GIS-Based Assessment of Land Suitability for Rubber Cultivation in Chittagong District, Bangladesh

Md. Ahasanul Hoque[1*], *Rezwan* Ahmed[2]

[1]Geospatial and Data Management Expert, The World Bank, Dhaka – 1207, Bangladesh
[2]Department of Geography and Environment, University of Dhaka, Dhaka - 1000, Bangladesh

Abstract. This research examines the viability of rubber cultivation in Chittagong, Bangladesh, employing Geographic Information System (GIS) methodologies and a detailed multi-criteria model. Given Bangladesh's conducive agroclimatic conditions, rubber cultivation offers a promising avenue for sustainable economic expansion. This study evaluates essential parameters such as temperature, elevation, slope, soil texture, pH, and depth to gauge the aptness of land for rubber plantations. The research's main objective is to identify the potential of rubber cultivation in Chittagong, given its climatic advantages and economic incentives. This analysis aids stakeholders, including policymakers, farmers, and investors, in aligning with larger goals of economic development and agricultural diversification. Key findings suggest that Chittagong's attributes, including optimal temperature, suitable elevations, moderate slopes, and fitting soil properties, make it ideal for rubber cultivation. Further analysis incorporates factors like land use and river proximity. The central region emerges as particularly promising, while urban and aquatic regions are omitted, highlighting conscientious land use. These insights can guide stakeholders toward sustainable rubber cultivation, fostering rural development, job creation, and foreign exchange benefits in Bangladesh. This research is pivotal for the economic diversification strategy and the sustainable growth of rubber cultivation in the area.

1 Introduction

Bangladesh, a country known for its agriculture, tea plantations, and fruit orchards, could thrive in the rubber (Hevea brasiliensis) plantation business, which is still relatively young in Bangladesh compared to other nations because the country's environment is ideal for the production of rubber. Due to these advantageous conditions, the government has encouraged plantings in hilly areas since 1980; however, only roughly 45,000 acres of land have been allocated to the BFIDC and 32,500 acres to private landowners for rubber plantations as of yet. In Bangladesh, rubber plantations are primarily located in areas such as Madhupur, Sherpur, Rangamati, Bandarban, Chittagong, Khagrachari, Cox's Bazar, Sylhet, and Mymensingh. The country features 1,304 private and 29 government-managed plantations, in addition to various community and privately-owned gardens. Altogether, these plantations cover an area of 140,000 hectares and produce an annual yield of 67,939 metric tons of latex. The ability of rubber trees to absorb carbon three times more efficiently than any other tree makes them a valuable resource for the Global Carbon Trading and Environmental Fund, which offers millions of dollars in foreign currency.[1] The development of this industry is also influenced by a wide range of additional factors. There is a significant gap left as more nations switch from producing rubber to producing palm oil, which might be filled by potential Bangladeshi producers. [2]

Bangladesh's rubber production is expanding as a result of rising internal demand and booming exports, mainly to India's neighbor. In the current fiscal year, rubber export revenues increased dramatically by 57 percent year over year to $28 million from $18.3 million in the prior year's comparable period. The most recent export statistics outperformed earnings data from previous years, with the exception of the most recent fiscal year, when overall earnings reached $34 million, the most in ten years. [3]

In summary, a well-executed land suitability analysis for rubber production in Bangladesh can not only boost agricultural and industrial output but also promote rural development, employment, and foreign exchange earnings. It plays a vital role in diversifying the economy, reducing import dependency, and contributing to sustainable economic growth. However, it's important to ensure that this expansion is carried out with responsible and sustainable practices to maximize long-term benefits.

The suitability of the land to provide the best prospects for a specific land use form directly and significantly affects the appropriateness of that land use form. Thus, land suitability is a crucial fundamental element in the management of

* Corresponding author: hoque.ahasan@gmail.com

the environment. The optimum approach to use a certain piece of land is determined by the results of a land suitability evaluation. In other words, it alludes to a certain category of land use. Geographic Information System (GIS) techniques have evolved into essential tools for land use planning, fostering sustainable development across the globe. In agriculture, they have played a pivotal role in determining optimal locations for different types of cultivation based on a variety of environmental, climatic, and socio-economic factors. One such promising venture is the cultivation of rubber especially in Bangladesh, where the agro-climatic conditions are highly favorable for this type of plantation.

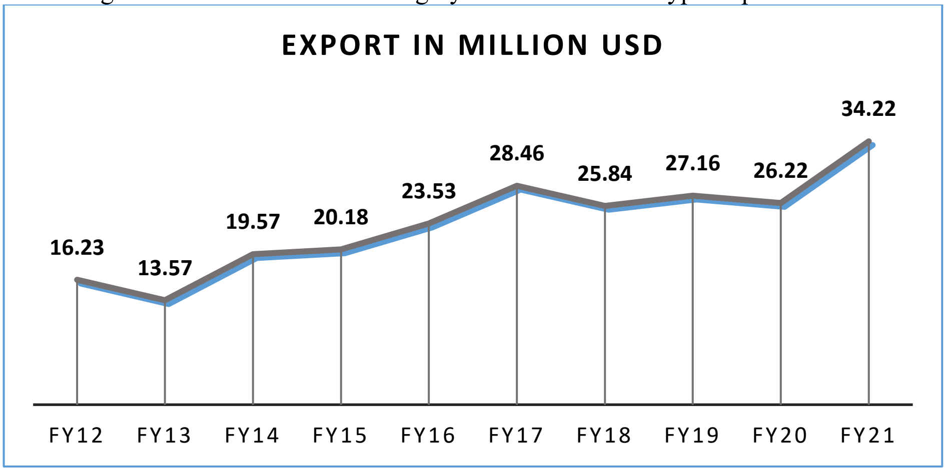

Fig. 1. Rubber export scenario in Bangladesh.

