Evaluating Land Suitability for Rice Cultivation in West Tripura Using Multicriteria Decision Analysis and Geospatial Techniques

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Abstract: ***Sustainable and smart agricultural development requires adjustment between land potentiality and ideal crop yield. If these two conditions are matched adequately then crop production increasing significantly. The study assesses the suitability of land for rice cultivation in West Tripura, India using Multi-Criteria Decision Analysis (MCDA) and Geospatial Techniques. It examines various factors like topography, drainage, soil texture, climate, and land use to determine the most suitable areas for rice farming. Rice is the primary staple crop of the West Tripura district. It is cultivated in both seasons that kharif and rabi. The rice production is high in plain land when compared to hilly areas. During 2019-20, the farmers cultivated rice 26931 hectares and production was 88396 metric tons. At that time, the average rice yield was 3282 kg/ha. The findings indicate that 35.18% of the land is effectively suitable for rice cultivation, and the remaining land with minimum effort can be suitable for rice cultivation in marginal land.***

Keywords: Geospatial techniques, Land suitability, Multicriterial Decision analysis, Rice cultivation, West Tripura

1. Introduction

The worlds growing population exerts immense pressure on agricultural land to mitigate the demands of food. The unplanned cultivation of fertile land deteriorates the quality and its impact on productivity of crops. It may lead to food deficit and raise food security problems. Thus, sustainable agricultural land management is urgently required to maintain stable productivity [1]. Implementation of sustainable agriculture practices through smart land use planning solves food problems and enhances developmental processes in the region [2]. In India, agriculture contributes 16% of GDP, and 58% of the people depend on the agriculture sector for their livelihood [3]. The productivity in agriculture would remain intact through the proper utilization of land [4]. Thus, evaluating land capability and crop suitability is important to identify the potential land for agricultural practices [5]. Land capability gives an idea about land productivity, whereas land suitability gives an understanding of environment and suitability of crops [6],[7]. The main goal is to find suitable land for cultivation and increase productivity to solve food problems [8]. Land suitability can be evaluated by soil characteristics, morphology, drainage, and lithology [9],[10]. Based on these relevant parameters with application of multi-criteria technique the evaluate the suitable land for cultivation of crops [11]. The entire concept depends on the quality of land, the essential crop environment, and the landscape characteristics [12]. If these three conditions are met, the land highly suitable for crop cultivation and high production. Assessing land suitability is an effort to make balance between demand of crops and production [13]. In west Tripura, farmers are practiced two separate agricultural techniques that intensive rice cultivation in plain land and slash-and-burn cultivation in hilly areas also known as shifting cultivation. Recently, remote sensing data has been very significant for determining optimal land utilization [14]. Only fusion is needed between remotely sensed data and observed field data through GIS [15],[16]. Thus, GIS has been frequently utilized to assess the suitability of land, capability of land and productivity of agricultural land [17],[18]. In the study area, the population growth rate was higher (12.5%) compared decade wise population data. The urban population increased from 15% to 42% from 1981 and 2011 since the state capital city of Agartala situated in the West Tripura district. The amount of potential land steadily declined under the urbanisation process and urban sprawl. Therefore, the paper aims to assess land suitability for rice cultivation in the west Tripura district using MCDA and geospatial techniques.

2. Significance of the study

The study's significance lies in its potential to enhance agricultural productivity and food security in the West Tripura district by identifying the most suitable land for rice cultivation. Its methodology could be applicable to other regions with similar geographic and climatic conditions, contributing to more efficient and sustainable agricultural practices.

