RESEARCH ARTICLE

Evaluation of Land Capability and Sustainable Agricultural Suitability in Khowai District, Tripura, India: An Integration of RS, GIS & AHP Approaches

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Abstract

Land capability and agriculture suitability analysis are essential for sustainable land development, where land capability indicates the inherent capacity of land, and suitability reflects the degree of land utilisation for a specific type of crop. This paper aims to evaluate the land capability for agriculture suitability of Khowai District, to provide valuable insights for minimum land resource utilization for sustainable management in an ecologically diverse regions in India. The study area consists of very appropriate regions located in low-elevation zones around Khowai and its tributaries. These low-lying areas characterized by rich alluvial soil and are well-suited for agriculture. The current study employs a multidisciplinary approach that integrates Remote Sensing and Geographical Information System (GIS) to assess land capability for sustainable agriculture suitability. To estimate land capability, the selected factors are soil properties, topography, climate, land cover, hydrology, environment, and landforms characteristics. Further, the weighted overlay analysis method adopted to weightage the factors, and performed in QGIS 3.18 software to generate a comprehensive land capability and agriculture suitability map based on FAO guidelines. The findings indicates that 87% of the overall area is suitable for cultivating a wide variety of crops, as rice, maize, sesamum, pea, potato, banana, pineapple, orange, mango and vegetables. Whereas, the remaining 13% are not capable due to persistent constraints related to the terrain, slope, and soil depth. The study will provide valuable understandings for land use planners and local communities in making well-informed decisions and optimising land resource for sustainable and resilient agriculture practices in future.

Keywords: AHP approach, Geographical Information System, Khowai district, Land capability, Sustainable Agriculture Suitability, Remote Sensing, Tripura.

Highlights

- The land capability and agriculture suitability analysis of Khowai district was performed based on weighted overlay technique in open-source software.
- The most suitable region is characterized by low elevation, gentle slopes, and alluvial types of soil.
- The assessment reveals that 87% of the total area is suitable for cultivating various field crops, such as rice, maize, and potatoes.
- The unsuitable areas, comprising 5.36% of the total area, are distributed across high-elevation regions characterized by landforms and surrounded by dense vegetation cover.

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Introduction

The assessment of land capability for agriculture suitability is crucial in determining agricultural productivity and deploying sustainable land management strategies. In the context of a growing global population and increasing food demand, understanding these concepts is essential in order to build effective and resilient agricultural practices. The Khowai district is mostly dependent on agriculture and tourism. The main staple crops, such as paddy, maize, wheat, and pulses are predominant. However, the local farming community faces challenges related to agricultural knowledge, selection of land and the adoption of effective farming techniques, which leads to lower yields. Thus, it is imperative to evaluate the potential and suitability of land for agricultural purposes to ensure the long-term sustainability of land resources and improve agricultural productivity (Mallick *et al.,* 2024).

Land capability refers to the inherent capacity of an area to support agricultural practices, while suitability considers the compatibility between land attributes and specific crop requirements (Montgomery *et al.,* 2016; Abd El-Kawy *et al.,* 2010). Assessing land potential requires a comprehensive analysis of various factors such as soil quality, terrain, climate, and water availability (Saha and Mandal, 2022). These factors influence a land's potential to sustain different crops and agricultural

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practices (Kumar and Ravikumar, 2018). Land suitability studies involve comparing individual crop requirements with land characteristics, helping in the identification of best crop selection for a specific area (Hopkins, 2014). By considering factors like water availability, temperature, soil pH, and nutrient content, this approach enables informed decisions about crop selection, agricultural practices, and resource allocation (Ahmed *et al.,* 2016). Assessing land capability and suitability is vital for effective land management and sustainable agricultural practice (Qiu *et al.,* 2013). Farmers and land managers can enhance agricultural productivity, conserve resources, and address environmental issues by recognizing land's intrinsic potentiality and capability (Elnaggar, 2017; Krishnaiah, 2017). Therefore, this research work aims to evaluate the land capability and sustainable agricultural suitability in Khowai district of Tripura. This understanding will foster the efficient utilization of limited land resources, contributing to global food security and the well-being of both rural and urban populations (McDonald and Brown, 1984).

Study area

The district of Khowai is located in the northeastern region of Tripura state, India. It was formed in January, 2012, and the district headquarters is Khowai town. It is situated between the latitudes of 23.53°N and 24.14°N and the longitudes of 91.23°E and 91.56°E, covering a total geographical area approximately of 1377.28 sq.km. The elevation varies from 19 to 413 meters, featuring terraced crops on the hilly slopes, providing a distinctive and captivating landscape. The district is located in between Bangladesh, West Tripura district, and Sipahijala district by northern, western and southern. The district of Khowai is divided into two sub-divisions: Khowai and Teliamura, both are municipalities, and 55-gram panchayats. According to the Census of India (2011), Khowai district has a population of approximately 3,27,564. The major population is of indigenous peoples, such as the Tripuris, Reangs, Jaimati, and others. Agriculture is the major source of livelihood for the people of the district. During the summer, temperatures frequently exceed 30°C, and in the winter season, it ranges from 15°C to 25°C. The southwest monsoon is mainly responsible for the yearly precipitation. The district is drained by the Namouras River System, where the Khowai is the main river, which runs from the Atharamura Hills in the south and ends in Bangladesh in the north. The area is thickly forested, with both deciduous and evergreen trees (Fig. 1).