Implementing GIS techniques allows for a systematic analysis of the land characteristics, rainfall, soil type, precipitation patterns, and other critical factors to identify potential zones suitable for rubber cultivation in Bangladesh. By merging this technological advancement with the country's agricultural practices, Bangladesh can maximize the yield and economic benefits, while also contributing positively to global climate change mitigation efforts.

1.1 Objectives

- To systematically assess and determine the potential areas or parcels of land in Chittagong district are most suitable for cultivating rubber trees.
- To build a GIS based multi-criteria model for land suitability analysis for finding potential areas of land for rubber production in Bangladesh.

1.2 Scope of the Study

The study’s primary focus lies within the Chittagong district of Bangladesh, where it endeavours to ascertain the suitability of land for rubber tree cultivation by conducting a comprehensive analysis of factors encompassing soil quality, climate, topography, and socio-economic conditions. The study’s intended beneficiaries encompass policymakers, farmers, and prospective investors who harbour an interest in advancing rubber cultivation within the Chittagong district, with the overarching objective of harnessing rubber’s economic potential for the development and diversification of Chittagong’s agricultural landscape. In future use, this study provides an invaluable resource for those seeking to make informed decisions regarding rubber cultivation in this region, promoting sustainable economic growth and land use planning.

2 Materials and Method

2.1 Study Area

Chittagong is one of the oldest and biggest districts in Bangladesh located, in the south-eastern region of Bangladesh with an area of 5283 sq km^2. Chittagong District (Figure 2) is characterized by its diverse topography, encompassing both low-lying coastal areas and the Chittagong Hill Tracts in the east. The district is intersected by several rivers, including the Karnaphuli, Sangu, and Matamuhuri, providing a network of water resources. The hills and valleys offer varying altitudes and microclimates, which are essential considerations for rubber cultivation. Chittagong is known for its strategic location as the country's primary seaport. This district is not only economically significant but also ecologically diverse, making it an ideal candidate for site suitability analysis for rubber cultivation.

2.1.1 Climatic Conditions

Chittagong District experiences a tropical monsoon climate. It is influenced by the Bay of Bengal, leading to high humidity levels and substantial rainfall during the monsoon season. The climatic conditions of the district manifest as discernible wet and dry phases, exerting influence on the growth and productivity of rubber trees.

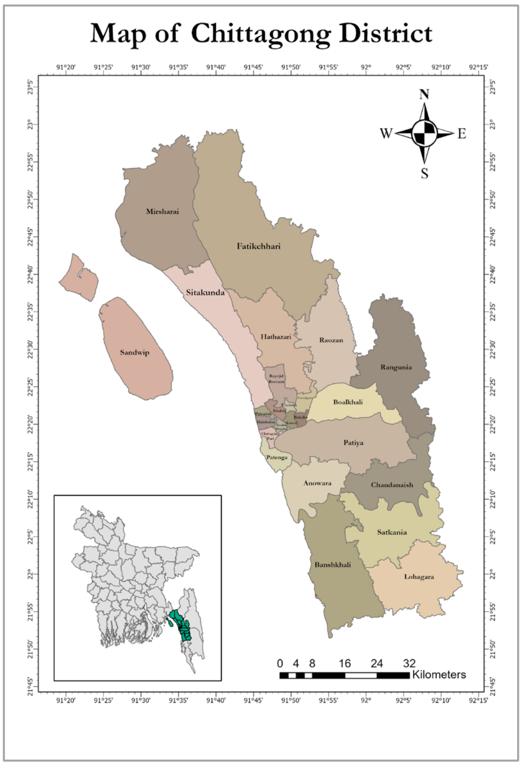

Fig. 2. Map of the study area.

2.1.2 Rainfall

In the climatic context of Chittagong, significant seasonal fluctuations in monthly precipitation levels are observed. According to data sourced from the Bangladesh Meteorological Department, the region undergoes a prolonged wet phase that spans approximately 9.8 months, commencing on February 16 and culminating on December 9. Throughout this interval, the mean cumulative rainfall is reported to be 2,700 millimetres. Of particular note is the month of July, which emerges as the wettest month, characterized by an average precipitation level of 443 millimetres. In contrast, the region witnesses a dry phase lasting for 2.2 months, which extends from December 9 to February 16. This study underscores the acute variability in precipitation patterns in Chittagong, which holds implications for water resource management and ecological sustainability in the area.

2.1.3 Vegetation and Land Use

The natural vegetation in Chittagong District includes evergreen forests, mangroves along the coast, and various types of grasslands. Agriculture is a significant contributor to the district's economy, with rice, jute, tea, and betel leaf being some of the primary crops. However, there is untapped potential for rubber cultivation, which can diversify the agricultural landscape.

2.1.4 Socio-Economic Context

Chittagong District is home to a diverse population, including indigenous communities in the Chittagong Hill Tracts. The socio-economic status of the inhabitants varies, with agriculture being a primary source of livelihood for many. Introducing rubber cultivation could contribute to increased income and employment opportunities.

2.2 Methodology

The methodology for site selection is predicated on a defined set of local criteria, encompassing factors such as current land use, slope gradient, soil depth, soil texture, precipitation levels, and proximity to water bodies.[4] To quantitatively evaluate site suitability, a scoring and weighting system was implemented across these multiple dimensions. A comprehensive schematic of the methodology is illustrated in Figure 3.