3. Study Area

Physiographically, the study area is a combination of ridge and valley topographies. The lung is the most fertile land where agriculture is practiced, but the tilla is infertile and usually used for settlement and plantations. Most agricultural land is found in the river's floodplain and lunga areas. The lunga is a distinct physical characteristic for its fertile nature and efficiency for intensive cultivation. The hills are situated in the eastern part of the study area and extend from north to south. A maximum elevation of 285 meters has been found in the hills, whereas a minimum height of less than 30 meters has been observed in the river valley. The main river, Haora, originates from the Baramura range and flows towards the western side before entering Bangladesh. The floodplains of the river are the most fertile land for agriculture. The district experienced a sub-tropical climate with five distinct seasons, i.e., spring, summer, monsoon, autumn, and winter. West Tripura has become one of the prosperous agricultural districts in Tripura. Its latitudinal extension is 23˚40'N to 24˚07'N and the longitudinal extension is 91˚12'E to 91˚32'E (Figure 1). The district shares its boundary with Bangladesh, the study area is more significant in geopolitically.

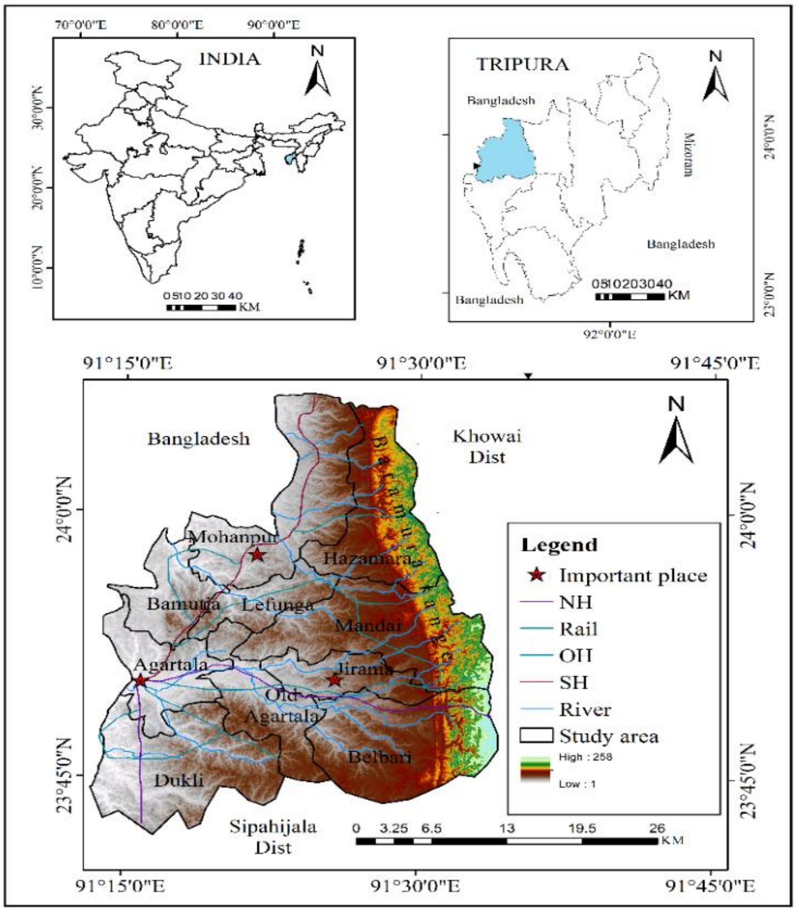

Figure 1: Location map of the study area

4. Methodology

The selected parameters are slope, elevation, drainage, soil texture, climate (rainfall & temperature), land use and land cover, soil moisture, and soil pH to understand the land suitability for rice cultivation in the West Tripura district (Table 1). The importance of each parameter has been evaluated in three ways: firstly, through a literature survey; secondly, based on interviews with experts in the agriculture field; and thirdly, considering the farmers' opinions [19],[20].

