and Coimbatore South and it is characterised by pediment, Pediplain and rough hills. It is located in the eastern part of Tamilnadu. It covers an area of 2,506 km^2 and is located between 10°20'N and 11°20'N latitudes and 76°30'E and 77°20'E longitudes (Fig 1). The average annual rainfall is 650 mm and the temperature varies between 15° to 31°C. The research area's general geology indicates that recent sediments overlie Precambrian rocks, with no significant Phanerozoic representation other than a huge unconformity. Charnockite, granite, hornblende biotite gneiss, fissile hornblende biotite gneiss, and pyroxene granulite are among the Precambrian rocks found in the study region (GSI, 2006). Clayey soil, calcareous loamy soil, and loamy soils are all found in the studied region (NBSS, 1996). The research area's elevation ranges from 12 to 2684 metres above sea level. The study area porous formations are characterised by alluvium and colluvium. Colluvial formations are found along the western border of Coimbatore district, particularly in the Chinnathadagam and Chitrachavadi sub-basins of the Noyil river basin.

Materials And Methods

DRASTIC model

DRASTIC is a widely used method for determining aquifer vulnerability. The United States Environmental Protection Agency was the first to develop this approach (Aller et al., 1987). This model uses hydrogeological characteristics to determine aquifer vulnerability. The DRASTIC index, also known as the vulnerability rating, is a numerical value that adds up all of the significant hydrological and geological factors that influence groundwater flow along vertical profiles at a particular location. D for depth to water, R for net recharge, A for aquifer media, S for soil media, T for topography, I for vadose zone effect, and C for hydraulic conductivity are the seven characteristics that make up DRASTIC. To build the geo database and merge the layers for aquifer vulnerability, Arc GIS software was employed.

The severity characteristics have been given different weights ranging from 1 to 5, with 5 being the most essential and 1 being the least important in terms of contamination likelihood. The weights of seven parameters are shown in Table 1. And, depending on its impact on pollutant concentration, each severe parameter has been assigned a rating ranging from 1 to 10. Finally, the weights and ratings are compounded to determine each parameter's index value, which is then added together to generate the final drastic index. The greater the hydrogeological sensitivity to contaminants seeping into the soil, the higher the value. The following equation shows the formula for computing drastic indexes.

$$DI = Dr \times Dw + Rr \times Rw + Ar \times AW + Sr \times Sw + Tr \times Tw + Ir \times Iw + Cr \times Cw$$

Where D, R, A, S, T, I, C represent the 7 Drastic parameters, r represents the rating, and w indicates the weight applied to the individual parameters.

Table 1
Weight assigned for seven parameters

Drastic Parameters	**Weights**
Depth to water table	5
Net **R**echarge	4
Aquifer media	3
Soil media	2
Topography	1
Impact of vadose zone	5
Hydraulic **C**onductivity	3

Each theme parameter map was constructed with 30 m × 30 m pixel cells and then classified based on its own weights. Finally, the final severity index map was constructed and classified into five vulnerability classes using the weighted overlay technique: very low vulnerability, low vulnerability, medium vulnerability, high vulnerability, and very high vulnerability.

Lineament Index

Lineaments are curved or straight structures that resemble the overall surface depiction of underlying ground surface cracks (Pradhan and Youssef 2010). These characteristics may imply vegetative impacts, drainage, or rock solubility in cavern/fissure conduits, and they might be the result of geomorphologic or structural factors (Meijerink et al. 2007). The topography of the ground's underlying structural components is reflected in these lineaments. They indicate the fault and fracture zones in the subordinate layers, which result in increased porosity and permeability. Groundwater sinking and penetration into the subsurface are facilitated by such features, which are particularly essential in hydrogeology (Pinto et al. 2017). Devi et al. (2001) suggest that there is a significant link between lineament and groundwater in terms of storage and mobility because fissures allow outside runoff to infiltrate into the subsurface. Increased lineament density might indicate a higher risk of pollution of groundwater. Using existing tools and processes, lineament extraction and construction of lineament index maps may be done manually or automatically.

