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Land Suitability For Sandalwood In Chamarajanagar District Using GIS Techniques.

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Abstract

This study assesses the land suitability for sandalwood cultivation in Chamarajanagar District, Karnataka, using Geographic Information System (GIS) and Multi-Criteria Decision Analysis (MCDA) techniques. Ten environmental and geographical parameters, rainfall, elevation, slope, soil moisture, soil organic carbon, soil pH, NDVI, land use/land cover, Topographic Wetness Index (TWI), and Topographic Ruggedness Index (TRI), were integrated through a weighted overlay analysis in ArcGIS. The Analytical Hierarchy Process (AHP) was employed to assign weights based on the ecological requirements of sandalwood. The resulting suitability map classified the district into five categories: Very Highly Suitable, Highly Suitable, Moderately Suitable, Not Suitable, and Highly Not Suitable. The study demonstrates the effectiveness of GIS-based spatial analysis in identifying optimal areas for sustainable sandalwood cultivation and resource management.

Keywords: Sandalwood Land Suitability, Chamarajanagar, GIS, Multi-Criteria Analysis. Analytical Hierarchy Process (AHP).

1. Introduction

Indian sandalwood (Santalum album) is widely regarded as the most valuable tree among the 17 reported species of the genus Santalum in the international marketplace. It is one of the costliest tree species, alongside African blackwood (Dalbergia melanoxylon), agarwood (Aquilaria malaccensis), red sanders (Pterocarpus santalinus), and ebony (Diospyros ebenum). Over the past 3000 years, the Santalum species has been woven into people's traditions, culture, heritage, and religious values from cradle to grave. The fragrance of sandalwood and its oil are essential components of auspicious occasions and of cremation, as the aroma of heartwood serves as a carrier of the soul to heaven. Classical literature and stories from many countries highlight the significance of sandalwood and its uses.

A popular belief is that the tree is the epitome of human excellence, imparting the fragrance even to the axe that fells it. Internationally, sandalwood is extensively utilized, with its heartwood oil serving as an important component in the cosmetic and perfume industries, its wood esteemed for carving and furniture-making, and its oil prized for its aromatic and fixative qualities. Additionally, certain Santalum species produce edible nuts, and the heartwood oil is used to flavor food products and chewing tobacco, reflecting a long history of traditional uses. The presence of santalol (66.7–79.5%) in Indian sandalwood oil makes this species more costly and more valuable than Australian sandalwood oil, in which the santalol content is 39%.

In India, the natural extent of sandalwood was estimated at 9,000 sq. km. Of that, approximately 8300 sq. km (90%) are mainly concentrated in Karnataka, Tamil Nadu, and parts of Kerala, and are widely scattered in the semi-arid regions of Maharashtra, Telangana, Madhya Pradesh, and parts of Uttar Pradesh. Karnataka accounts for 5245 square kilometers. Over-exploitation, illegal harvesting, smuggling, grazing and lopping, frequent forest fires, the introduction of exotic monoculture plantations, the invasiveness of lantana (Lantana camara), and the epidemic incidence of sandal spike disease have led to a decline in the natural population of sandalwood. As a result, the species was placed in the International Union for Conservation of Nature (IUCN) Vulnerable category in 1997. Currently, economically viable sandalwood trees with a diameter at breast height of more than 30 cm are hard to find in many parts of India, and they have been reported to be commercially extinct.

Sandalwood supply has been significantly diminished due to theft and vandalism of natural plantations and the failure to replace this invaluable tree species, resulting in a global shortage and surging market prices. According to government records, the country's sandalwood production declined dramatically from 4,000 tons per year in the 1960s to only 500 tons per year in 2007, and then further to 350 tons per year in 2014. According to Volza's India Export data, India stands as the world's largest exporter of sandalwood, accounting for 90% of global production. Subsequently, the production was reduced by 60–70%; however, the average auction price climbed by more than 600%. The current auction price of sandalwood heartwood in various states ranges from INR 7.9 million to 12.5 million per ton. The cost of cultivating sandalwood per hectare is about INR 3.4 million for a 15-year rotation. It yields a net present value of INR 2.58 million per hectare. The species is renowned as the "dollar-earning parasite" due to its ever-increasing value in international markets and the remarkable return achieved from cultivation.