Table 1: Parameters and their data source

Parameters	Data Source
Slope	Analyzing DEM by surface analysis tools in ArcGIS 10.7
Elevation	SRTM DEM repository http://earthexplorer.usgs.gov
Drainage	Drainage map through raster calculation in ArcGIS 10.7
Soil Texture	National Bureau of Soil Survey and Land Use Planning https://esdac.jrc.ec.europa.eu/content/tripura-soils-sheet-1
Climate (Rainfall & Temperature)	IMD Grided data https://www.imdpune.gov.in
Land use Land Cover	Derived from Landsat 8 OLI (04.02.2020, Path & Row 136,44)
Soil moisture& Soil pH	Collected and tested in the laboratory

The slope, elevation, and drainage were extracted from the Digital Elevation Model (DEM) through raster calculation with help of GIS technique. The soil texture data was collected from the National Bureau of Soil Survey and Land Use Planning data portal. In contrast, climatic data (rainfall and temperature) was extracted from IMD gridded data. The LULC of the study area has been determined using maximum likelihood classification, and soil samples have been collected to test in the laboratory for assessment of soil's pH and soil moisture. Each thematic layer has been converted into the raster data set, and all raster data have been classified into sub-categories. Multi-criteria decision analysis has been performed with these factors to examine the suitability of land for cultivation (Figure 2). All influential parameters need to combined to make land suitability index (LSI) where qualitative and quantitative characteristics of the individual parameters have been examined based on the relations between land and crops to get a real-time scenario of the study area [21]. Factors directly related to land suitability are accepted as high-value factors like slope, elevation, drainage, soil, and climate. On the other hand, factors indirectly related to land suitability, like land use and land coverare considered low-value factors. The importance of the factors has been converted The consistency of the scale value has been evaluated by calculating the consistency ratio. The formula for the consistency ratio is CR= CI/RI. Where CI= Consistency Index, and RI= Random Index.

Consistency index: The consistency index is expressed as: $CI = \frac{\lambda max - n}{n-1}$

into the quantitative weight by applying the Analytic Hierarchy Process (Table 2). A pairwise comparison matrix has been calculated using Saaty's (1980) nine-point scale to implement the Analytic Hierarchy model [22].

Table 2: Intensity rating scale of Saaty's (1980)

Intensity rating scale	Explanation
1	Equal importance
3	Moderate importance of one over another
5	The strong or essential importance
7	Extremely important one variable than the other
9	Extremely more importance of one variable than other
2,4,6 and 8	An intermediate value between the adjacent value

Where CI is the consistency index, 'n' is the number of elements, and '$\lambda max'$' is the largest or principal eigenvalue of the matrix.

Random Index (RI): It has been randomly generated depending on the number of elements. The table for R.I is

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49	1.51	1.54	1.56	1.57	1.58

If the CR value is less than 0.10 or the same, then the AHP is considered correct otherwise if the value is greater than 0.01 then the AHP value should be rechecked.

Weighted overlay analysis: It can execute the critical spatial operation for land capability and suitability by accounting for several corresponding parameters [23],[24]. After assigning the probability weight for all individual parameters and converting the raster layers into a common scale value (WGS 1984), multiplication was done in GIS and a weighted overlay was performed for the final suitability output. Land suitability has been calculated by adopting the formula.

LS=$\sum_{i=1}^{n} Wi\,Xi$

Where LS indicates the land suitability score, Wi = Weight of land suitability class, Xi indicates the sub-criteria score and 'n' represents number of land classes. Finally, the Receiver Operating Characteristic (ROC) curve has been drawn to validate the model.