Images from the Landsat 8 Operational Land Imager were used to create a study area map of lineament distribution with a cell size of 30 x 30 metres. The PCI Geomatica approach was used to extract the lineament distribution over the research region. The spatial analysis tool in Arc GIS was used to construct the lineament density map. As the strength of lineament features in the studied region rises, the risk of a pollutant migrating into groundwater increases. The research area's lineament distribution and density maps are depicted in the figure. The density map of lineaments has been divided into five categories: very low, low, medium, high, and very high. The high rating value of 5 denoted extremely high lineament density, while the low rating value of 1 denoted extremely low lineament density.

Modified Drastic Model With Lineament Index

The lineament index is incorporated to the general model to make the DRASTIC model represent a more realistic vulnerability assessment of groundwater. This is because previous studies have found a substantial correlation between lineament and groundwater occurrence, flow, and output. The following formula was used to calculate the modified Drastic model with lineament index.

$$DL(i) = Di + Li$$

Where, DL(i) is the DRASTIC index altered with lineament; Di is the general DRASTIC index, and Li is the lineament index.

Results And Discussion

The Drastic parameter depth to water table was calculated using data from 25 water level locations gathered during a field research. The data was mapped in Arc GIS using the interpolation method, and the results were classed into four categories: 25–30, 30–35, 35–40, and > 40 m. The ranges have been given a rating of 10, 9, 8, and 7 accordingly (Fig. 2a). Because it is generally located closer to the ground surface, which is quickly affected by any contamination, shallow water levels are given a higher grade.

Net recharge refers to the amount of water that enters per unit area of soil. In this restoration, slope, land cover, permeability, rainfall, and the amount of water seeping in all play a role (Shirazi et al., 2013). A high recharge means there's a larger chance of contamination, while a low recharge means there's a reduced risk. This is due to the fact that more water flowing inwards has the potential to transport more pollutants. The ground water fluctuation technique was used to compute the recharge.

$$R = h \times Sy$$

Where R represents net recharge in metres, h represents the difference in water level in metres, and Sy is the percentage of specific yield for an unconfined aquifer. The net recharge value classified into 5 classes likely, 7-7.5, 7.5-8, 8-8.5, 8.5-9 and 9 inch (Fig. 2b).

A cemented foundation and unconsolidated rocks and pebbles that hold water make up the aquifer media, which also contains pores and fractures. The rate of permeability and consequent pollutant dissolution in groundwater are influenced by the fundamental rock formations. The aquifer media map for the research region was created using data from the Indian Geological Survey (1:500000 scale). The research area's aquifer media were categorised as charnockite, fissile hornblende-biotite gneiss, granite, garnet-sillimanite-graphite gneiss, pyroxene granulite, and hornblende-biotite gneiss (Fig. 2c). This study's soil media were generated from data from the National Bureau of Soil Survey and landuse palling (1:500000 scale). Calcareous loam soil, calcareous clayey soil, cracking clayey soil, gravelly loam soil, loamy soil, clayey soil, and rock outcrop are the seven soil media types found in the research region (Fig. 2d).

Topography of the study area was prepared from Shuttle Radar Topographic Mission (SRTM) data with 30m spatial resolution in Arc GIS and it was reclassified into five classes namely, < 30, 30–40, 40–50, 50–80 and > 80 and there ratings are assigned as 10, 9, 8, 7 and 6 respectively (Fig. 3a). The under-saturated zone directly above the water table is known as the vadose zone. The vadose zone is essential for controlling the quantity of polluted water entering the system. The impact of a vadose zone map derived through geology data analysis. Clay, clay and sand, sand, sand & gravel, and gravel are the five classifications of vadose zone influence in the research region (Fig. 3b). With the aid of the equation below, the hydraulic conductivity will be calculated using transmissivity data and the lithological map of the aquifer.

$$K = \frac{T}{b}\left(ms^{-1}\right)$$

Where K denotes hydraulic conductivity (ms-1), T denotes transmissivity (m2s-1), and b denotes the aquifer's saturation thickness (m). The hydraulic conductivity values are classified as five classes likely, < 5, 5-7.5, 7.5–10, 10–12 and > 12. The rating are assigned as 1, 2, 3, 4 and 5 respectively (Fig. 3c).

