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Geospatial Technology for Agricultural Land Site Suitability Assessment in Upper Vellar River Basin, South India

Tecnologia Geoespacial para Avaliação da Adequação de Terrenos Agrícolas na Bacia do Rio Vellar Superior, Sul da Índia

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Abstract

Agriculture is one of the oldest and prime activities of the human being. It has remained an important source of food. In spite of growing industrialization and urbanization in the world, nearly fifty per cent working population still engaged in agriculture. To make an in depth and comprehensive study, the main objectives present research is to analyze the changes in agricultural land use in the study region, to demarcate and to analyze the agricultural cropping land suitability and methods of cultivation, and to suggest remedial measures for the better agricultural planning and development of Upper Vellar River basin, Tamil Nadu, India using geospatial technology. Depending on their significance and importance in the agriculture seven different constraints and criteria were selected. The identification of different criteria depended on maximum limitation method that influences the product yield of agriculture which includes topographic wetness index (TWI), land use and land cover (LULC), soil, drainage density, slope, aspect and geology. The derived land suitability zones were classified into five classes i.e., not suitable, poor suitable, moderately suitable, highly suitable, and very high suitable zones. The not suitable zone cover 35 sq.km (1%) found in Belur, and Valapadi, poorly suitable zone covers 688 sq. km (8%) found in near Tammpampatti, Moderately suitable zone covers 976 sq.km (36%) found in northern part of study area, southern parts of the study area, highly suitable zone covers 1092 sq.km (43%) found in northern and central part of the study area and Very high suitable zone covers 152 sq.km (17%) found in Central and southern part of the total study area. Paddy crop is useful for developing in the highly suitable zone. The oilseed is the better decision to develop in the moderately suitable zone of the study area. In the low suitable region of study area, it is preferable to grow wheat. Examining the agricultural management plan of the study area shows that only 17% of the area is currently used for agricultural activities. Highly suitable lands for agriculture are the most suitable lands for agricultural production. These lands have the highest potential for agricultural production.

Keywords: Remote Sensing; GIS; Land capability factors

Resumo

A agricultura é uma das atividades mais antigas e primordiais do ser humano. Ela continua sendo uma importante fonte de alimento. Apesar da crescente industrialização e urbanização no mundo, quase cinquenta por cento da população ativa ainda se dedica à agricultura. Para realizar um estudo aprofundado e abrangente, os principais objetivos da presente pesquisa são analisar as mudanças no uso da terra agrícola na região de estudo, demarcar e analisar a adequação da terra para cultivo agrícola e os métodos de cultivo, e sugerir medidas corretivas para um melhor planejamento e desenvolvimento agrícola da bacia do Alto Rio Vellar, Tamil Nadu, Índia, usando tecnologia geoespacial. Dependendo de sua significância e importância na agricultura, sete diferentes restrições e critérios foram selecionados. A identificação dos diferentes critérios dependeu do método de limitação máxima que influencia o rendimento do produto agrícola, que inclui o índice de umidade topográfica (TWI), uso e cobertura da terra (LULC), solo, densidade de drenagem, declive, aspecto e geologia. As zonas de adequação da terra derivadas foram classificadas em cinco classes, ou seja, zonas não adequadas, pouco adequadas, moderadamente adequadas, altamente adequadas e muito altamente adequadas. A zona não adequada cobre 35 km² (1%) encontrados em Belur e Valapadi, a zona pouco adequada cobre 688 km² (8%) encontrados perto de Tammpampatti, a zona moderadamente adequada cobre 976 km² (36%) encontrados na parte norte da área de estudo, partes do sul da área de estudo, a zona altamente adequada cobre 1092 km² (43%) encontrados na parte norte e central da área de estudo e a zona muito altamente adequada cobre 152 km² (17%) encontrados na parte central e sul da área total de estudo. A cultura do arroz é útil para o desenvolvimento na zona altamente adequada. A oleaginosa é a melhor decisão para se desenvolver na zona moderadamente adequada da área de estudo. Na região pouco adequada da área de estudo, é preferível cultivar trigo. O exame do plano de gestão agrícola da área de estudo mostra que apenas 17% da área é atualmente usada para atividades agrícolas. Terras altamente adequadas para a agricultura são as terras mais adequadas para a produção agrícola. Essas terras têm o maior potencial para a produção agrícola.

Palavras-chave: Sensoriamento Remoto; SIG; Fatores de capacidade do solo

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1 Introduction

Site suitability assessment for agricultural development includes a large amount and variety of physiographic data, climatic characteristics (rainfall and temperature), internal soil condition (depth, moisture, texture, salinity and natural fertility), and external soil conditions (slope, accessibility and flooding) (Wang 1994). Perveen et al. (2007) used the parameters of soil texture, soil moisture, soil consistency, soil pH, soil drainage, organic matter content and slope in agricultural land suitability analysis. The use of the AHP method for determination of land suitability has gained popularity recently. There are different studies discussing the uses of Analytical Hierarchy Process (AHP) in the literature. Among them, there are studies on the land use suitability for different crops (Mustafa et al. 2011). The World Commission on Environment and Development associated land suitability with sustainable development and defined sustainable development as meeting the needs of the present without compromising the ability of future generations to meet their own needs (Feizizadeh & Blaschke 2012).

Akinci et al. (2013) studied the agricultural land use suitability analysis using GIS and AHP technique in the Yusufeli district of Artvin city (Turkey). The parameters of great soil group, land use capability class, land use capability sub-class, soil depth, slope, aspect, elevation, erosion degree and other soil properties were used. In determining the weights of the parameters, experts' opinions were consulted, and the agricultural land suitability map generated was divided into 5 categories according to the land suitability classification of the United Nations Food and Agriculture Organization (FAO 1977). The development of agriculture will not only improve the rural economy but also promote the diversification of poor farmers and rural tourism that can prevent the migration activity of poor people from hilly areas to the plain lands (Boori et al. 2014). Pramanik (2016) have analyzed site suitability for agricultural land use of Darjeeling district using AHP and GIS techniques. Bera et al. (2017) discussed the land suitability analysis for agricultural crop using remote sensing and GIS in Purulia District.