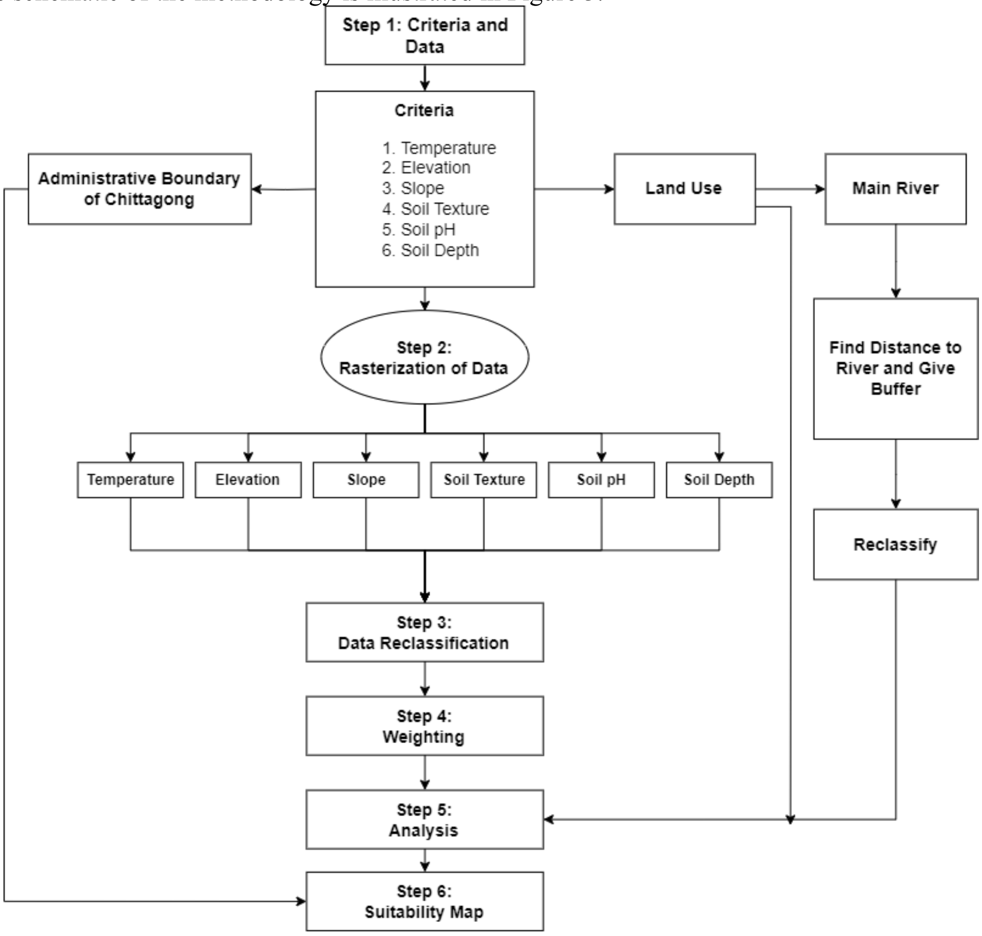

Fig. 3. Flow diagram of overall methodology of land suitability analysis.

2.2.1 GIS Based Land Suitability Analysis

In contemporary land use planning and environmental science, Geographical Information Systems (GIS) have emerged as indispensable tools for site suitability analysis. The multifaceted capabilities of GIS offer more than just spatial visualization; they provide a platform for the integration, manipulation, and interpretation of multifarious datasets that can depict land characteristics and potential impacts of various land uses.[5] Critical to any suitability analysis is the foundation of base data. Land qualities relevant to this study included existing land use, slope, water bodies, flood hazards, soil attributes, annual rainfall, and more. [6] A composite score is then generated, culminating from the weighted attributes affecting suitability. For this assessment, the parameters delineated for suitability analysis encompassed are: (i) Temperature; (ii) Elevation; (iii) Slope; (iv) Soil Texture; (v) Soil pH; (vi) Soil Depth; (vii) Existing Land use; (viii) Rainfall; (iv) Rivers/streamlines.

In the context of Chittagong District, Bangladesh, where diverse landscapes from hills to coastlines intersect, the nuanced approach offered by GIS is particularly crucial. Ensuring sustainable and beneficial land-use outcomes necessitates a delicate balance between environmental conservation, social imperatives, and economic development, a balance that can be efficiently negotiated with the analytical depth of GIS.

2.2.2 Data Collection

Data forms the cornerstone of any analysis. GIS amalgamates spatial and attribute data, creating potent insights by relating them. [7] The study required a comprehensive amount of spatial and attribute data, focusing on variables pertinent to site selection. The data were collected (Table 1), such as mean surface temperature, annual rainfall, soil texture, elevation, and existing land use patterns, from several GIS databases, tailored explicitly to Chittagong District. The following table catalogs the data types and their sources:

Table 1. Data, data type and data sources.

SL No.	Data Name	Data Type	Sources
1.	Temperature	Raster	BMD
2.	Elevation	Raster	NASA 30m SRTM DEM
3.	Slope	Raster	NASA 30m SRTM DEM
4.	Soil Texture	Vector	Bangladesh Agricultural Research Council
5.	Soil pH	Vector	Bangladesh Agricultural Research Council
6.	Soil Depth	Vector	Bangladesh Agricultural Research Council
7.	Land use	Vector	Supervised classification of Landsat 9 Imagery
8.	Rainfall	Raster	World Clim Historical Data
9.	Rivers	Vector	Survey of Bangladesh

2.2.3 Data Processing

For the digital manipulation of the data, the assessment leaned on the functionalities of the ArcGIS Pro. Through its myriad extensions, including spatial analysis and Geo-processing, the data were proficiently processed and generated the desired outputs.