Figure 4a displays the lineament map created using the Landsat 8 Operational Land Imager, whereas Fig. 4b presents the lineament density index map. The lineament density map was divided into five categories: very low, low, medium, high, and very high, with ratings of 1, 2, 3, 4, and 5 assigned to each category. After merging this lineament index map with the drastic index map, a modified drastic index map was created. The dramatic weightage and rating values for the various hydrogeological situations are shown in Table 2.

Table 2
Drastic rating and weighting values for the several hydrogeological settings in the study area.

Parameters	Range	Rating	Weight	Total Weights Rating* Weight
Depth to Water Table (m)	25–30	10	5	50
	30–35	9		45
	35–40	8		40
	> 40	7		35
Net Recharge (Inch)	7.0–7.5	5	4	20
	7.5–8.0	6		24
	8–8.5	7		28
	8.5–9.0	8		32
	> 9	9		36
Aquifer media	Charnockite	5	3	15
	Fissile hornblende-Biotite Gneiss	8		24
	Fluvial	9		27
	Granite	3		9
	Garnet-Sillimanite-Graphite Gniess	4		12
	Pyroxene Granulite	5		15
	Hornblende-Biotite Gneiss	7		21
Soil media	Calcareous Loam Soil	8	2	16
	Calcareous Clayey Soil	6		12
	Cracking Clayey Soil	7		14
	Gravelly Loam Soil	6		12
	Loamy Soil	7		14
	Clayey Soil	6		12
	Rock Outcrop	9		18
Topography	< 30	10	1	10

Parameters (Degree of Slope)	Range	Rating	Weight	Total Weights Rating* Weight
	30–40	9		9
	40–50	8		8
	50–80	7		7
	> 80	6		6
Impact of vadose zone	Clay	5	5	25
	Clay and Sand	7		35
	Sand	4		20
	Sand and Gravel	7		35
	Gravel	3		15
Hydraulic Conductivity (m/day)	< 5	1	3	3
	5–7.5	2		6
	7.5–10	3		9
	10–12	4		12
	> 12	5		15

Drastic And Modified Drastic Index Mapping

The drastic index (DI) technique and seven distinct dramatic thematic layers integrated in Arc GIS utilising the raster calculation option were used to determine the groundwater danger zone in a section of Coimbatore. The severity index values for this study subject range from 45 to 147. Groundwater pollution classifications are divided into five categories: very low, low, medium, high, and very high susceptibility (Fig. 4). The modified drastic index values range from 48 to 160, and they are all classed as susceptibility level 1. The area and class intervals of severe and modified drastic index values are shown in Table 3.

Table 3
Drastic index and modified drastic index areas vulnerable to groundwater contamination

S.No	Degree of Vulnerability	Drastic Index range	Area Covered in Sq.km (DI)	Modified Drastic Index range	Area Covered in Sq.km (DL)
1	Very Low Vulnerability	45–100	840.26	48–100	965.35
2	Low Vulnerability	100–110	732.58	100–110	880.14
3	Medium Vulnerability	110–120	583.46	110–120	399.21
4	High Vulnerability	120–140	183.17	120–140	158.29
5	Very High Vulnerability	140–147	167.13	140–160	103.54

In both the extreme and modified drastic indexes, the regions of Alanthurai, Thodamuthur, Pichanur, and Pollachi have high and very high groundwater vulnerability. Similarly, in the areas of Aliyar, Anaimalai, Gurwaypatti, Sultanpet, and Koniyamuthur, the low and extremely low severe and modified drastic index values are shown. Because the hydraulic conductivity range is higher, the groundwater penetration rate is also higher, resulting in high and extremely high groundwater vulnerability in that location. Furthermore, due to the shallowness of the aquifer, agricultural contaminants readily combine with recharge water, causing further damage to the groundwater. When comparing the drastic and modified drastic indexes, it is clear that the modified one provides more precise regions of groundwater sensitive zones.