According to projections by Population Reference Bureau (PRB), the world population will reach 9.9 billion by 2050, up 2.3 billion or 29 percent from an estimated 7.6 billion people now (PRB 2018). With the increase in population, people have started to use lands more and more for their basic needs. So, agricultural, pasture and forest lands are constantly degraded. For this reason, land use types are being changed due to misuse of land. Everest et al. (2021) determined the agricultural land suitability with a multiple criteria decision-making method in Northwestern Turkey. Choudhary et al. (2023) has been discussed the Agricultural land suitability assessment for sustainable development using remote sensing techniques with analytic hierarchy process. Morán-Alonso et al. (2025) studied the urban planning; a methodology is proposed and applied to the Madrid region to analyse the suitability of agricultural land uses with respect to agrological quality. The identification of suitable lands which is having the highest productivity as well as highest net profit on lesser input is expected and prioritized in the plain areas. So, the suitability analysis of agricultural land is an appropriate and strong method for the plain areas. The main objectives of the study are to identify the suitable lands for the agricultural development using GIS and weighted overlay process in the study area.

2 Study Area

The Upper Vellar river basin is one of the seventeen major river basins of Tamil Nadu. The Vellar river originates in the Chitteri hills of Dharmapuri district in the name of Anaimaduvu river and Thumbal river and Singipuram aru originates at Jallattu reserve forest area at 8 km east of Salem taluk in Salem district and flows through Villupuram, Cuddalore, Namakkal, Trichy and Perambalur district and finally confluences with the Bay of Bengal. It falls in the Survey of India sheets 58 I and 58 M. The Vellar basin is situated between the co-ordinates of N latitude 11°13' - 12°00' and E longitudes 78° 13' -79° 47' (Figure 1). The Vellar basin is bounded by Ponnaiyar and Paravanar basins in the north, Cauvery basin in the west and south and the Bay of Bengal in the east.

3 Methodology

In the present study, multi-criterion site suitability modeling was developed to establish appropriate and potential locations for agricultural development based on a group of constraints and criteria. Depending on their significance and importance in the agriculture seven different constraints and criteria were selected. The identification of different criteria depended on maximum limitation method that influences the product yield of agriculture which includes topographic wetness index (TWI), land use and land cover (LULC), soil, drainage density, slope, aspect and geology. The IRS P6 and LISS III satellite data was utilized to generate land use land cover. Geology map interpreted using GSI report, soil order map was developed using soil survey information. Topographic parameters were examined in three categories. These are slope, elevation and aspect. Slope and aspect were derived from the SRTM DEM data with 90 m spatial resolution. The methodology adopted in the present study is shown in Figure 2.

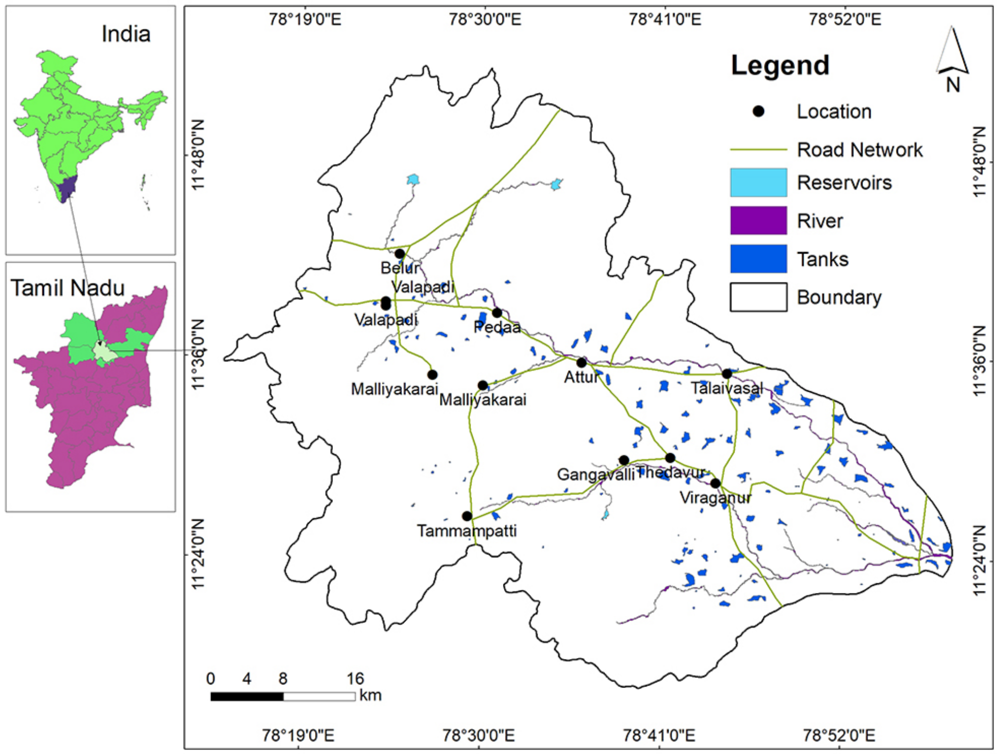

Figure 1 Location of the Upper Vellar sub-basin.