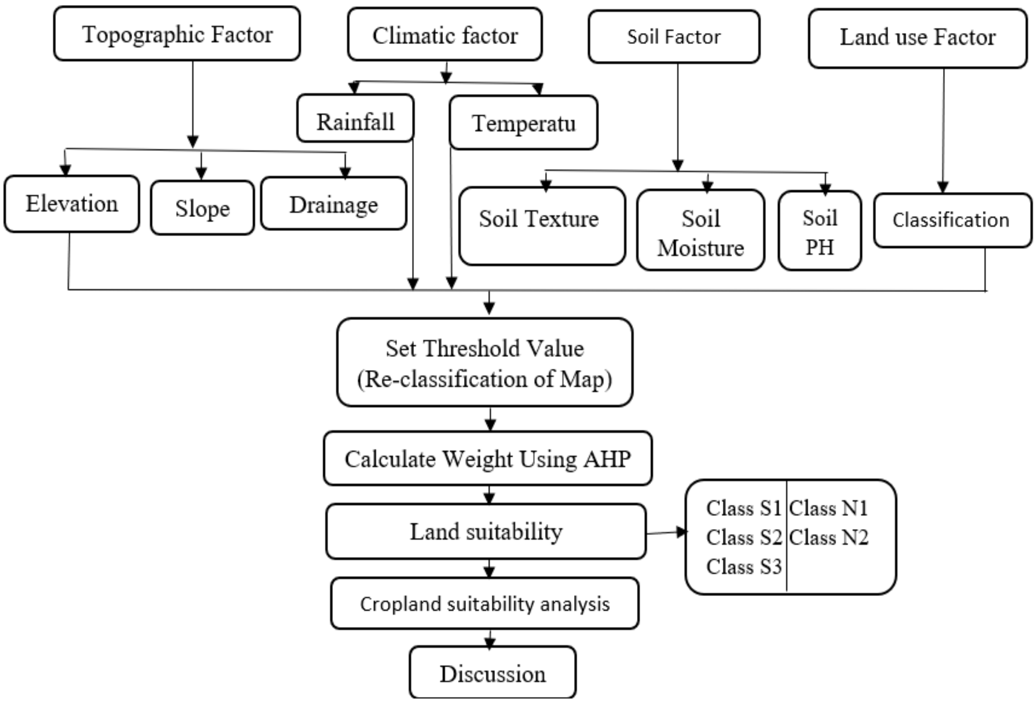

Figure 2: Flow chart for Land Suitability

5. Results & Discussion

The selected parameters of the slope, elevation, drainage, soil texture, climate (rainfall and temperature), land use and land cover, soil moisture, and soil pH were assessed to understand the land suitability for rice cultivation in the West Tripura district. As per FAO's guideline evaluating land suitability for rice cultivation in west Tripura district.

Slope: The slope is the primary element in understanding the landforms [25]. Together with other parameters, it may provide more information about soil loss, runoff, land capability, and suitability [26]. The study area consists of different slope features that depend on different landforms. The plain area is generally found in the western part, with a relatively low slope ranging from 5˚ to 10˚. This slope is ideal for all kinds of crop production and farming (Figure 3a). Moderately steep slope (<18˚) is found in tilla and upland areas, which are not suitable for crop cultivation but have more potential for plantation. The eastern part of the district is unsuitable for cropping since a steep slope is found (Table 3&4).

Elevation: Elevation is another important parameter to assess the terrain characteristic of the study area. The district has many variations in elevation within a short distance. This undulating topography has influenced the agricultural activities of the region. The maximum height of 258m has been found in the hilly eastern parts whereas the minimum elevation of less than 30m is found in the western plain area (Table 3&4). The height gradually decreases from east to west, but the gradient increases from west to east (Figure 3b).

Drainage: Drainage is a significant determinant of crop suitability as it influences plant growth [27]. Water availability not only helps in plant growth but can also increase productivity. The drainage density for the study area has been extracted from the digital elevation model (SRTM-DEM). It has been observed that numerous rivers, lunga, chara, and gangs drain the study area. High to moderate drainage density has been identified at the foothills of Baramura and in the plain land areas. However, low drainage density is found in the uplands and hills. Flooding in the rainy season poured sediments into the valley floor, which made the floodplain more fertile for intensive cultivation. The agricultural lands in the West Tripura district are situated on the valley side, where the irrigation facility is well developed (Figure 3c, Table 3&4).