2.2.4 Spatial Analysis

In the realm of geo-processing, satellite imagery played a pivotal role, enabling the identification of regions with the optimal vegetation index, thereby indicating their suitability for rubber cultivation. Advanced GIS tools such as weighted overlay, Euclidean distance, buffer, intersect etc. were employed to overlay multifaceted data layers, encompassing aspects such as soil texture, pH, slope, elevation, prevalent rainfall patterns, and current land use. This layered approach provided a comprehensive view of the land's potential for rubber cultivation. According to Bangladesh Meteorological Department, on average, the district receives around 2500 mm to 3000 mm of rainfall annually, with the majority of it occurring during the monsoon season, which typically spans from June to September. Hence, the entire Chittagong district falls under a highly suitable region for rubber growth and due to this important criterion (rainfall) for rubber cultivation and growth, has been ignored in the spatial analysis portion.

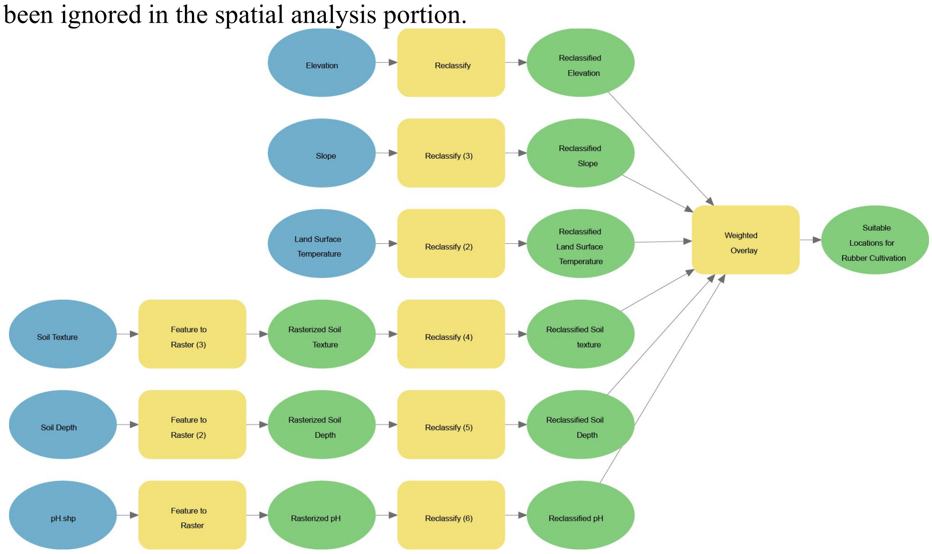

Fig. 4. Flow diagram of overall methodology of land suitability analysis.

2.2.5 Geo-processing

Geo-processing played a pivotal role in this assessment, acting as the bridge between raw data and actionable insights. Satellite imagery was employed as the primary tool for remote sensing, enabling the identification of regions with the optimal vegetation index, urban areas, waterbodies etc. These images provided a high-resolution view of the land's topography, vegetation density, and other critical factors that could influence rubber cultivation. The GIS mapping also facilitated the visualization of areas already under cultivation, urbanized zones, and protected regions, thereby aiding in pinpointing regions that could be converted to rubber plantations without causing significant environmental or socio-economic disruptions.

2.2.6 Weighted Overlay Based Suitability Assessment

This assessment was not a mere overlay of data but a deep dive into several critical ecological parameters using weighted overlay technique that play a pivotal role in land health and productivity. Weighted overlay represents a method employed in suitability modeling, and ArcGIS employs the subsequent procedure for conducting this analysis. In this assessment, within the framework of suitability analysis, each individual raster layer of criteria was allocated a specific weight. For the suitability assessment analysis, thorough literature review and sectoral expert opinions were conducted on the suitable conditions for rubber growth. The values contained within these raster layers are subsequently transformed and reclassified onto a uniform suitability scale (high, moderate, low) and used in a geo-processing model (Figure 4). The output of the review is noted in table 2.

Table 2. Criteria parameters, the level of suitability and scores for assessment. [8][9][10]

Factor	Class	Description	Weight
Temperature	25 - 34^0 C	High Suitable	25
	17 -25^0 C	Moderate Suitable	
	>34^0 C	Low Suitable	
Elevation	40 - 250 m (Low to Mid Elevations)	High Suitable	10
	250 - 450m (Mid to High Elevations)	Moderate Suitable	
	>450m (High Elevations)	Low Suitable	
Slope	0-8% (Gentle Slope)	High Suitable	15
	8-20% (Moderate Slope)	Moderate Suitable	
	>20% (Steep Slope)	Low Suitable	
Soil Texture	sandy clay loam	High Suitable	25
	sandy loam, loam	Moderate Suitable	
	Clay, clay loam	Low Suitable	
Soil pH	pH 6.0 – 7.0 (Slightly Acidic to Neutral pH)	High Suitable	10
	pH 5.5 – 6.5 Moderately Acidic to Slightly Alkaline pH	Moderate Suitable	
	pH < 5.5 or > 7.5 (Highly Acidic or Highly Alkaline pH)	Low Suitable	
Soil Depth	>1meter (Deep)	High Suitable	15
	0.6 -1meter (Medium)	Moderate Suitable	
	< 0.6 meter (Shallow)	Low Suitable	
Total			100