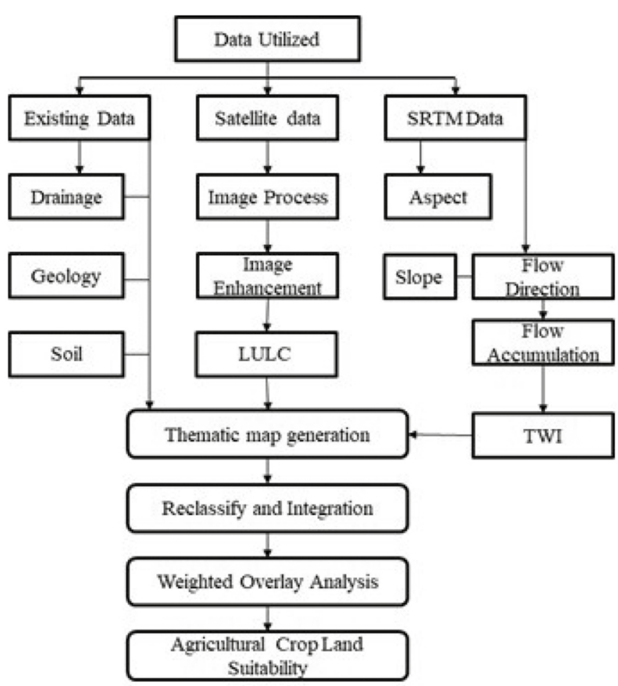

Figure 2 Site Suitability Analysis Method.

3.1 Calculation of Weighted Value

The weighted values computed with the help of multi influence factor (MIF) method, with assigning the distinctive parameters, topographic wetness index (TWI), land use and land cover (LULC), soil, drainage density, slope, aspect and geology (Figure 3). The impact of each major and minor factor is assigned weightage values of 1.0 and 0.5 as shown in (Table 1). The combined weighted of both major and minor impacts are considered for calculate the relative rates. This rate is additionally used to calculate the value of each impacting factor. The proposed score for each influencing variable is calculated by utilizing the Equation 1:

$$Wt = \frac{(A+B)}{\sum(A+B)}\ x\ 100 \qquad (1)$$

Where, A is the major interrelationship between two elements and B is the minor interrelationship between two variables. The concerned score for each affecting component was partitioned similarly and allocated to each reclassified factor.

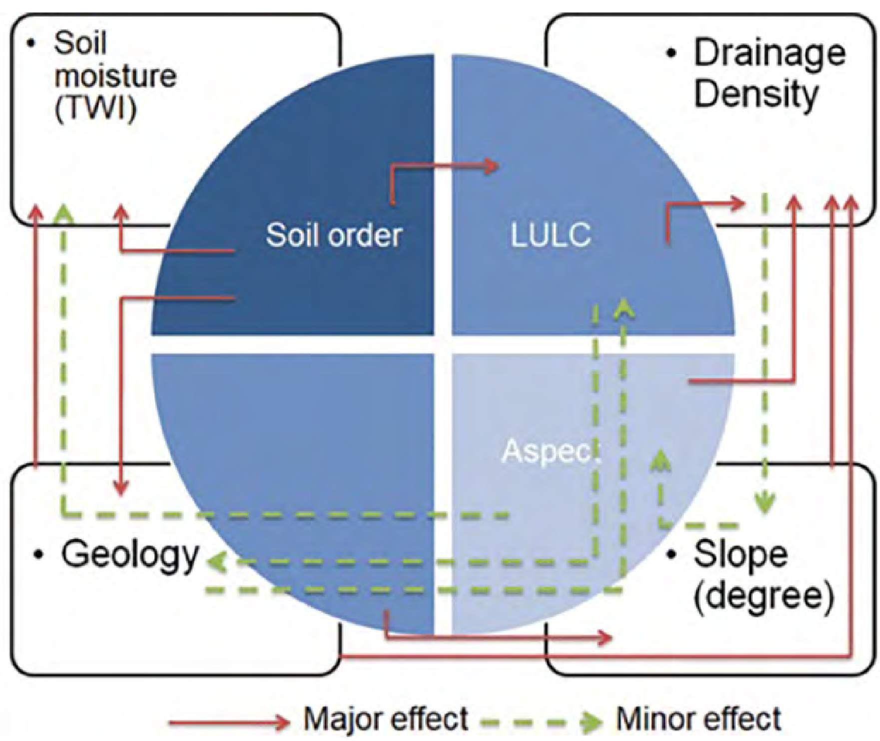

Figure 3 Interrelationship between the multi-influencing factors concerning the land capability.

Table 1 Effect of influencing factor, relative rates and score for each potential factor.

S.No	Factor	Major effect (a)	Minor effect (b)	Proposed relative rates (a + b)	Proposed score of each influencing factor
1	Topographic wetness index (TWI)	2	0	2	13
2	Land use and Land cover (LULC)	2	1.5	3.5	22
3	Soil Order (SO)	4	0	4	25
4	Drainage Density (DD)	1	0.5	1.5	9
5	Slope (Degree) (SL)	2	0.5	2.5	16
6	Aspect (AS)	1	0.5	1.5	9
7	Geology	0.5	0.5	1	6
		Total		16	100

3.2 Factors Influencing Land Capability

3.2.1. Topographic Wetness Index (TWI)

Topographic Wetness Index (TWI) has been widely used to explain the impact of topography conditions on the location and size of saturated source zones of surface runoff generation. Recently, TWI has been used for groundwater potential mapping (Moghaddam et al. 2013; Nampak et al. 2014) and describing spatial wetness patterns (Pourghasemi et al. 2012; Pourtaghi & Pourghasemi 2014). It is defined by Equation 2 (Moore et al. 1991):

$$TWI = Ln\left(\frac{A_s}{tan\beta}\right) \quad (2)$$

Where, A_S is the cumulative upslope area draining through a point (per unit contour length) and β is the slope gradient (in degree).