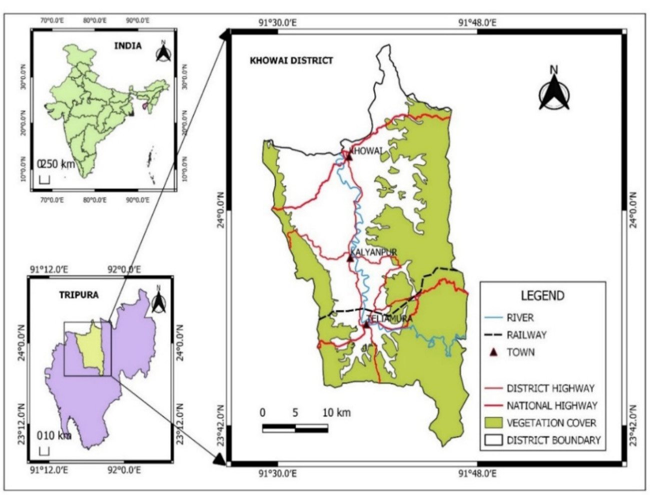

Fig. 1: Location of the study area

Materials and Methods

Database

A considerable amount of multi-source spatial and non-spatial data is necessary to analyse the land capability and land suitability for agricultural growth in a particular region. (Table 1) summarises the methodological approach and data used in the current study to assess the capability and appropriateness of agricultural practices in Khowai district.

Methodology

The current study includes various kinds of determinant factors, namely, topography (elevation, slope, and landforms), climate (rainfall, temperature, and relative humidity), soil (soil pH, soil texture and soil organic carbon), hydrology (Normalised Difference Water Index (NDWI) and River proximity) and environment (Land Use Land Cover and Normalised Difference Vegetation Index) (Fig. 2). For generating a land suitability map of the study area, the data was gathered from the Geological Survey of India's (GSI) Bhukosh website. The elevation and slope map of the study area were prepared in QGIS 3.18 software using SRTM-Digital Elevation Model (2019), which has been obtained from the United States Geological Survey (USGS).

The climate parameters are mean precipitation and temperature data were collected from IMD, Pune, and NASA power data access accordingly to the grid-wise with an accuracy of 0.25°×0.25° from the year 2011 to 2021. After that, the spatial distribution maps were prepared based on the Inverse Distance Weighted (IDW) interpolation method in a GIS platform. For the

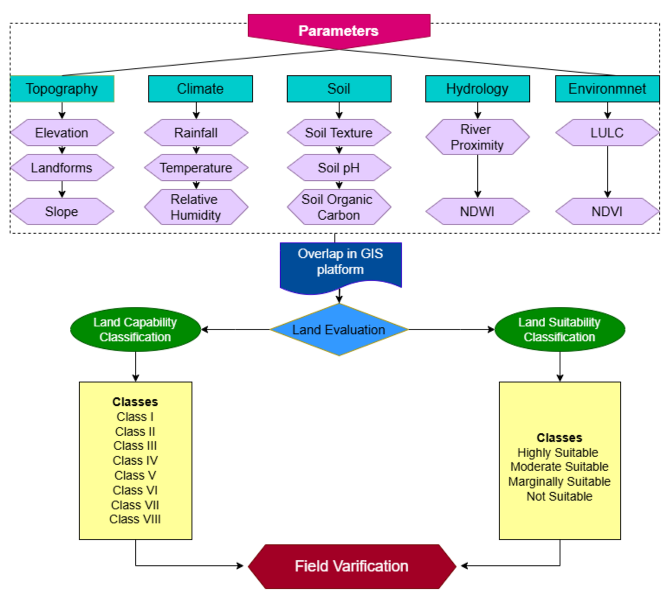

Fig. 2: Methodological flow chart

Table 1: Database of selected factors

Factors	*Sub-factors (f)*	*Data Source*	*Source of Website*
Topography	Elevation	DEM	https://earthexplorer.usgs.gov/
	Slope	DEM	https://earthexplorer.usgs.gov/
	Landforms	Geological Survey of India	https://bhukosh.gsi.gov.in/Bhukosh/Public
	Temperature	NASA power data access	https://power.larc.nasa.gov/data-access-viewer/
	Relative humidity		https://power.larc.nasa.gov/data-access-viewer/
	Rainfall	IMD, Pune (2011-2021)	https://mausam.imd.gov.in/responsive/rainfallinformation.php
Soil	Soil organic carbon	Raster	https://soilgrids.org/
	Soil pH	Vector layer	https://soilgrids.org/
	Soil texture	FAO	https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/faounesco-soil-map-of-the-world/en/
Hydrology	River proximity	DEM	https://earthexplorer.usgs.gov/
	NDWI	Landsat 8 OLI/TIRS	https://earthexplorer.usgs.gov/
Environment	NDVI	Landsat 8 OLI/TIRS	https://earthexplorer.usgs.gov/
	LULC	Landsat 8 OLI/TIRS	https://earthexplorer.usgs.gov/

soil texture map of the selected region was collected from the Food and Agriculture Organisation (FAO) website to develop the soil organic carbon and soil pH maps, the data with a resolution of 250 m were acquired from the soil gridded. In order to identify the proximity areas to the river, SRTM-DEM data is used to delineate the basin and drainage network for the study region.

The Normalized Difference Water Index was used by the investigators to determine the soil moisture areas based on Landsat 8 OLI imageries using the subsequent equation (Eq. 1).

$$NDWI = \frac{Green - NIR}{Green + NIR} \quad \text{(Eq. 1)}$$

NDWI = (Band 3 – Band 5) / (Band 3 + Band 5) for Landsat 8 OLI & TIRS data.