The increasing sandalwood prices have attracted many stakeholders from India and foreign countries. Many companies, such as Surya Vinayak Industries, DS Group, Namdhari Seeds Ltd., private builders, and large farmers, have invested in sandalwood plantations in India. There is no precise data about the extent of sandalwood cultivation in India. However, over the past decade, approximately 20,755 hectares of new plantations have been established in the southern states and parts of western and northern India. With this, commercial sandalwood cultivation is increasing manyfold and expanding across the agricultural landscape due to government liberalization policies; however, the production potential remains unknown and unpredictable. This article aims to assess the legal status, challenges, and opportunities of sandalwood cultivation and harvesting in India, and to investigate the technical gap between scientific research and practical issues in heartwood development. It seeks to identify and analyze key policy constraints and technical challenges faced by sandalwood cultivators, while also highlighting gaps in existing policies and technologies concerning sandalwood cultivation in India.

2. Study area

This district is located between latitudes 11° 40'58" to 12° 06'32" North and longitudes 76° 24'14" to 77° 46'55" East, near the southernmost point of Karnataka State. The district of Chamarajanagar has a total size of 5671.71 km2. Yelandur is the smallest of the five taluks, making up just 4.7% of the total geographical area, whereas Hanur (a recently established taluk) is the largest, making up 49.12%. The Southern Transition Zone and the Southern Dry Zone are the two agroclimatic zones that make up the region. The majority of the districts are occupied by the former, while the latter make up only a small portion. The weather is humid and tropical. From March through May, temperatures consistently rise from 32°C to 37°C. With an average high temperature of 38°C and an average low temperature of 24°C, April is the hottest month.