In this study, TWI map is grouped into four classes using quantile classification scheme (Tehrany et al. 2014) (Figure 4). The tendency of water to accumulate at any point in the catchment (in terms of α) and the tendency of gravitational forces to move that water down slope (indicated in terms of tan b as an approximate hydraulic gradient) are considered by the ln β tanα index. High TWI values indicate areas likely to be wetter due to large contributing areas and low slopes, while low TWI values suggest drier areas with small contributing areas and steeper slopes. Negative TWI values are unusual and might indicate errors in the Digital Elevation Model (DEM) or flow direction calculations. Primarily, the water infiltration depends upon material properties such as permeability and pours water pressure on the soil strength.

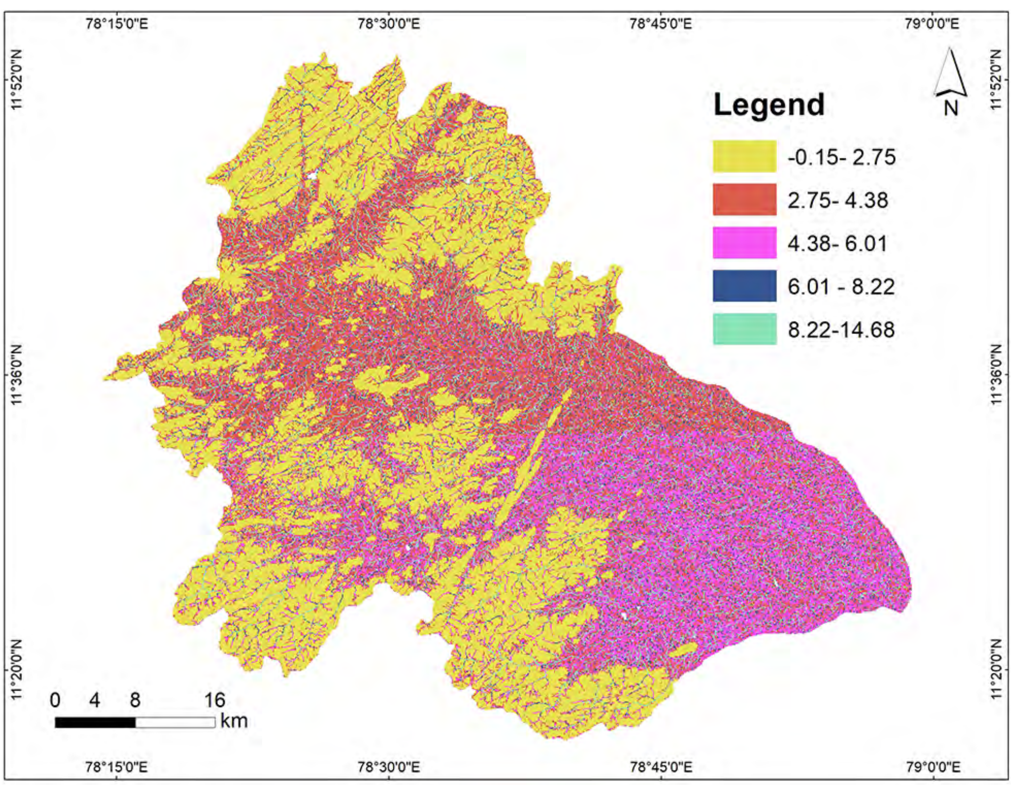

Figure 4 Topographic Wetness Index (TWI) of the study area.

3.2.2. Land Use / Land Cover (LULC)

Land use Land cover pattern of the study area provides the information about the spatial distribution of agricultural and fallow lands, land availability and agricultural production suitability. In other words, land use capability classification allows easier comprehension of a land survey. The study area has been classified into 5 categories (Figure 5). Among which, agricultural land possesses major portion of the study area followed by fallow land and Built-up lands.

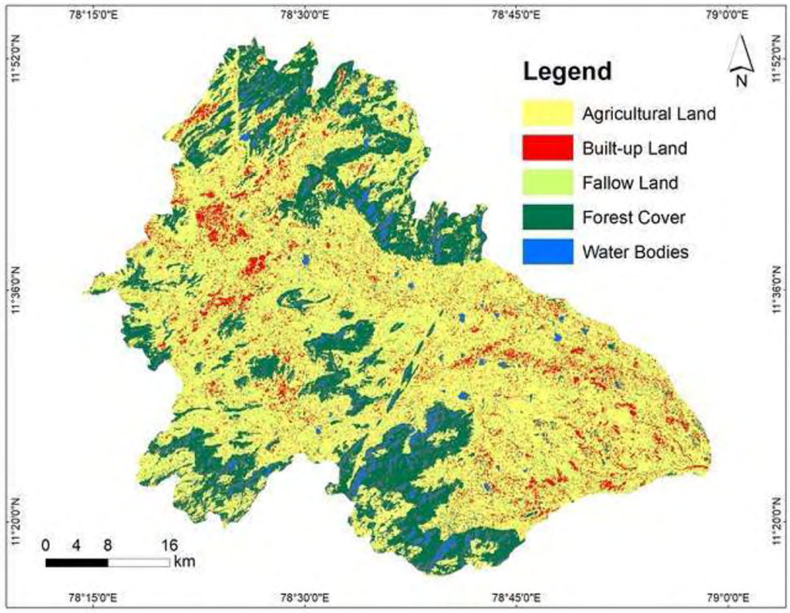

Figure 5 Land use and land cover pattern of the study area.

3.2.3. Soil

Major soil types categorised in the study area are alfisols, vertisols, entisols, inceptisol, reserved forest and swamp (Figure 6). The alfisols is most suitable type for the agricultural activity and the crop cultivated are rice, maize etc. become suitable for flooded and rainy condition.

3.2.4. Drainage Density

Drainage density map is developed from the drainage map using density analysis module in ArcGIS 10.2 software. Further, drainage density map was classified into five groups from very low to very high density (Figure 7). Up to 1 km from the river is extremely positive for growing crops in view of the presence of irrigational water.