In QGIS software, a vegetation map was created to check flora cover using the Landsat 8 satellite and the following equation (Eq.2). Landsat 8 OLI (30-m resolution) imagery from the US Geological Survey's (USGS) Earth Explorer portal was used to create the land-use land-cover map. Two tiles of Landsat images (row,143,144) were previously mosaiced. Later, techniques such as atmospheric correction, edge enhancement, and band composition were implemented. Finally, supervised classification with a maximum likelihood approach was used to build the final LULC classification map of the study region.

$$NDVI = \frac{NIR - Red}{NIR + Red} \quad \text{(Eq. 2)}$$

NDVI = (Band 5 – Band 4) / (Band 5 + Band 4) for Landsat 8 OLI & TIRS.

The current assessment of agricultural land capability and suitability draws on a range of data sources to produce the final output. To avoid output errors, the obtained criteria maps were rasterized, reclassified, and translated into the same cell size of 30 m resolution and converted into same projection system, i.e., Universal Transverse Mercator (UTM) projection, Zone 46 N. All the thematic layers are assigned a weightage value based on the influence on agriculture practice of one criterion compared to other using Analytical Hierarchy Process (AHP) (Table 2). The relative importance of the criteria was determined using Saaty's scale, assigning values ranging from 1 to 9. A value of 1 signifies equal importance between two criteria, while a value of 9 indicates the extreme dominance of one criterion over the other. Following that, to generate the final agriculture suitability model, all the layers were superimposed in the GIS environment using an overlay analysis technique.

Results and Discussion

Physical Factors

For this study, the physical factors include the component of elevation, slope and landforms of the earth surface, which has a great influence on the agricultural practice. Topography is closely related to the formation of soil, which is the main determining factor of the growth of various kinds of crops.

Elevation

The elevation map of Khowai district provides crucial insights into its topographical variations, and it can be divided into four division classes, from lowest to highest elevation range. The highest elevations, ranging from 200 to 436 meters, are found in the eastern Atharamura ranges, which border the district on the east and covered by 51.5 sq.km (4.95%) of the entire region. This high elevation is attributed to the presence of both the Baramura and Atharamura ranges flanking the district's eastern and western edges. In contrast, with the total area 696.44 sq.km (66.84%) the central section of the Khowai district associated with the lower elevation features, falling within the 19–100 meters range. Notably, the central areas exhibit a lower elevation profile compared to the rest of the district. Elevation plays a pivotal role in shaping agricultural productivity and crop

Table. 2 : Pare-wise comparison matrix of selected sub-factors (f) using the AHP method.

Sub-factors (f)	*f1*	*f2*	*f3*	*f4*	*f5*	*f6*	*f7*	*f8*	*f9*	*f10*	*f11*	*f12*	*f13*	*Wi*
f1 -Landforms	1	1	2	2	2	2	3	3	3	4	5	5	5	0.158
f2 - Elevation	1	1	1	2	2	2	3	3	3	4	5	5	5	0.149
f3 - Slope	0.50	1.00	1	1	2	2	3	3	3	4	5	5	5	0.135
f4 - River proximity	0.50	0.50	1.00	1	1	1	3	2	3	3	4	5	5	0.106
f5 – LULC	0.50	0.50	0.50	1.00	1	1	2	2	3	3	4	4	5	0.096
f6 - NDWI	0.50	0.50	0.50	1.00	1.00	1	2	2	2	3	4	4	4	0.091
f7 – Temperature	0.33	0.33	0.33	0.33	0.50	0.50	1	1	2	2	3	4	4	0.061
f8 – Soil texture	0.33	0.33	0.33	0.50	0.50	0.50	1.00	1	1	2	3	3	3	0.055
f9 – Rainfall	0.33	0.33	0.33	0.33	0.33	0.50	0.50	1.00	1	1	2	2	3	0.044
f10 – NDVI	0.25	0.25	0.25	0.33	0.33	0.33	0.50	0.50	1.00	1	1	2	2	0.035
f11 – Soil pH	0.20	0.20	0.20	0.25	0.25	0.25	0.33	0.33	0.50	1.00	1	1	2	0.026
f12 – Soil OC	0.20	0.20	0.20	0.20	0.25	0.25	0.25	0.33	0.50	0.50	1.00	1	1	0.023
f13 – Relative humidity	0.20	0.20	0.20	0.20	0.20	0.25	0.25	0.33	0.33	0.50	0.50	1.0	1	0.02

Wi - Weightage value

variety within the region (De Feudis *et al*., 2021). It influences climatic conditions and the physiological and morphological characteristics of local fauna and flora (Yousif *et al.,* 2020). Furthermore, crop yields can vary significantly based on the specific elevation ranges, with certain crops thriving at higher elevations, while others are more suited to lower elevations (Yohannes & Soromessa, 2019) (Table 3) and Fig. 3a).

Slope

The slope map serves as a valuable tool in comprehending the topographical features of the Khowai district. The slope map of Khowai district has classified into four distinct categories based on the FAO suitability and capability classes. The steepest slopes, ranging from 23.5° to 36°, are primarily concentrated in the eastern hilly ranges. These regions are characterized by ridges with sharply inclined slopes, which considered that the land has less capacity to hold agricultural crop due to less soil depth and high soil erosion (Saleh *et al*., 2015). Moderately steep slopes, with angles spanning from 7.5° to 23.5° covered by the total areas 134.23 sq.km are prevalent in both the eastern and western hilly ranges of the district, posing the moderate agricultural potential land. The central part of the Khowai district predominantly features the mildest slopes, ranging from 0° to 7.5° with the total area 907.60 sq.km. This area, characterized by valley terrain, offers relatively flat and plain land, rendering it highly suitable for a wide range of agricultural activities (AbdelRahman *et al*., 2016) (Table 3 and Fig. 3b).