Conclusion

The major purpose of this study is to determine the groundwater contamination susceptibility in the Coimbatore district. The Drastic model was used in the evaluation since it is the most widely used and has a simple methodology. While the typical DRASTIC model performs admirably on a broader scale in terms of inherent vulnerability, it quickly reveals that it fails to provide a true and realistic evaluation of groundwater pollution on a smaller and more granular scale. As a result, the generic model was revised to include a lineament density parameter in addition to the seven that it already included. The final modified DRASTIC model (DI + DL) yielded vulnerability index values ranging from 48 to 160. The part of Coimbatore district is classified into five vulnerability levels based on the index standards and maps created by both models (very high, high, medium, low, and very low). The modified drastic index covered an area of 965.35, 880.14, 399.21, 158.29 and 103.54 km2 respectively. The areas namely Alanthurai, Thodamuthur, Pichanur and Pollachi was fall under high and very high vulnerable zone in drastic and modified drastic model. As a result, drinking groundwater continuously in this extremely high and high area might have a negative impact on human health. As a result, protecting a location against pollution is both a crucial and challenging task. To reduce this pollution, technical land use practises, as well as effective watershed management, are necessary.

Declarations

Ethical approval: Not applicable

Consent to participate: Not applicable

Consent for publication: Not applicable

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Conflict of Interest: The authors declare no conflict of interests.

Availability of data and materials: All data generated or analysed during this study are included in this published article.