3.2.5. Slope and Aspect

Slope degree has a direct effect on soil depth, susceptibility to erosion, soil tillage, use of agricultural machines, irrigation, plant adaptation, etc. The 0-4.05 degree of the slope demonstrates the flat zone which is reasonable land for developing agriculture. 4.05-10.32 degree of the slope has some Steepness and is respectably reasonable for growing crop. 24.76-50.83-degree range of slope is the higher slope where upon it is not appropriate to develop growing crop because of surface run off of the rainfall water (Figure 8). Slope degree is the main factor determining erosion control (Koulouri & Giourga 2007). The number of materials carried away with erosion increases with the increasing degree of slope. Accordingly, with an increase in slope degree, the development of soils occurs slowly (Atalay 2006), and soil depth and fertility decrease. The aspect map shows in Figure 9.

3.2.6. Geology

The district is covered mostly by sedimentary and alluvial deposits. The minor rock of widespread occurrence in the district is granites and granitic. The geology map of study area is shown in Figure 10.

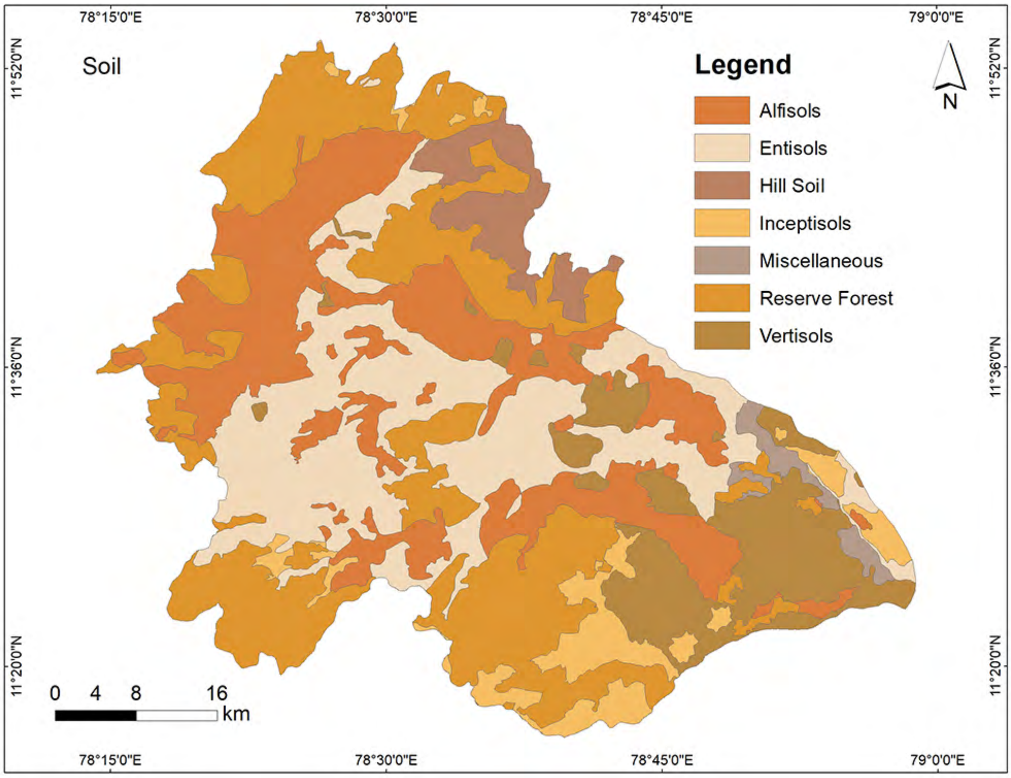

Figure 6 Soil order in the study area.

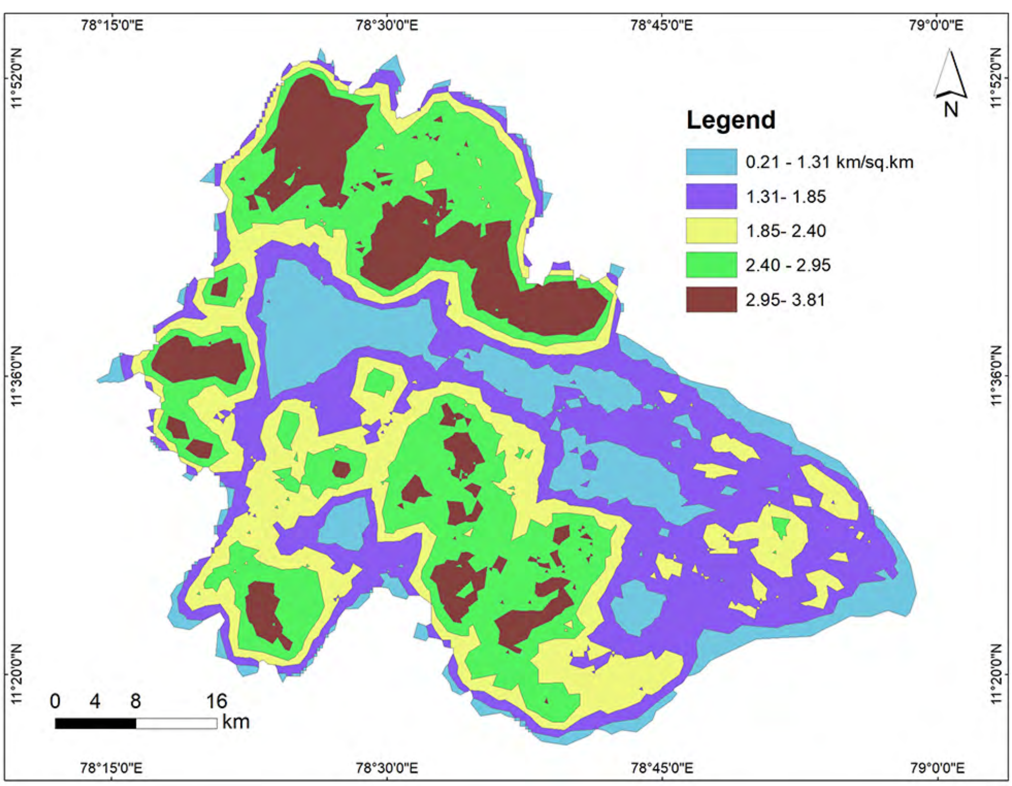

Figure 7 Drainage density of the study area.