3 Result and Discussion

3.1 Criteria for rubber cultivation

3.1.1 Temperature

Temperature is of paramount importance in rubber cultivation because it directly influences the growth, development, and overall productivity of rubber trees (Hevea brasiliensis). The highly suitable range of temperature is 24°C to 35°C (75°F to 95°F) that provides the most favorable conditions for rubber cultivation. Temperatures falling between 18°C to 24°C (64°F to 75°F) are considered moderately suitable for rubber growth. [11] In this range the growth may be slower, and latex production may not be as high, but it's still feasible. Temperatures below 18°C (64°F) are generally considered low suitable for rubber cultivation due to slower growth and reduced latex production [8][9][10]. The temperature profile [Figure 5 a(i)] of Chittagong district mostly favorable for rubber cultivation because most of the area fall under high suitable in terms of temperature followed by moderate and low suitable areas after the raster reclassification [Figure 5 a(ii)].

3.1.2 Elevation

Rubber cultivation is highly suitable in regions with low to mid elevations typically ranging from sea level up to around 500 meters above sea level. These elevations provide favorable temperature and climatic conditions for the healthy growth of rubber trees. Elevations between 200 meters to 500 meters above sea level can be considered moderately suitable for rubber cultivation. Elevations above 500 meters are generally considered less suitable for rubber cultivation. At higher elevations, temperatures tend to be lower, which may negatively impact the growth and latex production of rubber trees.[10][13][14] The distribution of land elevation of study area illustrated that the overall land elevation is maximum 330 meter in Chittagong district [Figure 5 b(i)]. After reclassification, elevation in the study area is divided into three classes: 40-250 meter, 250-450 meters and greater than 500 meters, which is illustrated in [Figure 6 b(ii)]. It can be stated that overall study area is highly suitable for rubber cultivation considering land elevation.

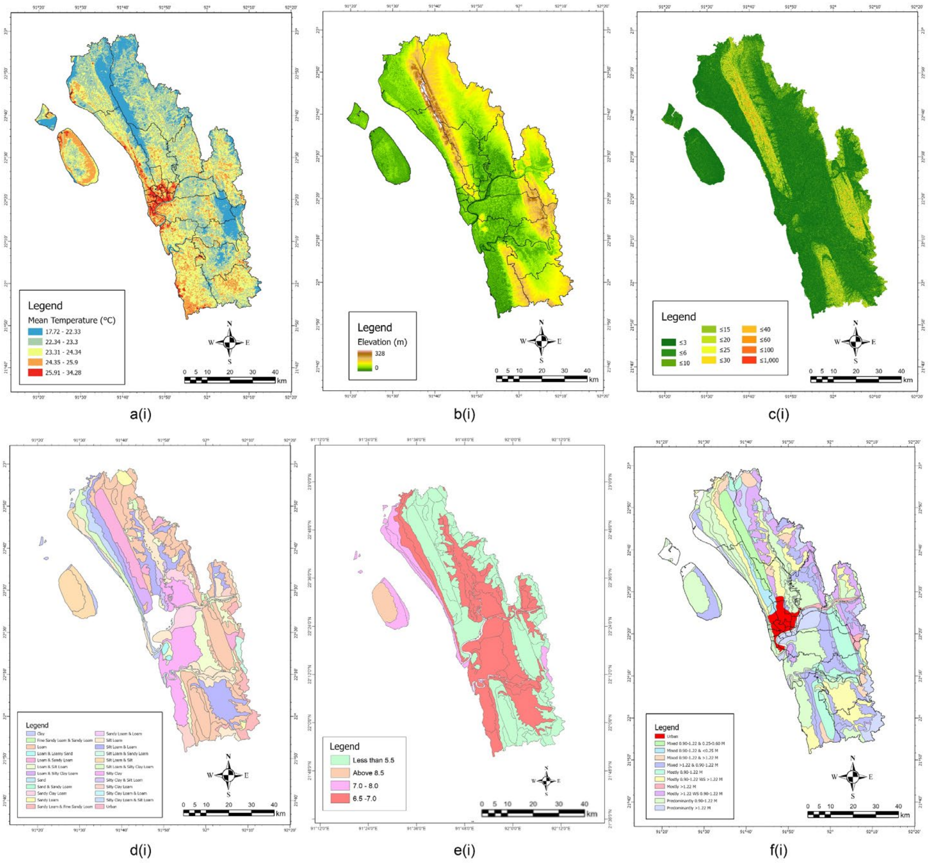

Fig. 5. Criteria for rubber cultivation.

3.1.3 Slope

Rubber cultivation is highly suitable on gentle slopes, typically ranging from 0% to 8%. These slopes provide adequate water drainage and reduce the risk of erosion, which is essential for the successful establishment and growth of rubber trees. Slopes between 8% to 20% can be considered moderately suitable for rubber cultivation[8][9][10] [Figure 5 c(i)] shows the distribution of land slope of study area. After reclassification, slope in the study area is divided into three classes, high suitable (0-8%), moderately suitable (8-20%) and low suitable (steeper slope, >20%), which is illustrated in [Figure 6 c(ii)]. It is found that considering land slope, Chittagong district is highly suitable for rubber cultivation.