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Figures

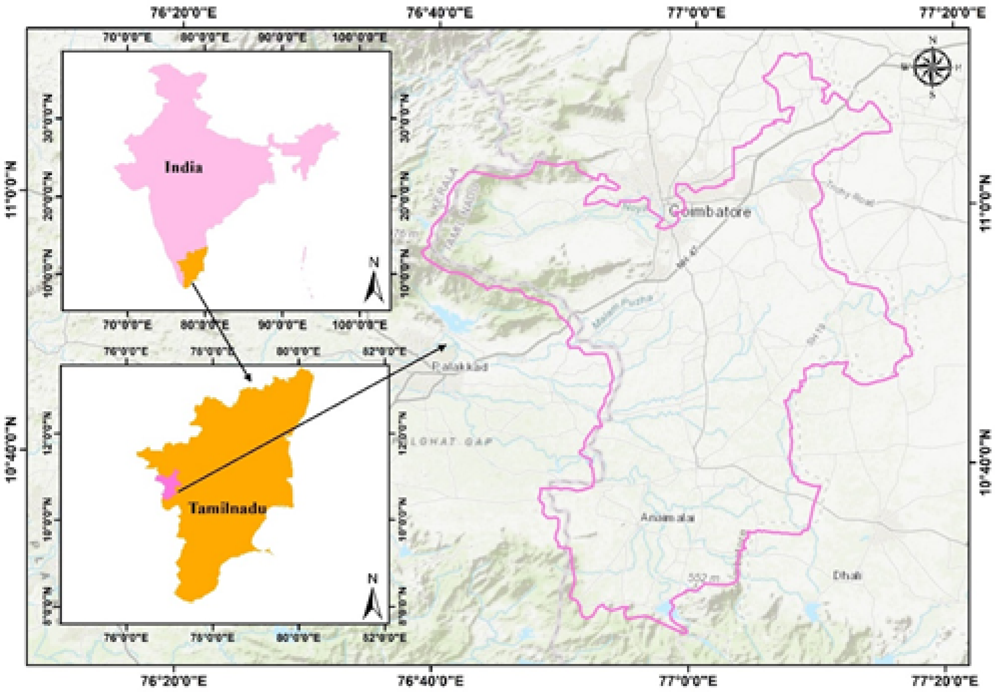

Figure 1

Study area location map

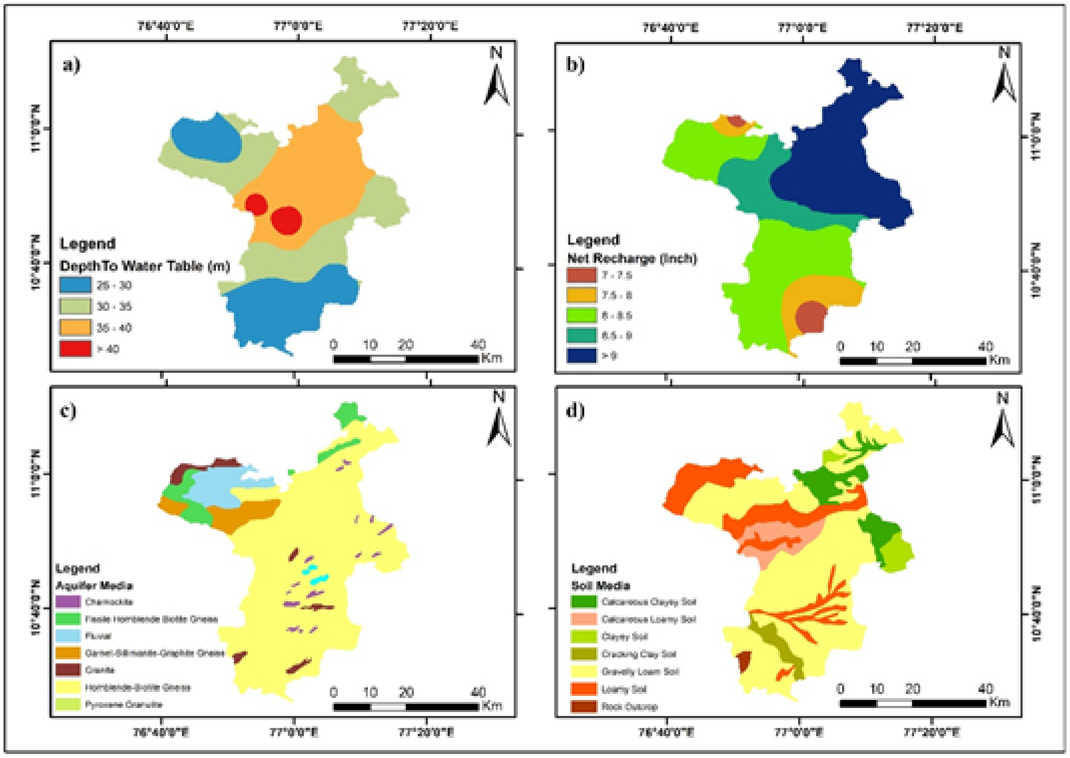

Figure 2

a) Depth to water table, b) Net recharge, c) Aquifer media, d) Soil media

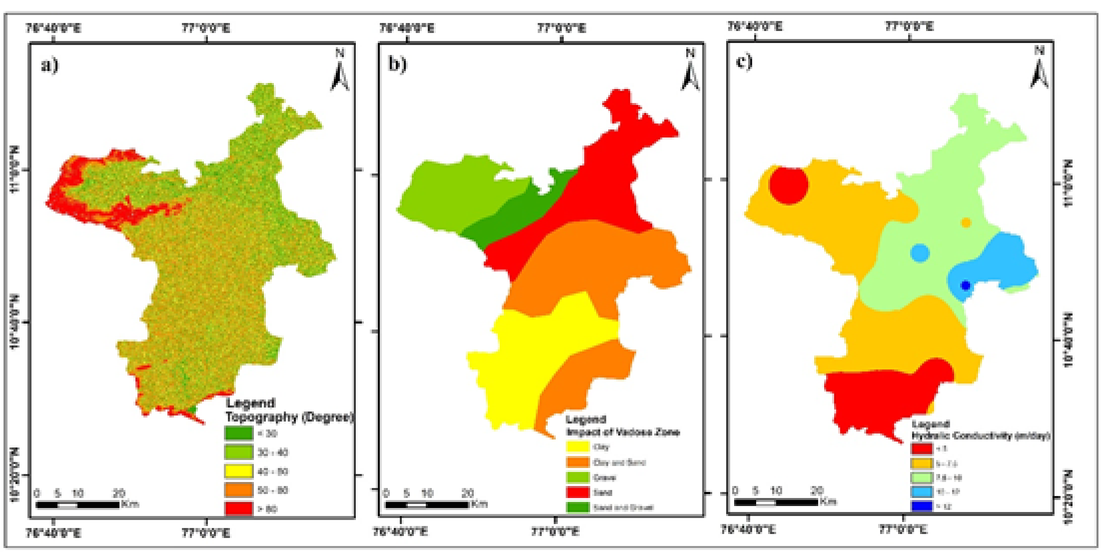