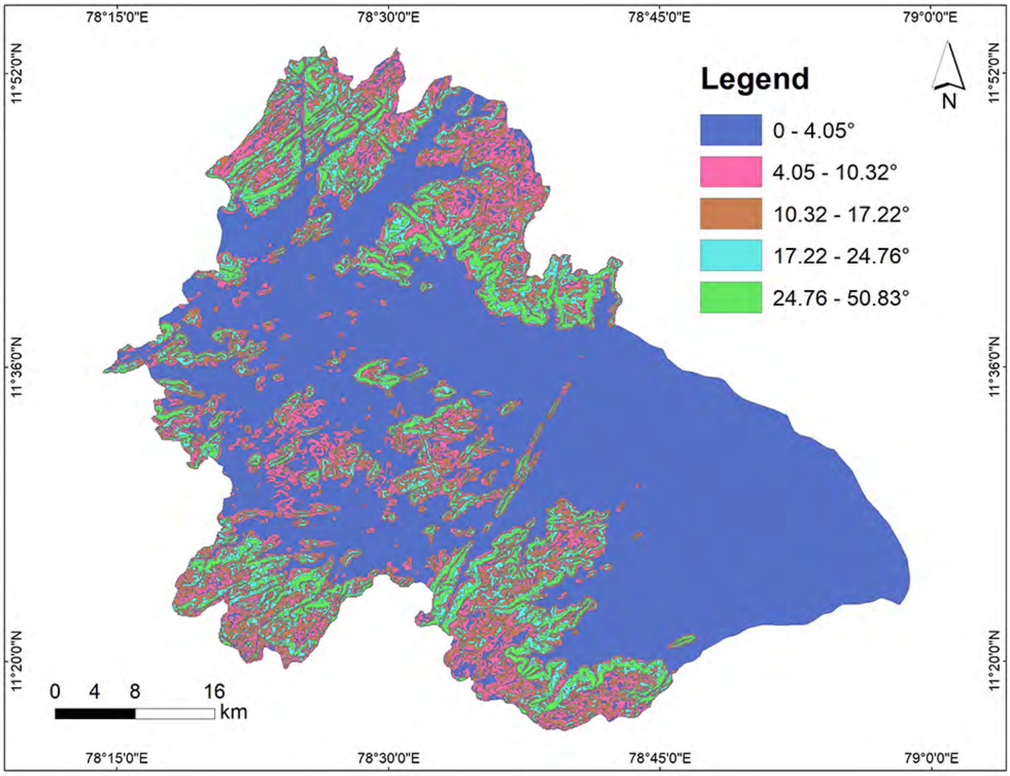

Figure 8 Slope (degree) in the study area.

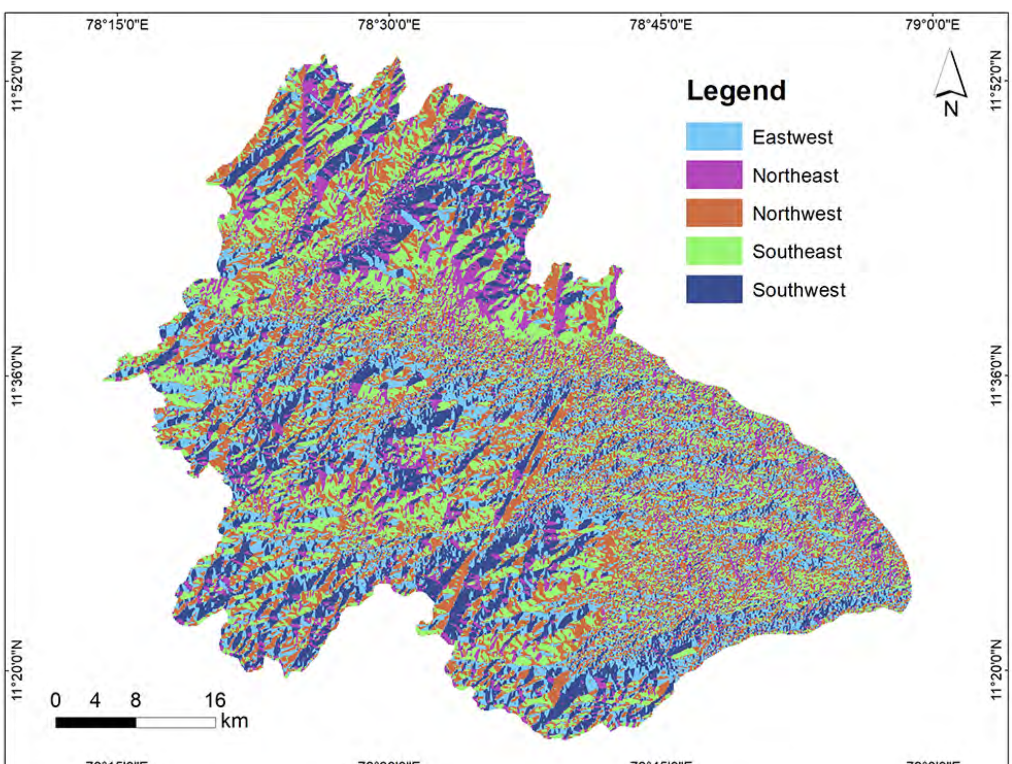

Figure 9 Aspect map of study area.