Landforms

The physiographic units play a crucial role in determining both land capability and agricultural suitability (Surya *et al*., 2020). The physical setups of the Khowai district are classified into the four categories based on their suitability for agriculture. The study region is primarily consisting of antiformal hills, synformal valleys, and valley fill areas. Among these, the valley fill region, located near the Khowai River and covering 388.85 sq.km (37.32%), stands out as highly suitable for agriculture due to the periodic deposition of fertile soil transported by river floods (Rajesh *et al*., 2018). In contrast, synformal valleys, which make up 507.32 sq.km (48.69%) of the Khowai area, present challenges such as soil erosion, reduced soil fertility, and limitations on agricultural productivity (Tesfay *et al*., 2017). Highly distorted hills, covering 10.03 sq.km (0.96%) are unsuitable for agriculture due to high surface runoff and high soil erosion. Additionally, antiformal hills, strike ridges, water bodies, rivers, and ponds across the district, totalling 135.69 sq.km (13.02%) are permanently unsuitable for agriculture (Table 3 and Fig. 3c).

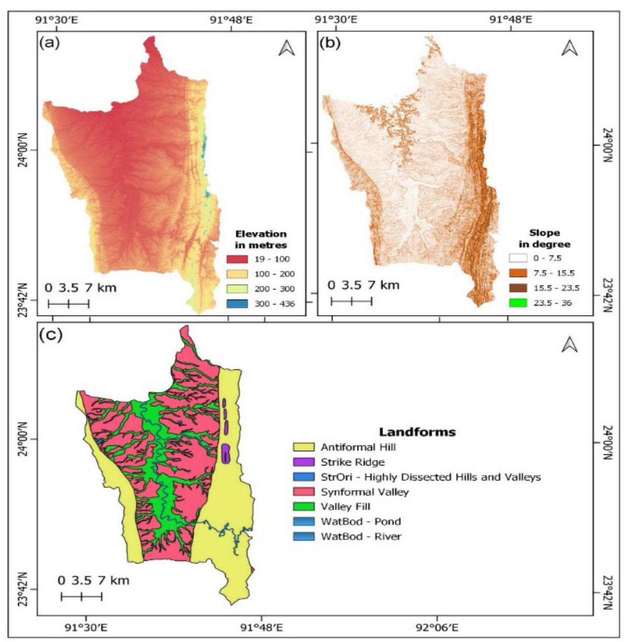

Fig. 3 : Topographic factors a) Elevation, b) Slope, and c) Landforms in the study area

Climatic factors

Climatic elements, encompassing factors like temperature, precipitation, and relative humidity, exert a substantial impact on agricultural practice.

Temperature

In the Khowai region of Tripura, temperature variations between 2011 and 2021 have been categorized into four classes. In the northern part, temperatures are higher, averaging between 24.91°C to 25.2°C. This is primarily due to lower elevation and reduced forest cover. In the southern region, temperatures are cooler during summers, ranging from 24.20°C to 24.45°C. The southern and northern areas are considered moderate for agriculture; it covered an area of 837.87 sq.km (80.42%). Moving to the Central Valley areas, temperatures range from 24.68°C to 24.91°C, influenced by the flat terrain and limited forest cover (Das *et al*., 2020). In the eastern hilly and undulating surface areas, temperatures are milder, ranging from 24.45°C to 24.68°C, attributed to slightly higher elevations and forested landscapes. These regions are considered optimal for agriculture and covered by an area of 204.02 sq km (19.58%) (Table 3 and Fig. 4a).

Relative humidity

The relative humidity map for 2011-2021 reveals distinct variations in across Khowai district. In the northwest, relative humidity is at its lowest, ranging from 78.30% to 79.14%. Moving southeast, towards the southern region, humidity significantly increases to a range of 80.66% to 81.45%. This heightened humidity in the south is attributed to the presence of forests and water bodies. The hilly and forested eastern and western ranges exhibit variable humidity levels, approximately from 79.90% to 80.66%. The central area maintains moderate humidity, ranging between 79.14% to 79.90% and is considered highly suitable for agricultural activities. These differences arise due to geographical features, with southern areas benefiting from greater moisture retention and northern regions experiencing lower humidity due to reduced forest cover and increased openness (Sayed & Khalafalla, 2021) (Table 3 and Fig. 4b).

Rainfall

Based on information from the India Meteorological Gridded dataset from 2011 to 2021, the mean annual rainfall in the Khowai district varies from 1390 to 1980 mm, which has been reclassified into four distinct categories (Table 3). In the southern part of Khowai, the annual rainfall is the highest, averaging between 1831-1980 mm, covering an area of 157.71 sq.km (15.14%) of the total area. The northwestern region of the district, the amount of rainfall decreases steadily to about 1390-1542 mm per year. The area covers roughly about 516.94 sq.km, which is 49.62% of the total district. The reduction of rainfall corresponds to the transition from the southern mountainous and hilly areas of Khowai to the northern region. Conversely, the central part of Khowai experiences annual rainfall between 1542-1831 mm, making it suitable for agricultural activities, covering an area about 367.24 sq.km (35.24%) of the district (Table 3 and Fig. 4c).

Soil factors

Soil factors, including pH, soil organic carbon (SOC), and texture, greatly influence agriculture practices. They affect crop selection, nutrient management, and irrigation strategies, all of which are crucial for successful and optimal agricultural practices (Mallick et al., 2025).