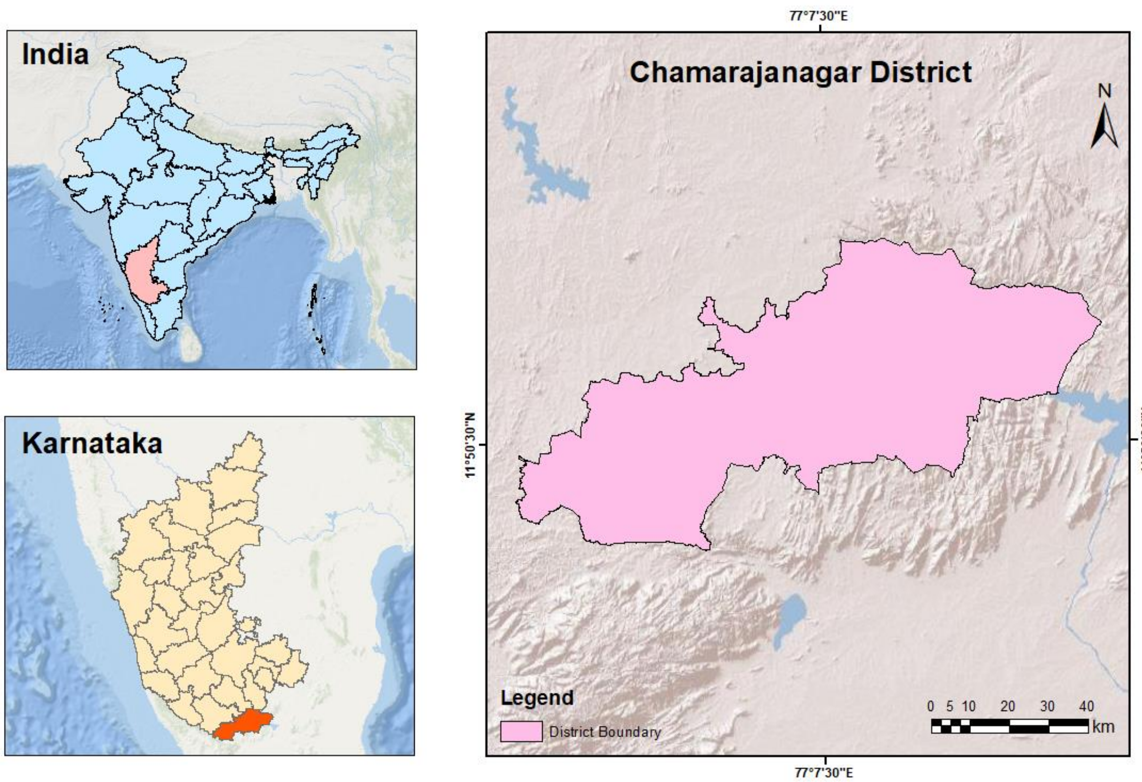


Figure 1: Location map of the study area

3. Database and Methodology

The methodology was developed for suitability analysis in this study area, and various spatial maps were generated, such as slope, relief, soil pH, NDVI, soil texture, TWI, TRI, Soil Organic Carbon, rainfall, land use, and land cover. Data were obtained from various sources, converted to raster format using spatial analysis tools, reclassified, parameter-weighted, and ranked using the ArcGIS 10.7.1 platform. The map of sandalwood land suitability was created and classified into five categories: very highly suitable, highly suitable, moderate, not suitable, and very not suitable for sandalwood.

3.1 Thematic map preparation

1. **Rainfall**

A sharp southwest-to-northeast meteorological gradient is evident throughout the district in the annual rainfall distribution map. With high to very high rainfall, the southwest tip of Gundlupet taluk receives the most precipitation. Precipitation decreases rapidly as one moves northeast across the area. The major farming zones of Gundlupet, Chamarajanagar, Yelandur, and western Kollegal are covered by the large central corridor, which experiences a consistent, very low rainfall regime. Although there is a very small, very low pocket embedded in the far eastern highlands, precipitation increases slightly along the eastern edges of Hanur taluk and returns to a low classification.

2. **Elevation:**

The elevation map shows the differences in terrain height in the study area. High-elevation areas are mostly in the hilly and upland zones, while low-elevation areas are in the valley and plain regions. These changes affect the drainage pattern, soil formation, vegetation distribution, and agricultural suitability. Generally, moderate heights are good for growing crops and for settlement.

3. **Slope**

The slope map indicates the degree of surface steepness in the study area. The gentle-slope areas are suitable for agriculture, irrigation, and human settlements due to a lower risk of erosion. Moderate slopes are associated with mixed land use and plantation activities, and steep slopes are mainly associated with hilly terrains and forest regions. Areas with steep slopes are more prone to soil erosion and runoff, thereby limiting intensive agricultural activities.

4. **Soil moisture:**

The soil moisture map displays the spatial distribution of moisture availability in the study area. High soil moisture is mainly observed in irrigated areas, water bodies, and dense vegetation, indicating favorable conditions for crop cultivation and groundwater recharge. Zones of moderate moisture support seasonal agriculture and mixed land use practices. Low soil moisture zones are associated with dryland areas and sparse vegetation, and with higher surface runoff than high soil moisture zones, thereby increasing drought vulnerability and reducing agricultural productivity. Soil moisture variability results from the interaction among rainfall, soil properties, topography, and land use.

5. **Soil Organic Carbon (SOC)**

The Soil Organic Carbon (SOC) map shows soil fertility and organic matter content. Areas with high SOC values are fertile soils that retain more moisture and provide more nutrients for crop growth and vegetation. Moderate SOC regions are characterized by average soil productivity, whereas low SOC areas are associated with reduced soil fertility and degradation. The spatial distribution of SOC helps to identify the areas that need soil conservation and sustainable land management practices.