3.1.4 Soil Texture

For optimal root penetration, nutrient absorption, and water drainage, rubber trees necessitate loamy soils. Such soils balance moisture retention and drainage, ensuring aeration and preventing waterlogged conditions detrimental to the roots. Sandy Clay Loams are best to grow rubbers in Bangladesh. Chittagong, blessed with a deltaic and fluvial landscape, boasts significant areas of loamy soil composition.[15] From the spatial data the distribution of soil texture portrays a vivid range of soil classes [Figure 5 d(i)]. The raster reclassified map of soil texture indicates that most of the areas of Chittagong district comprises sandy loam and loam soil, which is moderate suitable for rubber cultivation followed by high (sandy clay loam) and low (clay, clay loam) suitable areas [Figure 6 d(ii)]. Most of the higher suitable soil texture for rubber cultivation available in the central and southeastern part of the district.

3.1.5 Soil pH

Rubber trees can tolerate a slightly wider pH range; however, careful soil management practices may be necessary to ensure optimal nutrient availability in the soil. Rubber cultivation is highly suitable in soils with a slightly acidic to neutral pH ranging from 6.0 to 7.0. This pH range provides an optimal environment for the availability of essential nutrients required for the healthy growth and latex production of rubber trees. Soil pH ranging from 5.5 to 6.5 can be considered moderately suitable for rubber cultivation. Soils with highly acidic or highly alkaline pH levels, i.e., below 5.5 or above 7.5, are generally considered less suitable for rubber cultivation. Extreme pH levels can adversely affect nutrient availability and uptake by rubber trees, leading to nutrient deficiencies and poor growth [8][9][10] The soil pH of the Chittagong district is distributed from 6.5 to more than 8.5 [Figure 5 e(i)]. and after reclassification, the soil pH is divided into three classes high suitable (pH 6.0 – 7.0); moderate (pH 5.5 – 6.5; low (< 5.5 or > 7.5) suitable, which are illustrated in [Figure 6 e(ii)]. It also stated that the overall study area is highly and moderately suitable for rubber cultivation.

3.1.6 Soil Depth

Rubber cultivation is highly suitable in areas with deep soil profiles exceeding 1 meter. Deep soil provides ample room for root development, ensuring access to nutrients, water, and anchorage for the rubber trees. Soil depth ranging from 0.6 to 1 meter are considered moderately suitable for rubber cultivation. Soils with shallow depths of less than 0.6 meter are generally considered less suitable for rubber cultivation. Surveys of Chittagong's soil depth reveal profiles that are predominantly deeper than 1.5 meters, ensuring ample space for root expansion [15]. [Figure 5 f(i)]. shows the distribution of soil depth of Chittagong district and after reclassification, soil depth of Chittagong is divided into three classes: high, moderate and low in terms of suitability for rubber cultivation [Figure 6 f(ii)]. The analysis suggests that the majority of regions within the Chittagong district exhibit moderate suitability for rubber cultivation, followed by areas of high and low suitability.

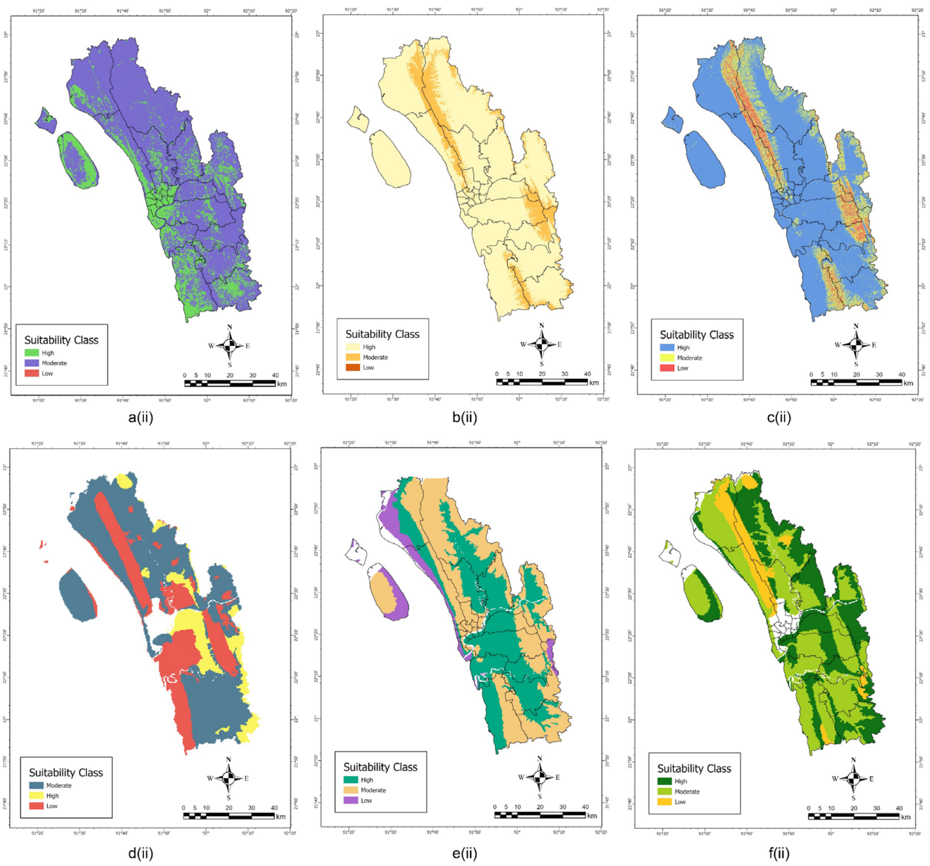

Fig. 6. Reclassified to suitability of criteria for rubber cultivation.