Soil texture: The hilly area is coarse loam soil, which is unsuitable for cultivation as it has poor water retention capacity. Fine loam-to-clay soil has been identified in the tilla and lunga areas, whereas clay-to-clay loam soil is observed in the floodplain. The floodplain and lunga are the most suitable area for intensive cultivation in the study area (Figure 3d, Table 3&4).

Rainfall: The district has received more rainfall between 2459mm and 2540mm in the eastern parts (hilly) than the western plain area. The amount of rainfall gradually decreases from the east to west. The heavy rain during the rainy seasons accelerates soil erosion from hills and tillas, which makes it unsuitable for cultivation (Figure 3e). This erosive soil deposits minerals in floodplain areas, making it more fertile and suitable for cultivation. The rainfall is high in the hilly areas, but agriculture is unsuitable because of the constraints of slope and soil characteristics. However, the district practices rainfed agriculture, so most agricultural land is observed in the floodplain areas (Table 3&4).

Temperature: Temperature shows less variation throughout the year (Figure 3f).The degree of temperature is relatively higher in the western part than in the eastern. The eastern part is covered with natural vegetation so the temperature is less whereas settlements are found in the western part of the district. The whole study area is under tropical to sub-tropical climatic regions where rice cultivation is suitable (Table 3&4).

Land use and land cover: The categorization of LULC with the help of the GIS technique using supervised classification based on Maximum Likelihood Classification algorithms to estimate the significant land use classes in the study area. The eight major land use classes have been identified in the district (Table 3&4). Among all categories, natural vegetation acquired the maximum land area of 26.35%. The second largest class is rubber plantation, which has 22.41% area. The third largest types are settlements, acquiring 21.34%, and agricultural land, which acquired around 16.42% of the area, as the fourth largest class. The other classes are tea plantations; water bodies, shrubland, and bare land, which acquired the geographical area of the district of 5.39%, 3.38%, 3.25%, and 1.41%, respectively (Figure 3g). With time, natural vegetation, shrubland, water bodies, tea plantations, and agricultural land are gradually converted into rubber plantations, which may threaten the food security of the district.

Table 3: Land suitability for rice cultivation

Land characteristics	Suitability classes	Rice cultivation	Weight (%)
Slope	S1	Level	15
	S2	Very gentle	
	S3	Gentle	
	N1	Moderate	
	N2	Steep	
Elevation (Meter)	S1	0-35	9
	S2	35-60	
	S3	60-96	
	N1	96-146	
	N2	146-258	
Soil texture	S1	Clay loam	31
	S2	Fine loam	

	S3	Fine sandy loam	
	N1	Sandy loam	
	N2	Coarse loam	
Drainage	S1	Very Poor	22
	S2	Poor drained	
	S3	Moderately drained	
	N1	Well drained	
	N2	Excessive drained	
Soil pH	S1	5.70-5.77	1
	S2	5.77-5.80	
	S3	5.80-5.83	
	N1	5.83-5.86	
	N2	5.86-5.91	
LULC	S1	Plain agricultural land	7
	S2	Undulating agricultural land & shrubland	
	S3	Upland and tea plantation	
	N1	Waterbody, Bare land	
	N2	Rubber, Forest, Settlement	
Rainfall (mm)	S1	2099-2206	3
	S2	2206-2305	
	S3	2305-2385	
	N1	2385-2459	
	N2	2459-2540	
Temperature (˚C)	S1	25.24-25.32	2
	S2	25.16-25.24	
	S3	25.06-25.16	
	N1	24.95-25.06	
	N2	24.81-24.95	
Soil Moisture	S1	Very high	5
	S2	high	
	S3	Moderate	
	N1	Low	
	N2	Very low	