Figure 3

a) Topography, b) Impact of vadose zone, c) Hydraulic Conductivity

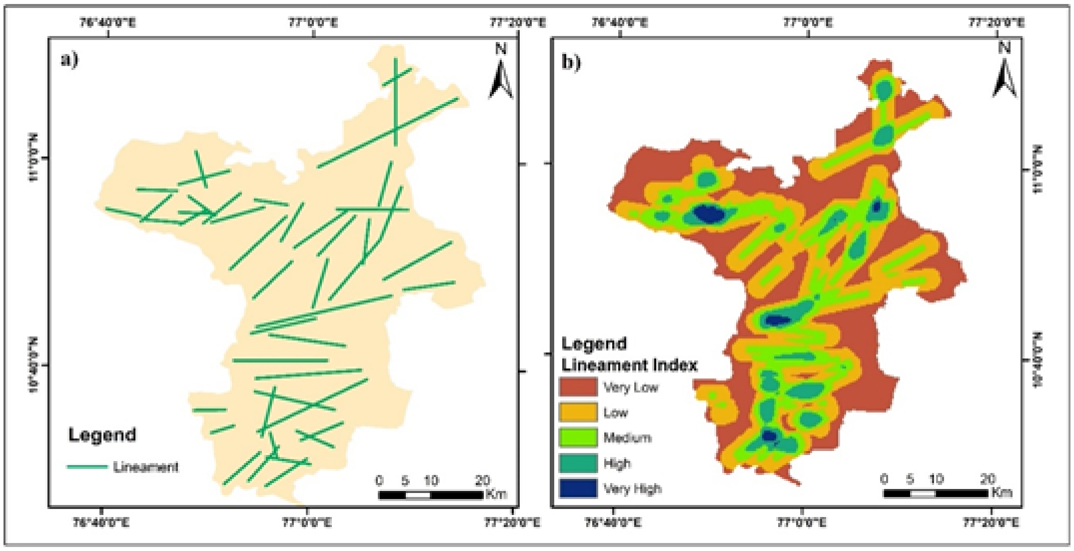

Figure 4

a) Lineament map, b) Lineament density index map

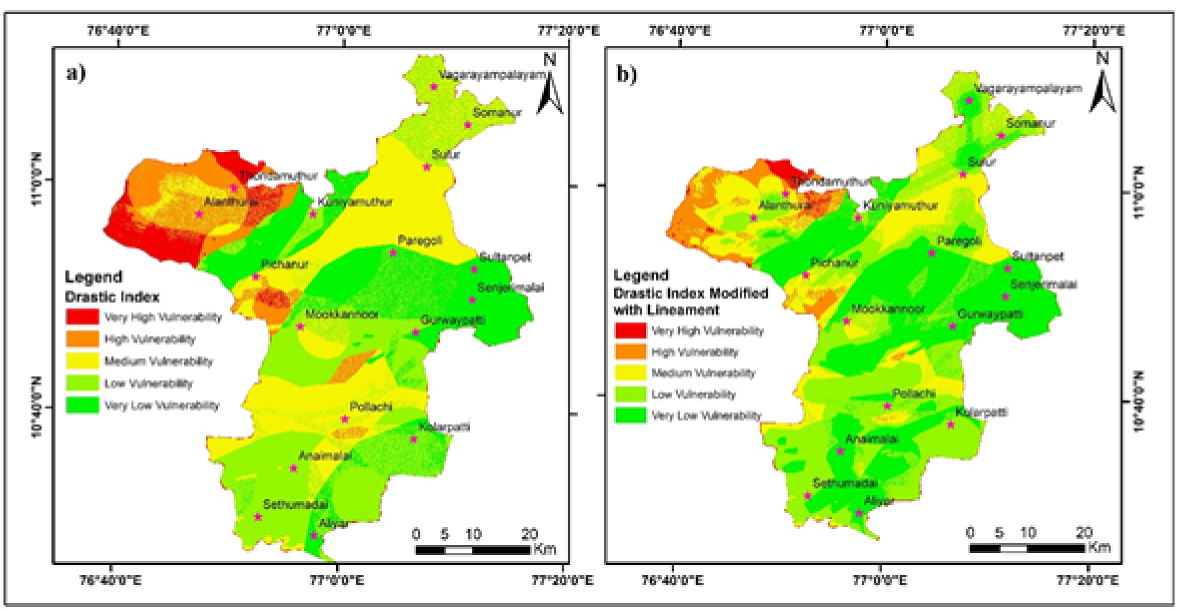

Figure 5

a) Drastic index, b) Modified Drastic index