6. **Soil PH**

The study region exhibits a distinct spatial polarization of soil chemical properties, with values ranging from a minimum of 0 to a maximum of 8.0. It is found in the northern, central-left, and upper-east corridors, which represent neutral-to-slightly alkaline soils. Such higher pH areas are typically found in lower plains or valleys where base minerals naturally accumulate over time. which are heavily concentrated in the southwest, central-south, and far-eastern pockets, indicate much lower pH values. These zones indicate acid soil conditions, commonly associated with higher elevations, where increased rainfall causes leaching of essential bases from the soil profile.

7. Topographic Ruggedness Index (TRI)

With values ranging from a practically flat 0.04 to a highly rocky 162.68, the Topographic Ruggedness Index (TRI) reveals a landscape that is mostly homogeneous yet disrupted by strong terrain features. The extensive area represents the flat to moderately undulating plains that make up the great portion of the district. However, distinctive features that indicate extreme topographical complexity abruptly disrupt this plain. The entire eastern boundary exhibits dense, severe roughness, while a notable ridge line advances north-south along the south-central and eastern-central transition zones. This denotes heavily divided, steep, or mountainous terrain typical of a ghat or a significant hill-range boundary.

8. Topographic Wetness Index (TWI)

The hydrological flow accumulation and drainage characteristics throughout the terrain are efficiently mapped by the Topographic Wetness Index (TWI), which ranges from -4.53 to 16.10. The map shows areas with steep slopes and low catchment accumulation, which align with the well-drained upper slopes of the hilly regions. On the other hand, river channels, valleys, and natural drainage routes are represented by the branching linear networks that cut through the terrain. These channels, which have a particularly significant drainage system that runs prominently along the central-left valley corridor, show where surface runoff converges based on topography.

9. Land Use and Land Cover

The Chamarajanagar district's natural forest ecosystems and agricultural landscapes are clearly separated structurally, as shown by the Land Use and Land Cover map. The eastern and northern regions, which mostly include Hanur and portions of Kollegal taluk, are primarily covered in dense forest, with plantations and forest scrub serving as accent pieces. The western and southern borders of Gundlupet taluk are comparable. On the other hand, intensive farming creates a continuous, wide plain that pushes uphill into central Kollegal and crosses the taluks of central Gundlupet, Chamarajanagar, and Yelandur. In this agricultural matrix, built-up urban areas appear as concentrated nodes, with the major settlements of Chamarajanagar, Kollegal, Gundlupet, and Yelandur as the most notable examples.

10. Normalized Difference Vegetation Index (NDVI)

NDVI (Normalized Difference Vegetation Index) Map. NDVI is an index of vegetation health and density. High NDVI values indicate dense, healthy vegetation cover, suggesting better agricultural productivity and forest concentration. Moderate NDVI values indicate mixed vegetation or seasonal crops, while low NDVI values can reflect barren land, sparse vegetation, rocky surfaces, or built-up areas. The map shows clear spatial differences in vegetation distribution across the region.