3.2 Suitability Map of Chittagong District

3.2.1 Weighted Suitability Map of Chittagong District

According to the weighted suitability map, which employs specified criteria parameters for rubber cultivation, three distinct suitability classes are identified: highly suitable, moderately suitable, and low suitable. The data reveals that the Chittagong district, in general, ranges from moderate to high suitability for rubber cultivation. Specifically, regions in the Southern, Eastern, lower Northern, and Western parts of the district are identified as highly suitable for this agricultural practice.

3.2.2 Sensitivity Analysis

In determining viable regions for rubber cultivation, a comprehensive evaluation of current land use is paramount. Parcels dedicated to water bodies or agricultural activities should be sidelined from consideration due to their inherent incompatibility with rubber farming conversion. Equally, the ecological and socio-cultural value of forested regions necessitates their preservation and exclusion from potential cultivation sites.[16] A weighted suitability map, pivoted on physical parameters, demarcates optimum zones predominantly in the southern and mid-eastern parts of the district. The natural proclivities of rubber trees, which display an aversion to inundation and water stagnation, mandate the incorporation of proximity to rivers as a pivotal criterion [Figure 7 a]. Urban landscapes and forested regions[Figure 7 c] should also be omitted. For enhanced clarity, suitability was categorized based on river proximities: 0-5 km (low suitability), 5-25 km (high suitability), and >25 km (moderate suitability) [Figure 7 b]. Land use data from the Chittagong district elucidate the prevalence of croplands, vegetative, and built-up sectors. Water bodies are discernible, particularly centrally [Figure 7 c]. The definitive rubber cultivation expanse is computed by excising these unsuitable tracts from the initially earmarked suitable terrain, grounded on stipulated criteria.

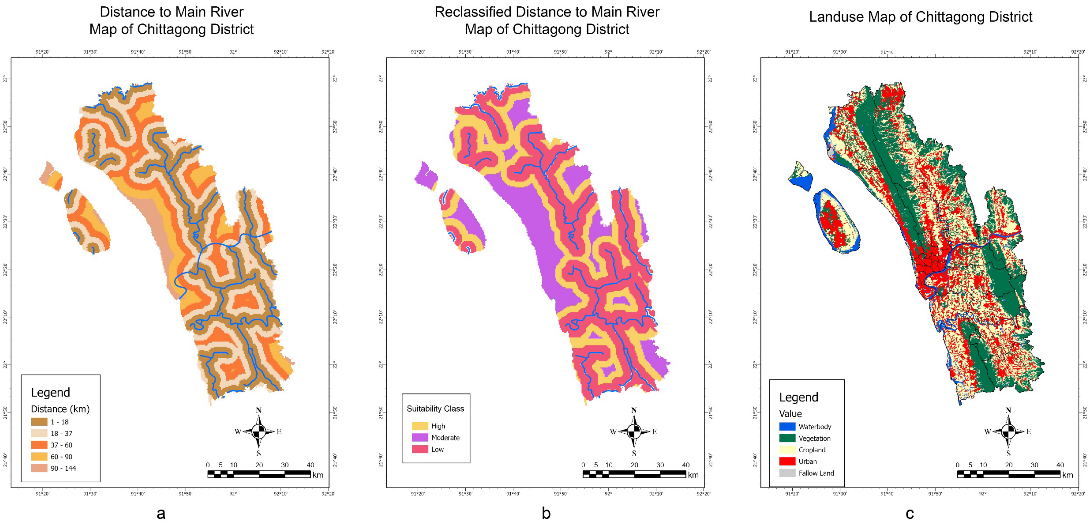

Fig. 7. Sensitivity criteria for suitability analysis for rubber cultivation in Chittagong district.

3.2.3 Final Suitability Map for Rubber Cultivation

The final suitability map involves the sensitivity analysis using distance to river [Figure 8 a] and land use profile [Figure 8 b] of Chittagong district to achieve the potential suitable area for rubber cultivation. From this figure it can be illustrated that the area which remains after subtracting the urban land use and considering the buffer of more than 5 kilometers, is suitable for rubber cultivation. Therefore, some regions, especially the central region becomes suitable for rubber cultivation [Figure 8 c].

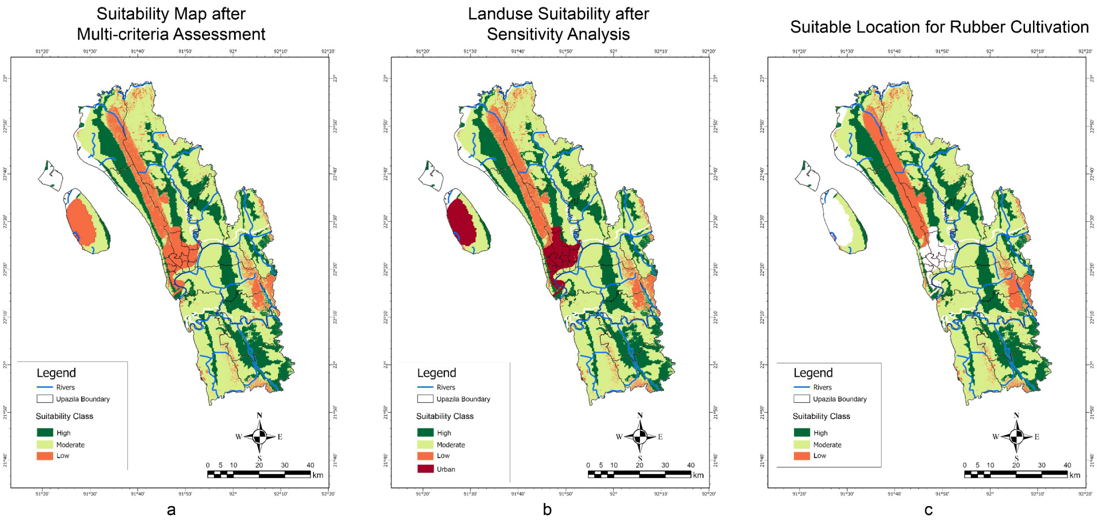

Fig. 8. Land suitability map for rubber cultivation in Chittagong district.