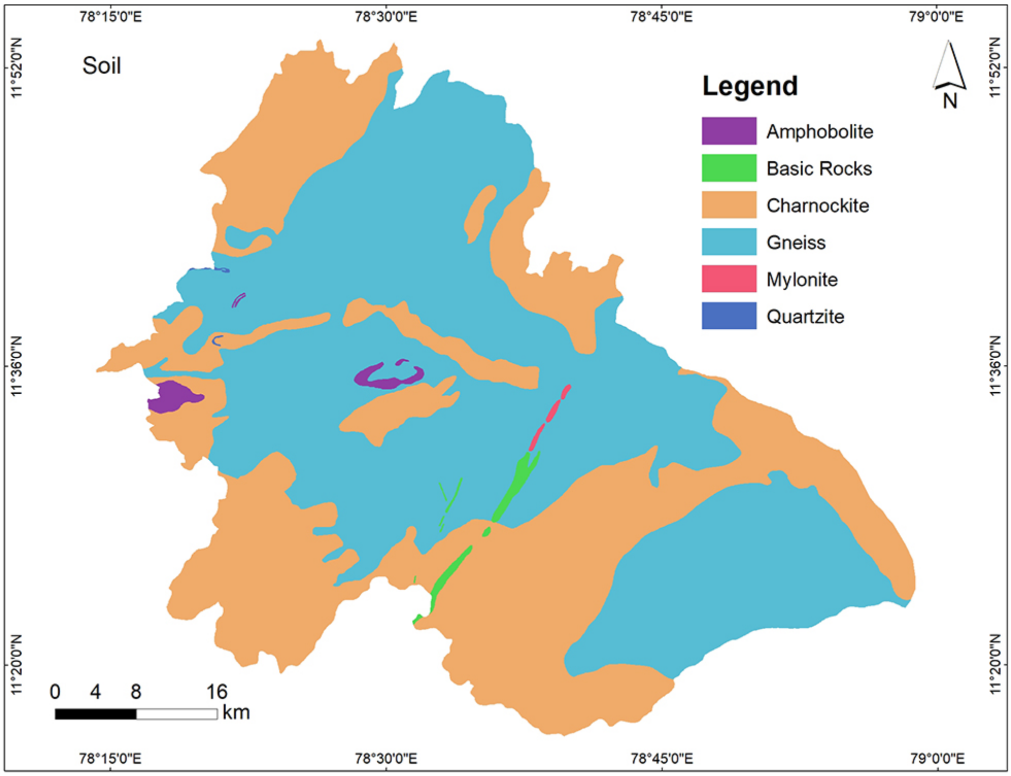

Figure 10 Geological features of the study area.

3.3 Agricultural Land Suitability Assessment

Weighted overlay analysis was used to calculate the agricultural land suitability. A model was created using the model builder tool on ArcGIS to perform overlay analysis. The vector maps and resulting scores were imported into the model. By overlying the suitability and weighted values of the criteria in GIS, the suitability values for crop cultivation were calculated. The following Equation 3 has been used to calculate the Agricultural land suitability analysis.

$$S = \sum_{i=1}^{n} (Wi.Xi) \qquad (3)$$

In this formulation,

- S is total land suitability score;
- Wi is the weighted value of the land suitability criteria; for the sub-criteria score of Xi
- 'i' is land suitability criteria; and
- n is the total number of land suitability criteria.

The final land suitability map was created by means of weighted overlay analysis. The resulting map was reclassified for FAO (1977) based on the suitability analyses. The final suitability map was classified into five classes. In this classification, S1 indicates land which is highly suitable for agriculture with no limiting factors, S2 indicates land which is moderately suitable for agriculture with some limiting factors, S3 indicates land which is marginally suitable for agriculture with severe limiting factors, and N indicates land which is not suitable for agriculture. The agricultural crop land suitability delineates utilizing weighted overlay analysis in the wake of allocating weighted an incentive through MIF technique (Table 2).

4 Results and Discussion

The derived land suitability zones were classified into five classes i.e., not suitable (cyan colour), poor suitable (light green colour), moderately suitable (blue colour), highly suitable (brown colour), and very high suitable (yellow colour) zones (Figure 11). The Not suitable zone cover 35 sq.km (1%) found in Belur, and Valapadi, poorly suitable zone covers 688 sq. km (8%) found in near Tammpampatti, Moderately suitable zone covers 976 sq.km (36%) found in northern part of study area, southern parts of study area, Highly suitable zone covers 1092 sq.km (43%) found in northern and central part of the study area and Very high suitable zone covers 152 sq.km (17%) found in Central and southern part of the total study area (Table 3). Paddy crop is useful for developing in the highly suitable zone. The oilseed is the better decision to develop in the moderately suitable zone of the study area. In the low suitable region of study area, it is preferable to grow wheat.

Table 2 Effect of land influencing Factor, Relative Rates and Score for each factor.

Sl. No.	Theme	Sub-class	Rank	Weight	Score
1	Topographic Wetness Index (TWI)	Very high (8.22-14.68) High (6.01 - 8.22) Moderate (4.38- 6.01) Low (2.75- 4.38) Very Low (-0.15- 2.75)	5 4 3 2 1	13	52 39 26 13
2	Land use and Land cover (LULC)	Agricultural Land Built-up Land Fallow Land Forest Cover Water Bodies	5 1 4 3 4	22	110 22 88 66 88
3	Soil Order (SO)	Alfisols Entisols Inceptisols Reserve Forest Hill Soil Vertisols Miscellaneous	5 4 3 1 1 2 3	25	125 100 75 25 25 50 75
4	Drainage Density (DD) (km/sq.km)	Very low (0.21 - 1.31) Low (1.31- 1.85) Moderate (1.85- 2.40) High (2.40 - 2.95) Very high (2.95- 3.81)	1 2 3 4 5	9	9 18 27 32 45
5	Slope (Degree) (SL)	0 - 4.05° 4.05 - 10.32° 10.32 - 17.22° 17.22 - 24.76° 24.76 - 50.83°	5 4 3 2 1	16	80 64 48 32 16
6	Aspect (AS)	Eastwest Northeast Northwest Southeast Southwest	1 3 1 4 3	9	9 27 9 32 27
7	Geology (GL)	Gneiss Basic Rocks Charnockite Amphobolite Quartzite Mylonite	2 3 4 2 1 5	6	12 18 24 12 6 30