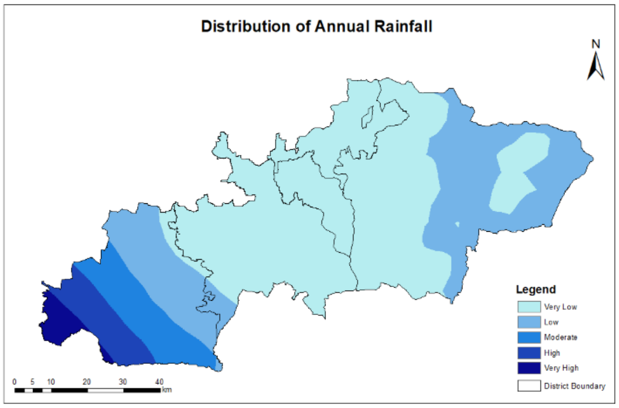
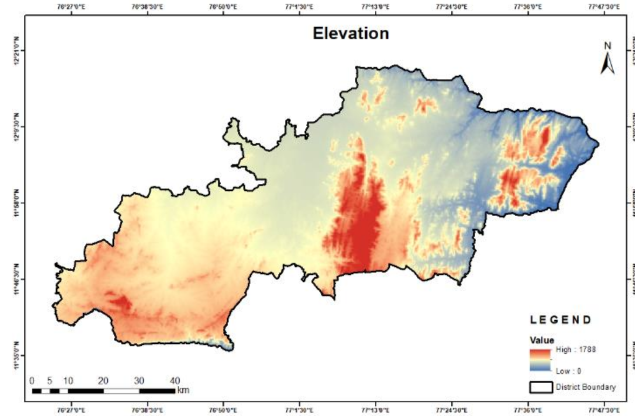


Figure 2: Rainfall map



3: Elevation map

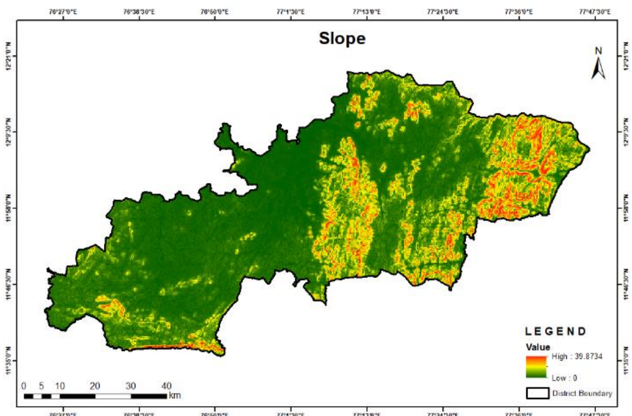
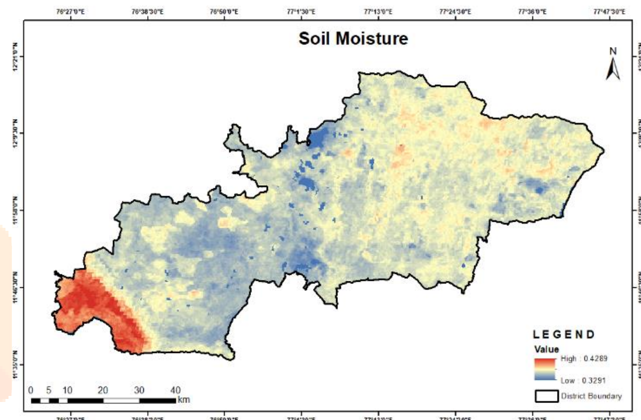