Table 4: Pairwise comparison matrix for rice suitability

Parameters	Soil Texture	Drainage	Slope	Elevation	LULC	Soil Moisture	Rainfall	Temperature	Soil pH	Weightage
Soil Texture	**1.000**	3.000	5.000	5.000	5.000	3.000	5.000	9.000	9.000	0.315
Drainage	0.333	**1.000**	3.000	3.000	3.000	5.000	5.000	9.000	9.000	0.220
Slope	0.200	0.333	**1.000**	3.000	3.000	5.000	5.000	7.000	9.000	0.158
Elevation	0.200	0.333	0.333	**1.000**	2.000	2.000	3.000	5.000	7.000	0.094
LULC	0.200	0.333	0.333	0.500	**1.000**	3.000	3.000	3.000	5.000	0.077
Soil moisture	0.333	0.200	0.200	0.500	0.333	**1.000**	2.000	3.000	5.000	0.054
Rainfall	0.200	0.200	0.200	0.333	0.333	0.500	**1.000**	2.000	3.000	0.038
Temperature	0.111	0.111	0.143	0.200	0.333	0.333	0.500	**1.000**	1.000	0.022
Soil PH	0.111	0.111	0.111	0.143	0.200	0.200	0.333	1.000	**1.000**	0.017

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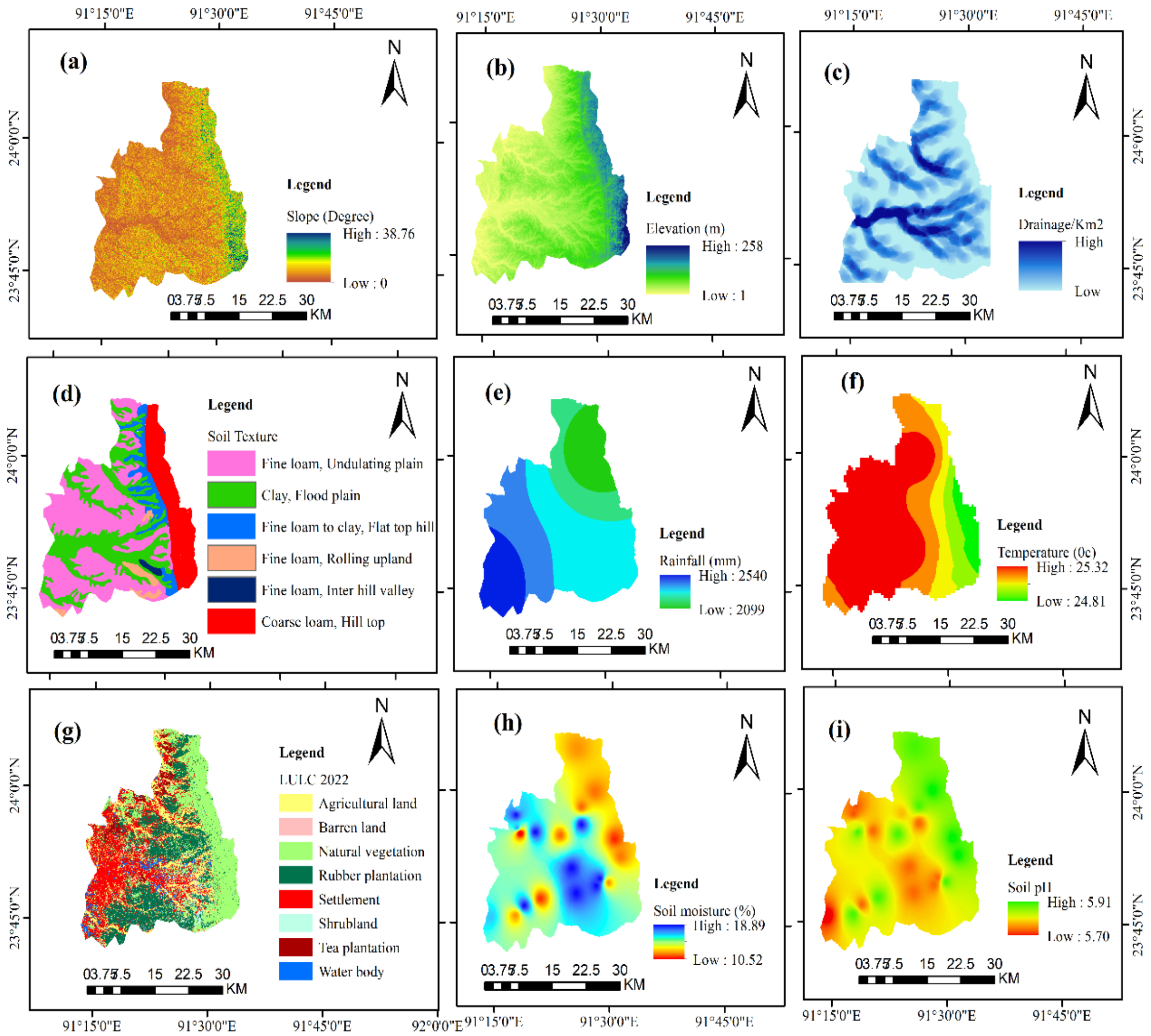