Soil Organic Carbon

Soil organic carbon (SOC) plays a pivotal role in determining plant nutrient availability and supporting optimal plant growth (Ennaji *et al*., 2018; Abdullahi *et al*., 2020). The distribution of soil organic carbon in the study area is categorized into four distinct classes. The majority of the study area, spanning 516.94 sq km (61.47%) falls within the 125-165 mg/kg range, indicating varying levels of SOC content from marginal to substantial. Remarkably, soil near the Khowai River banks exhibits significantly higher SOC levels, ranging from 165-228 mg/kg, covering an area of 392.55 sq.km (37.67%). This emphasizes the river's significant contribution to agriculture, as these soils are optimal for agricultural activities and beneficial for plant growth (Moursy and Thabit, 2022). In hilltop and upland areas, the SOC content records in the range of 228-303 mg/kg, encompassing 8.86 sq.km (0.86%) of the total area (Table 3 and Fig. 5a).

Soil pH

The agricultural potential of the Khowai area has been evaluated by categorising the region into four groups according to its pH levels. The Khowai district predominantly displays acidic soil conditions, with the Atharamura range being the most acidic, registering a pH level below 5.2. Acidity increased with rapid water movement in hilly terrain, resulting in the leaching of essential elements like Magnesium (Mg), Potassium (K), and Calcium (Ca), ultimately intensifying soil acidity (Abdullahi *et al*., 2020). Agricultural areas and settlements in the district also tend to possess acidic soils with a pH below 5.5, primarily due to intensive farming practices and the excessive use of nitrogen-based fertilizers, especially ammonium-based ones, known contributors to soil acidification (Ennaji *et al*., 2018). However, areas with soil pH ranging from 5.5 to 5.7, particularly those near rivers and valleys, are considered suitable for agricultural

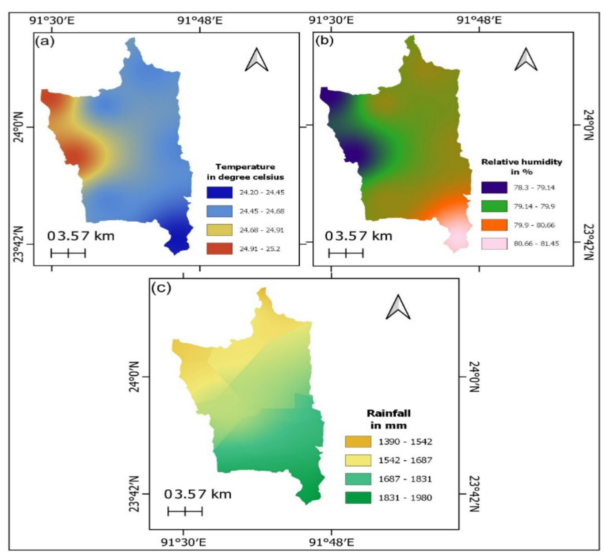

Fig. 4: Climatic factors, a) Temperature, b) Relative Humidity, and c) Rainfall in the study area

activities. It is important to note that human activities, such as construction and infrastructure development, have the potential to disrupt natural soil profiles and introduce minerals and chemicals, further influencing soil pH levels (Das *et al*., 2020) (Table 3 and Fig. 5b).

Soil texture

Ideal soil texture selection is crucial for sustaining soil health, which optimises production efficiency by reducing water and fertiliser use in the agricultural field. In this region, there are two types of soils available, which are Eutric gleysols (Ge) and Dystric cambisols (Bd). The maximum part of the district, i.e., approximately 98.4% is encompassed by Dystric combisols type of soil group, which is characterized by medium textured, good structural stability, and good water holding capacity, that seems to be more suitable for agricultural activities (Yohannes and Soromessa, 2019). A relatively small part of the district (1.6%) is associated with Eutric gleysols type of soil group and consisted with the weathered materials. In the tropical and subtropical region rice are widely cultivated in the gelisols soil group (AbdelRahman *et al*., 2016) (Table 3 and Fig. 5c).

Hydrological factors

Hydrology factors, including water availability and soil moisture, influence agriculture by determining irrigation needs, crop selection, and drainage systems. Adequate water supply is essential for plant growth, and proper management of water resources is crucial for sustainable and productive agricultural practices (Karimi *et al*., 2018).

River Proximity

The rivers' proximity Khowai District serves as crucial water sources for irrigation and agriculture, ensuring consistent farming practices and food production. The rivers are essential for sustaining agriculture, especially during drought periods, as they provide vital irrigation water (Feizizadeh & Blaschke, 2013). Consequently, the proximity of land to the river is taken into consideration and categorized into five classes, ranging from very close to remote. The most suitable location for agricultural production is approximately within 1 kilometre of the rivers (Yohannes & Soromessa, 2018). The analysis reveals that land within 0-1000 meters from the rivers is well-suited for agricultural activities, covering around 51.04% of the total area, while distances exceeding 1000 meters from the river are considered unsuitable for agriculture (Table 3 and Fig. 6a).

NDWI

A Normalized Difference Water Index (NDWI) map was accurately developed for the Khowai district, enabling a comprehensive assessment of water availability and moisture levels in the region (Roy *et al*., 2023; Krishnaiah, 2011). The results indicate that the central region along the Khowai river boasts notably high moisture content, reflected a near positive NDWI score i.e., -0.13 to -0.0033. The NDWI score of -0.0033 to -0.1359 signifies optimal moisture levels, particularly in areas predominantly covered by dense vegetation and crops (Table 3 and Fig. 6b). Conversely, areas exhibiting a white patch with a score of more than -0.4011 indicate barren lands and severe drought conditions, signifying minimal water content which considered less ideal for crop harvesting (Swafo & Dlamini, 2022).

Environmental factors

Environmental factors, including NDVI and LULC, profoundly impact agriculture. They dictate crop selection, irrigation, and land management strategies. Farmers must choose the crops to suitable for local environmental conditions to optimize productivity and minimize environmental harm with sustainable agricultural practices (Masri, 2021; Mallick et al., 2023).