In addition, the extent to which the present agricultural lands correspond with the suitability map and how they will be affected by the drainages were determined in this study. Examining the agricultural management plan of the study area shows that only 17% of the area is currently used for agricultural activities. Highly suitable lands for agriculture are the most suitable lands for agricultural production. These lands have the highest potential for agricultural production. Urbanization is the major problem with these lands. Many researchers pointed out those agricultural areas are destroyed due to urbanization (Ricketts & Imhoff 2003; Ravallion et al. 2007; Everest 2017).

5 Conclusions

The detailed geographical analysis was carried out using Remote sensing and GIS technology and the result reveals that the study area falls under very high crop suitability class, so it is necessary to improve the soil quality parameters to sustainable agricultural practices in the study area. Organic farming has improved the soil quality to withstand drought. With light showers in the midst, the water was enough to grow traditional. Drought-resistant and salt-resistant crop kaivara samba rice. The very high and high suitability of agricultural field about 42% are favorable for agricultural if irrigation facilities are available and most suitable for agriculture area. Water bodies available in the study area is the source of water for cattle and crucial for paddy farming. The remote sensing and GIS were successfully utilized in this research. The methodology and output may be useful to the agricultural planners in this area.

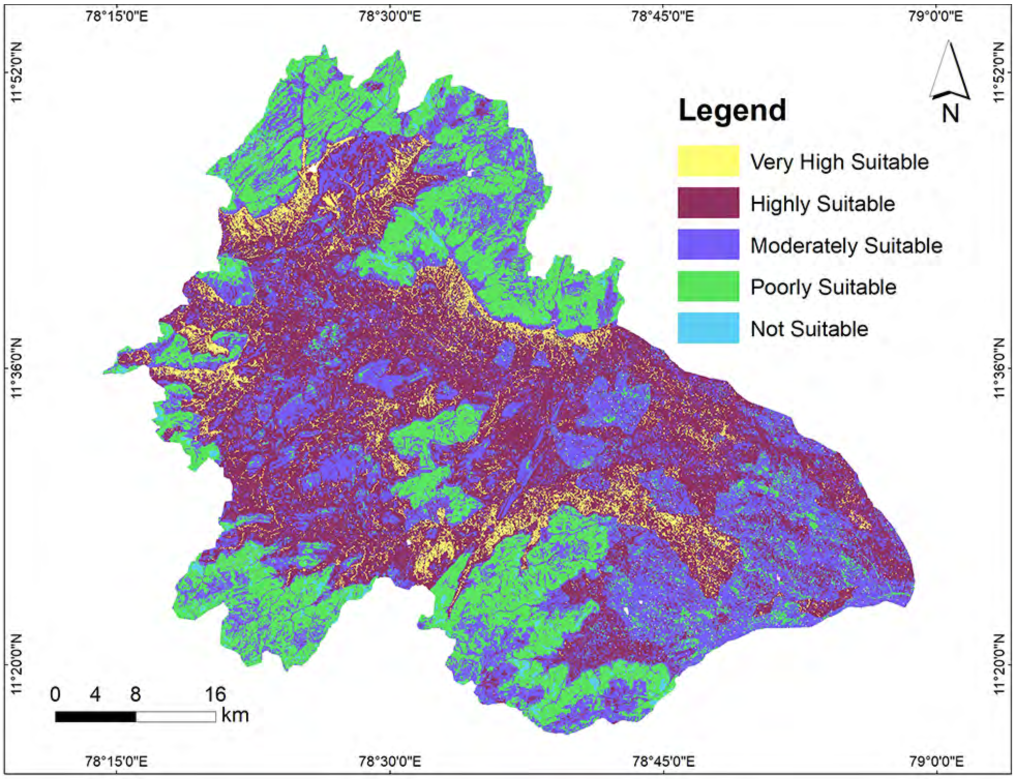

Figure 11 Agricultural Crop Land Suitability.

Table 3 Land suitability level and their land characteristics

Sl. No.	Suitability class	Area (Sq.km)	Area in %	Land qualities/ characteristics	Remarks
1	Not suitable (N1)	35	1	Flat slope, with reserved forest, barren land no drainage availability	The land is not suitable for agriculture, areas under dense vegetation, barren rocks, open rocks are not suitable for agriculture
2	Poorly suitable (N2)	688	24	Less slope, less soil moisture with low elevation entisols low drainage density	Less suitable land for agriculture with careful farm management, necessary protection from drainage and intensive erosion
3	Moderately suitable (S3)	976	33	Gentle to stiff slopes, with micro terracing, medium soil moisture with lower elevation, vertisols, moderate drainage capacity	Suitable for agriculture, favorable area for agriculture if irrigation facilities are available
4	Highly suitable (S2)	1052	36	Gentle to steep slopes with gullies, high soil moisture with lower elevation, entisol soil good drainage capacity	Favorable for agriculture if irrigation facilities are available
5	Very high suitable (S1)	152	6	Gentle slopes with gullies, high soil moisture with lower elevation, alfisol soil good drainage capacity	Most suitable for agriculture, favorable area for intensive agriculture if irrigation facilities are available
Total		2902	100		

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Author contributions

Jothibasu Arumugam: conceptualization; formal analysis; methodology; validation; writing-original draft; writing – review and editing; visualization. **Prabakaran Ganesan**: methodology; validation; supervision.

Conflict of interest

The authors declare no conflict of interest.

Data availability statement

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