The final output reveals that there are 609.86 km^2 areas are found highly suitable, 2970.33 km^2 is moderately suitable, 1429.3 km^2 for rubber cultivation and 273.61 km^2 is urban.

4 Conclusion

This research delineates a comprehensive land suitability assessment for rubber cultivation in Bangladesh's Chittagong district, employing a Geographic Information System (GIS)-based multi-criteria decision analysis (MCDA). The study systematically scrutinizes an array of agro-climatic and edaphic parameters, including temperature, elevation, slope gradient, soil texture, soil pH, and soil depth, with the aim of providing actionable insights to an interdisciplinary audience of policymakers, agronomists, and economic investors.[17] Our analyses reveal that the Chittagong district manifests a confluence of favorable agro-climatic attributes conducive to rubber cultivation. Temperature indices align well within highly suitable climatic bounds, while elevational gradients predominantly favor optimal rubber tree growth. Additionally, the topographical undulations, characterized by gentle slopes, are conducive to efficient water drainage—an elemental factor in rubber cultivation. Furthermore, edaphic properties such as soil texture, pH, and depth are found to be commensurate with, or surpassing, the requisite conditions for rubber tree agronomy. In conclusion, the findings elucidate significant untapped potential for rubber cultivation in the Chittagong district, in alignment with broader sustainability goals and economic diversification targets. The strategic utilization of these inherent agro-climatic advantages, undergirded by ecologically responsible agricultural practices, has the potential to catalyze socio-economic transformation in rural communities, including job creation and foreign exchange revenue enhancement.[18] Therefore, this study should be regarded as an essential empirical foundation for stakeholders interested in optimizing the latent potential for rubber cultivation in the Chittagong district, offering a sustainable development trajectory that could benefit both local communities and the national economy.

5 Limitation of the study

The study's limitations include its restricted geographical focus on the Chittagong district, making it less directly applicable to other regions in Bangladesh or different countries with distinct environmental and socio-economic conditions. The study's findings are temporally constrained, based on conditions during the research period, which may not account for future changes in environmental and socio-economic factors. Furthermore, environmental impacts and mitigation measures, regulatory frameworks, alternative land uses, stakeholder engagement, economic viability assessment, and ethical considerations related to rubber cultivation are not explicitly addressed.

6 References

1. S.R. Maggiotto, D. de Oliveira, C.J. Marur, S.M.S. Stivari, M. Leclerc, C. Wagner-Riddle, Acta Scientiarum. Agronomy 36, 239-245 (2014).
2. S. Mostafiz, Business Post BD. (2022, September 12).
3. J. Chakma, The daily observer. (February 18, 2022).
4. S. Roy, S. Hazra, A. Chanda, S. Das, J. Earth Syst. Sci. 131, 201 (2022).
5. M. Giaoutzi, C. Papadopoulou, (2021).
6. S.W. Kamau, D. Kuria, M.K. Gachari, 5(6), 121–132 (2015).
7. G. Andrienko, N. Andrienko, P. Jankowski, D. Keim, M.-J. Kraak, A. MacEachren, S. Wrobel, Int. J. Geogr. Inf. Sci. 21(8), 839-857 (2007).
8. A.K. Azad, N.S. Pitol, Y. Hara, Int. J. Environ. Agric. Biotechnol. 6.3 (2021).
9. J. Waewsak, S. Ali, Y. Gagnon, Biomass Bioenergy 137 (2020).
10. F.U. Ahmed, N. Khan, Farming practices and sustainable development in the Chittagong Hill Tracts. CHTDB and VEFP-IC. pp105-112 (2002).
11. B. Kositsup, P. Montpied, P. Kasemsap, P. Thaler, T. Améglio, E. Dreyer, Trees 23, 357-365 (2009).
12. L. Samarappuli, W. Wijesuriya, D. Dissanayake, S. Karunaratne, K. Herath, J. Environ. Prof. Sri Lanka. 3 (2014).
13. M. Chandrakala, S. Ramasamy, A. Kumar, S. Karumathil, R. Hegde, S. Singh, H. Nirmala, Curr. J. Appl. Sci. Technol. 35, 1-9 (2019).
14. L. Agbogun, A. Umweni, H. Kadiri, F. Okunsebor, Ilmu Pertanian (Agricultural Science) 6, 156 (2021).
15. M. Alamgir, M. Islam, N. Hossain, M. Kibria, M. Rahman, Int. J. Plant Soil Sci. 7, 362-372 (2015).
16. M. Rendana, A. Rahim, S. Lihan, I. Tukimat, A. Rahman, Zulfahmi, 14, 1019-1025 (2014).
17. I. Hassan, M. Javed, M. Asif, M. Luqman, S. Ahmad, A. Ahmad, S. Akhtar, B. Hussain, Pak. J. Agric. Sci. 57, 1509-1519 (2020).
18. K.N. Ahmed, S.K. Khisa, Sustainable Development 8.1, 1-10 (2000).