NDVI

The Normalized Difference Vegetation Index (NDVI) is used to enable the precise detection of variations in vegetation coverage within Khowai district. The NDVI values were classified into four distinct categories, delineating the spectrum from the lowest to the highest degree of vegetation cover (Girmay *et al*., 2018). The analysis of NDVI values ranging between 0.1511 and 0.0102, unequivocally denotes areas devoid of vegetation or primarily allocated to agricultural use, such as barren lands, sandy terrain, and water bodies. This region is predominantly

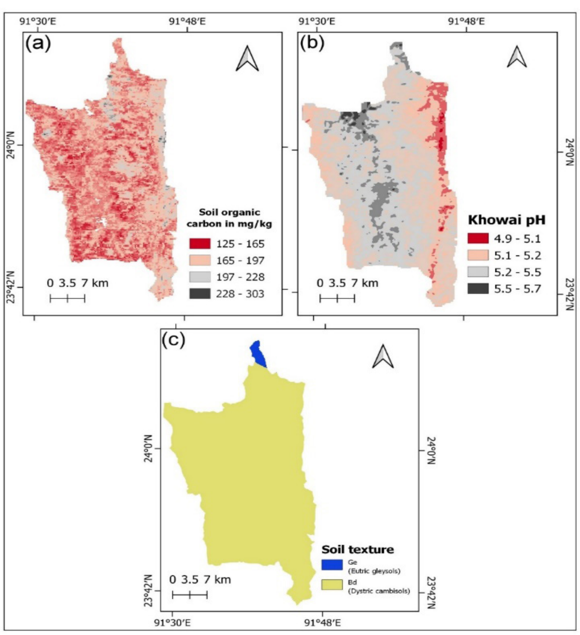

Fig. 5: Soil factors a) Soil organic carbon, b) Soil pH, and c) Soil texture in study area

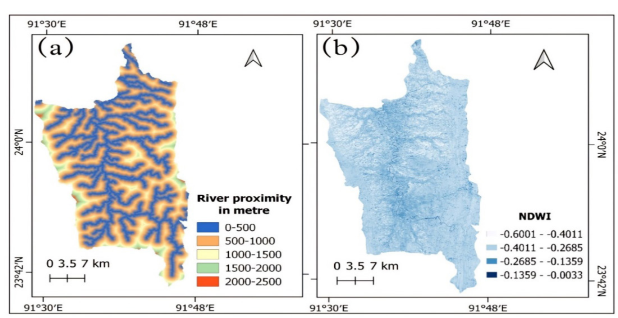

Fig. 6: Hydrological factor a) River proximity, and b) NDWI in the study area

Table 3: Weightage value of the selected sub-factors

Sub-Factors (f)	Categories	Suitability classes	Area (Sq. km)	Area (%)	Weightage Value
Elevation (m)	19-100	S1	696.44	66.84	0.149
	100-200	S2	293.95	28.21	
	200-300	S3	41.95	4.03	
	300-436	N	9.55	0.92	
Slope in degrees	0-7.5	S1	907.2	87.1	0.135
	7.5-15.5	S2	116.37	11.2	
	15.5-23.5	S3	17.86	1.6	
	23.5-36	N	0.46	0.1	
Landforms	Antiformal, Strike Ridge, Pond, River Strike Ridge	N	135.69	13.02	0.158
	Highly Dissected	S3	10.03	0.96	
	Synformal	S2	507.32	48.69	
	Valley Fill	S1	388.85	37.32	
Rainfall (mm)	1390-1542	S3	516.94	49.62	0.044
	1542-1687	S1	285.74	27.42	
	1687-1831	S2	81.5	7.82	
	1831-1980	N	157.71	15.14	
Temperature	24.20-24.45, 24.91-25.2	S2	837.87	80.42	0.061
	24.45-24.91	S1	204.02	19.58	
RH (%)	78.30-79.14,80.66-81.45	S2	820.18	78.72	0.020
	79.14-80.66	S1	221.71	21.28	
Soil texture	Eutric gleysols (Ge)	S2	16.3	1.6	0.055
	Dystric cambisols (Bd)	S1	1025.59	98.4	
Soil pH	4.9-5.1	S3	1015.1	97.43	0.026
	5.1-5.2	S2	22.35	2.14	
	5.2-5.7	S1	4.44	0.43	
Soil OC	125-165	S3	640.48	61.47	0.023
	165-197	S1	119.43	11.43	
	197-228	S2	273.43	26.24	
	228-303	N	8.86	0.86	
NDWI	< -0.27	S1	461.55	44.3	0.091
	-0.27 - -0.13	S2	570.24	54.7	
	-0.13 - -0.003	S3	7.92	0.8	
	>-0.003	N	2.18	0.2	
River proximity	0-500	S1	310.02	29.76	0.106
	500-1000	S2	221.77	21.28	
	1000-2500	N1	510.10	48.96	
NDVI	<0.12	S1	100.37	9.61	0.035
	0.12-0.22	S2	658.02	63.17	
	0.22-0.32	S3	278.09	26.69	
	>0.32	N	5.41	0.52	

	Water	N	181.92	17.6	
LULC	Agriculture, plantation	S1	266.77	25.8	0.096
	Vegetation	S2	541.89	52.4	
	Settlement	S3	42.83	4.2	

concentrated along the course of the Khowai River. The Khowai district, as observed from the map, predominantly features sparse vegetation, exemplified by an NDVI value of 0.2921. The lower vegetation cover is notably evident in the south-central region and along the Khowai River regions. This area is primarily utilized for agriculture, shifting cultivation, and plantation crops in the valley and uneven terrains (Raju, 2015). Contrastingly, in the northern reaches of Khowai, an NDVI value of 0.4330 signifies significantly higher vegetation cover, primarily attributed to the prevalence of evergreen forests and plantation crops (Table 3 and Fig. 7a).