Figure 4: Slope map



5: Soil Moisture map

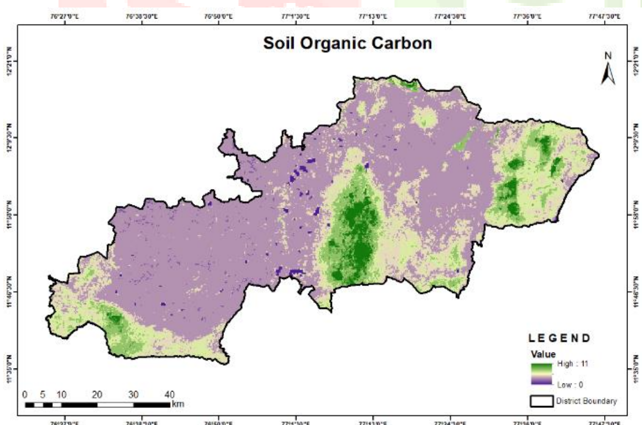


Figure 6: Soil Organic Carbon map

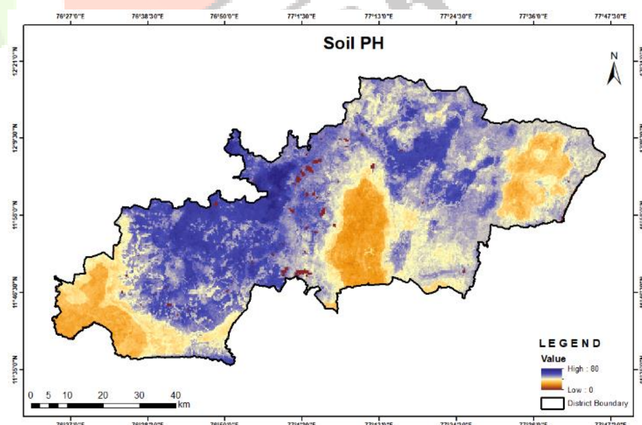


Figure 7: Soil pH map

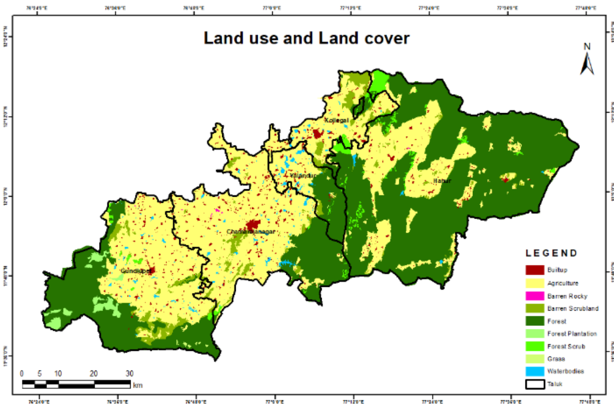


Figure 8: LULC map

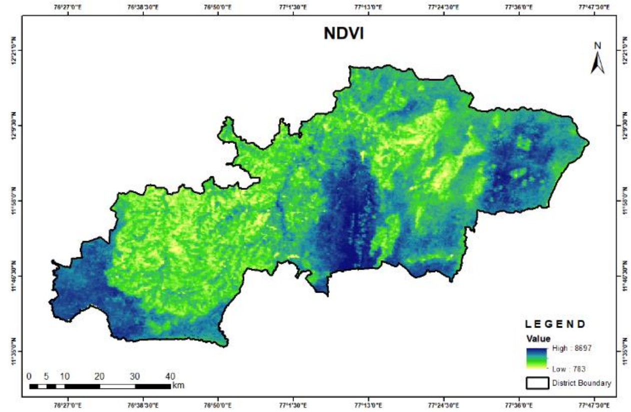


Figure.9: NDVI map

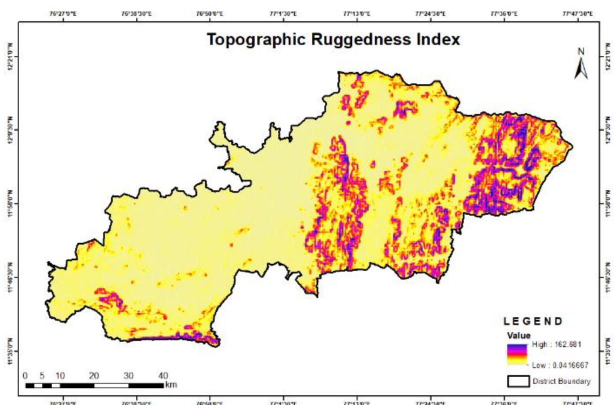
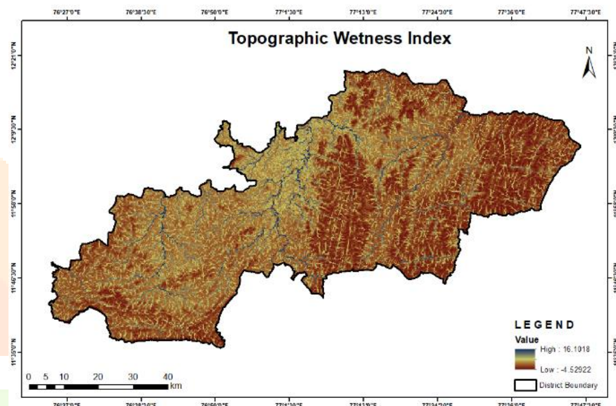