Figure3: Spatial variation map (a) Slope (b) Elevation (c) Drainage (d) Soil Texture(e) Rainfall (f) Temperature (g) LULC (h) Soil Moisture (i) Soil pH map of West Tripura district.

Soil moisture: Soil moisture is another important parameter for the growth of crops. In the study area, high moisture content has been observed in the river valley, lunga, and charas areas (>15%), but the moisture content is low in hills, tilla, and upland areas <15%) (Figure 3h). Those crops that need more moisture content are suitable in the valley and lunga areas. In contrast, plantations like rubber and tea are suitable in the tilla and hilly areas, which need minimum soil moisture (Table 3&4).

Soil pH: There are minimum differences in soil pH, though relatively high pH has been found in the hilly areas, and low pH is found in the tilla and plain land areas. However, the soil of the study area comes under mildly acidic conditions (Figure 3i). The plain areas are suitable for rice cultivation (Table 3&4).

6. Land suitability for rice cultivation

Rice is the main staple crop in the West Tripura district. The suitable condition for rice growth is 175 cm to 300 cm rainfall during the growing season. Temperature beneficial for rice is 27˚c to 30˚c. Fertile riverine alluvial soil and clayey loam soil in monsoon regions benefit rice cultivation. Land surface with a minor slope, alluvial deltas, and river basinsare more suitable for rice cultivation [28],[29],[30]. In the study area, the soil texture, drainage, and slope are the most significant suitable factors for rice cultivation. In West Tripura, 3.30% land is highly suitable, and 31.88% landis moderately suitable, the total land suitability for rice cultivation is 35.18%. The fertile land available near the bank of rivers has clayey to loamy soil texture. The total marginally suitable land is 44.65%located in the upland slope areas of the district. Thus, proper management is needed to make this land suitable for rice, remain 20.14% of the land is unsuitable for rice cultivation as the land is under hilly topography (Figure 4 & Table 5).

Table 5: Land suitability for rice cultivation in West Tripura (in %)

Land suitability classes	Area (sq. km)	Area (%)
High suitability	31.12	3.30
Moderately suitability	300.42	31.88
Marginally suitability	420.72	44.65
Currently unsuitability	165.94	17.61
Permanently unsuitability	23.92	2.53