Land Use and Land Cover (LULC)

Khowai district's land use and cover mapping has been developed to assess the distribution of various human activities engaged in land use. Nevertheless, based on the current research, the research area can be divided into 5 types, namely, vegetation, waterbodies, agriculture, plantation, and settlement. The LULC of Khowai district demonstrates that the majority of the area is covered by natural vegetation, i.e., approximately 541 sq.km, where the east and west parts of Khowai are largely covered by dense forest (Table 3 and Fig. 7b). Agricultural area, on the other hand, are moderate in the Khowai district due to the Khowai river and many water bodies like ponds and lakes located in the central part of the district, which provide fertile land and valley areas for agricultural practices.

Land Capability for Agricultural Suitability of Khowai District

Land capability represents the inherent potentiality of a given area to sustain various land uses over the years. In Khowai District, the capability classification follows eight distinct classes, ranging from highly suitable to permanently unsuitable for agriculture, based on factors such as landforms, proximity to rivers, Normalized Difference Water Index (NDWI), elevation, and slope (Rashed, 2019).

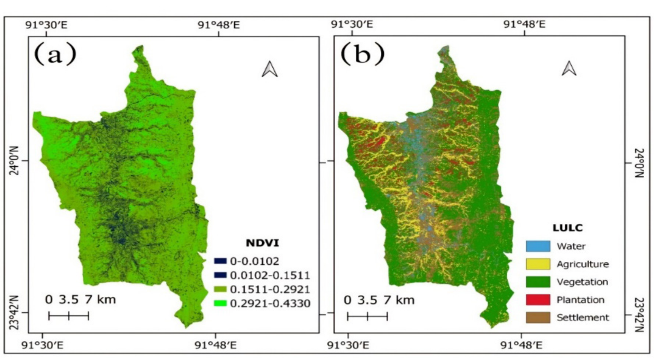

Fig. 7: Environmental Factor a) NDVI, and b) LULC in the study area

The analysis reveals that Class I land, covering an area about 10.53% of the total area, is highly competent and offers maximum potential for diverse agricultural activities without significant limitations. Class II land (37.82%) is also of good quality but faces minor constraints such as erosion risk. Moderate capable land (Class III) encompasses 26% of the total area, characterized by moderately steep slopes and erosion risk. Fairly good land (Class VI), considered for approximately 12.71% of the area, is hindered by its hilly terrain and steep slopes. Meanwhile, 9.8%, 2.4%, and 0.5% of the total area are categorized as Class V, VI, and VII, respectively. These categories indicate that the land is not appropriate for agricultural operations but is instead ideal for pasture and grazing, with limits that restrict its usage. Permanently not capable land (Class VIII), constituting 0.24% of the total area, is unsuitable for crop production and reserved primarily for recreational, wildlife, and aesthetic purposes. This class is mainly found in the southern hilly region of the district, where the physiographic characteristic is high elevation and steep slope topography with dense vegetation cover, posing an unsuitable environment for human activities. Overall, the findings highlight that while a substantial proportion of Khowai District has well suitable for agricultural activities i.e., 48.35%, moderate agricultural activities is 26% but steep slopes and erosion risk and remain area under constraints of topographical and environmental factors and remain 23.65% unsuitable (Table 4) & (Fig. 8).

Land Suitability for agriculture of Khowai District

Land suitability involves assessing the appropriateness of an area for particular agricultural crops. Based on some major food grain crops like paddy, maize, and wheat, the suitability analysis for the region has been performed. According to FAO guidelines, the final suitability map of Khowai district has been categorized into four classes: highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N) (Ghabour *et al.*,

Table 4: Classification of land capability for agricultural suitability (in sq. km)

Classes	*Area (in sq.km)*	*Area in %*
Class I	109.81	10.53
Class II	394.13	37.82
Class III	270.74	26
Class IV	132.4	12.71
Class V	102.14	9.8
Class VI	25.04	2.4
Class VII	5.03	0.5
Class VIII	2.6	0.24

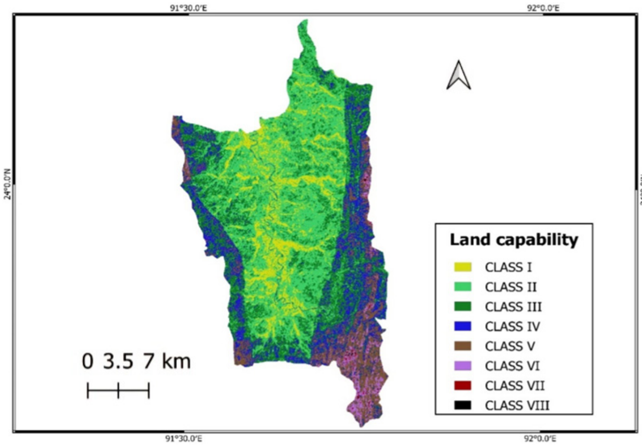

Fig. 8 : Land capability for agricultural suitability in Khowai district, Tripura

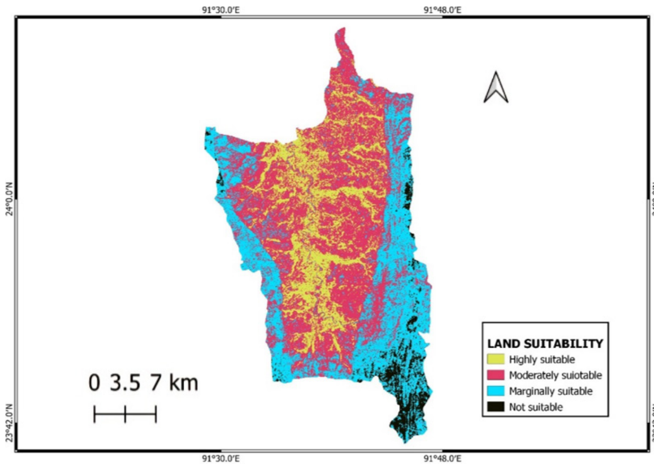

Fig. 9 : Land suitability for Agriculture in Khowai district, Tripura

2008). The classification is based on a comprehensive analysis of various factors, including landforms, river proximity, NDWI, elevation, slope, temperature, land use and land cover (LULC), soil texture, organic carbon content, rainfall, relative humidity, and NDVI, which collectively determine the suitability ranging from highly suitable (S1) to not suitable (N). The Khowai district's final suitability map, combining thirteen crucial criteria's, reveals that 194.28 sq. km (18.65%) of land is highly suitable for agriculture, while 492.77 sq. km (47.3%) is moderately suitable, reflecting the district's substantial potential for intensive agriculture with proper planning and management. These agriculturally favorable areas feature flat terrain, even topography, gentle slopes, optimal soil moisture, loamy soil composition, and suitable temperature and rainfall conditions. The central region, which benefits from fertile alluvial sediments deposited by the Khowai River, predominantly falls within the suitable agriculture zone. (Table 5) illustrates that approximately 298.96 sq. km (28.69%) are marginally suitable for development. These areas, characterized by hilly to undulating terrain, moderate to high slopes, acidic soil, poor soil moisture, coarse loam soil, and proximity to forested areas, require intensive farming practices and soil erosion control measures such as tillage conservation and crop rotation to enhance agricultural productivity. This study also identifies 55.88 sq. km (5.36%) as permanently unsuitable, mainly situated in the eastern and western parts of the Khowai District. These areas characteristics like dense vegetation, steep and undulating terrain, rocky surfaces, built-up regions, and highly acidic soils produced the land as unsuitable for agriculture. Furthermore, the agricultural potential in these places is restricted by the existence of forest canopy cover and the lack of adequate water management (Fig. 9).

Table 5: Classification of land suitability (in sq.km)

Suitable Class	*Area (in sq.km)*	*Area in %*
Highly suitable (S1)	194.28	18.65
Moderately suitable (S2)	492.77	47.3
Marginally suitable (S3)	298.96	28.69
Not suitable (N)	55.88	5.36

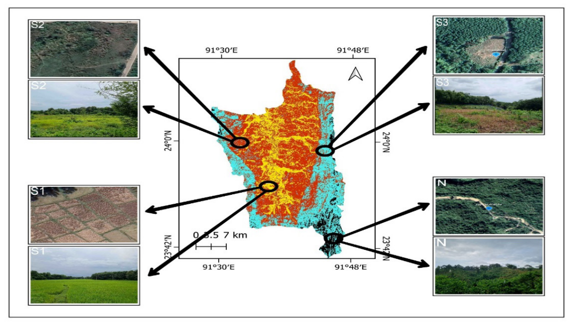

Fig. 10 : Ground truth verification of land suitability classes in Khowai District, Tripura

Ground Truth Verification

The primary approach for assessing the accuracy of classified images involves comparing its findings to ground truth data, which is essential to establish its reliability. The current study has implemented two validation techniques, which include a comparison between the suitability map and Google Earth images, as well as a comparison with real on-site photographs. Among these techniques, the comparison with Google Earth images emerged as the most dependable method for validating the result. To carry out this process, the study has identified highly suitable sites in Google Earth images and compared them with the obtained results. This comparison revealed a close alignment between the generated agriculture suitability map and the sites identified in Google Earth and actual field site photos, thus confirming the validity of the resulting findings (Fig. 10).

Conclusion

The land capability and land suitability for agriculture of Khowai districts worked out based on thirteen key factors, elevation, slope, landforms, rainfall, temperature, relative humidity, soil pH, soil texture, soil organic carbon, Normalised Difference Water Index, river proximity, land use land cover and Normalised Difference Vegetation Index. Land capability for agricultural purpose classified class -I to VII, but class -I and class -II land were highly potential for agricultural activities, class -III land moderately capable, the remain classes were not appropriate. Further, the land suitability for agriculture crops mapped for Khowai district, as per FAO, it has been categorized into four classes: highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N). Approximately 194.28 sq. km (18.65%) of the land is highly suitable (S1) for agriculture, offering fertile soils with excellent water retention and amenable to permanent irrigation systems. Moderately suitable (S2) an area covers about 492.77 sq. km (47.3%), it is characterized by moderate slopes, erosion risk, limited soil depth, and moderate fertility, indicating a careful management require for enhancing the crop productivity. Marginally suitable (S3) regions cover an area about 298.96 sq. km (28.69%) pose challenges like erosion susceptibility, shallow soils, and poor drainage. Intensive farming and erosion control measures are necessary in this study area. Notably, 55.88 sq. km (5.36%) are permanently unsuitable due to steep terrain, acidic soils, and dense vegetation. These areas have limited agricultural potential and should be conserved for other purposes. The result emphasizes the need for strategic land use planning, focusing on maximizing productivity in suitable areas while conserving ecologically sensitive zones. Proper land use management practices would play a pivotal role in achieving sustainable agricultural development in Khowai district.

Author contribution

All authors contributed equally.

Conflict of Interest

No conflict of interest among the authors.

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