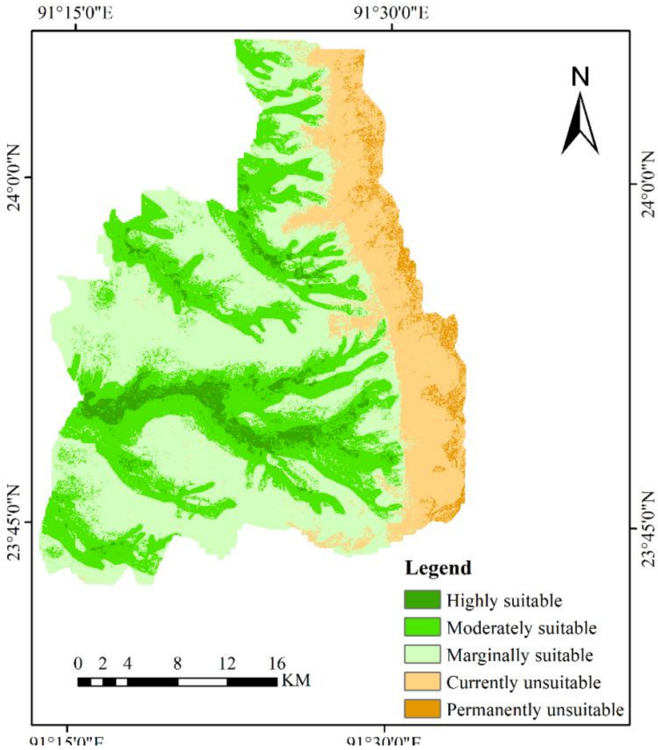

Figure 4: Land suitability for rice cultivationin West Tripura

7. Validation

Receiver Operating Characteristic (ROC) is the significant model validation method. The accuracy has been achieved by comparing the ground truth data with the land suitability model for rice cultivation. The presence of crops is designated as value '1', whereas the absence of crops is identified as '0'. The accuracy shows the area under the curve (AUC) for rice (0.77), which is greater than the threshold value of 0.5 (Figure 5). AUC curve values closer to '1' show that the model produces perfect predictions. The value indicates that the land suitability for rice is a more accurate estimation. Thus, the models can easily predict land suitability for rice cultivation in the West Tripura district.

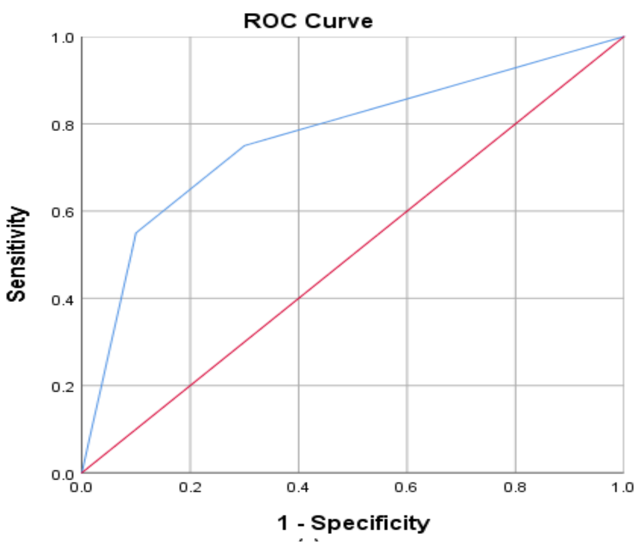

Figure 5: The Receiver Operating Characteristic (ROC) for Rice (0.77)

8. Conclusion

The plain topography, relief, minimal slope, and fertile soils are the significant factors for the production of crops in West Tripura rather than the variability in climatic factors. The floodplains, plain areas, and lunga (Palaeo-channel) have more potential for rice crop production where land is more fertile and capable of intensive farming and water availability. The tilla and the upland are moderate to marginally suitable for rice cultivation. The study reveals that 35.18% of the land is high to moderately suitable for rice cultivation. Thus, it can be concluded that another 44.65% of land can be included for rice cultivation with minimum effort through land levelling, land mulching, contour farming, increasing irrigation facilities, introducing drought-tolerant seed varieties, and smart agricultural practices.

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Conflict of interest
Both authors declare that they have no conflict of interest.

Declaration:
"I declare that the manuscript has not been published in any journal/book or proceedings or any other publication, or offered for publication elsewhere in substantially the same or abbreviated form, either in print or electronically.

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