Figure 10: TRI map



. Figure 11: TWI map

4. Results and discussion

The GIS-based land suitability analysis revealed significant spatial variations in the suitability of land for sandalwood cultivation across Chamarajanagar district. By integrating ten important environmental parameters, namely rainfall, elevation, slope, soil moisture, soil organic carbon, soil pH, NDVI, land use/land cover, Topographic Wetness Index (TWI), and Topographic Ruggedness Index (TRI), a comprehensive suitability map was generated. The results indicate that rainfall, soil moisture, elevation, and soil organic carbon are the most influential factors affecting sandalwood growth and distribution. The weighted overlay analysis successfully identified areas with varying levels of suitability, demonstrating the effectiveness of GIS and AHP techniques in land resource evaluation.

The spatial distribution pattern shows that the eastern, far eastern, and south-central parts of Chamarajanagar district are highly favorable for sandalwood cultivation. Moderate elevation, well-drained soils, adequate soil moisture, dense vegetation cover, and favorable climatic conditions characterize these regions. The presence of natural forest ecosystems and suitable host species further enhances the ecological suitability of these areas. Such conditions provide an ideal environment for sandalwood establishment, growth, and long-term survival, making these regions highly suitable for plantation development and conservation initiatives.

In contrast, the central-western plains and northern parts of the district were classified as not suitable or highly unsuitable for sandalwood cultivation. These areas are dominated by intensive agricultural activities, sparse vegetation, low soil organic carbon content, moisture stress, and comparatively unfavorable soil conditions. High levels of human disturbance and reduced ecological stability further limit the successful growth of sandalwood in these regions. As a result, the potential for large-scale sandalwood cultivation is considerably lower in these areas.

The suitability classification indicates that approximately 33.97% (1862.5 km²) of the district falls under the very highly suitable category, while 18.30% (1003.2 km²) is classified as highly suitable. Moderate suitability covers about 14.64% (802.89 km²) of the total area. On the other hand, 16.66% (913.22 km²) and 16.43% (900.92 km²) of the district are categorized as not suitable and highly not suitable, respectively. These findings suggest that more than half of the district has favorable environmental conditions for sandalwood cultivation, highlighting substantial opportunities to expand sandalwood plantations and promote sustainable agroforestry practices in the region.

The study demonstrates that GIS-based multi-criteria decision analysis provides a reliable scientific framework for identifying suitable locations for sandalwood cultivation. The generated land suitability map can serve as an important decision-support tool for farmers, forest managers, policymakers, and investors in planning sustainable sandalwood plantations and enhancing resource management strategies in Chamarajanagar district.

4.1 Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) method is widely used in GIS-based land suitability analysis to determine the relative importance of multiple environmental parameters. In the case of sandalwood cultivation, ecological and climatic conditions play a dominant role because *Santalum album* requires specific moisture, soil, topographic, and vegetation conditions for healthy growth. Based on the ecological requirements of sandalwood and previous forestry suitability studies, the following ranking and weightage are assigned to the selected parameters.

Table 1: Parameter weightage and ranking

Sl. No	**Parameter**	**Rank**	**Weight (%)**
1	Rainfall	1	18
2	Soil Moisture	2	15
3	Elevation	3	12
4	Soil Organic Carbon (SOC)	4	11
5	Land Use and Land Cover	5	10
6	NDVI	6	9
7	Soil pH	7	8
8	Slope	8	7
9	Topographic Wetness Index	9	5
10	Topographic Ruggedness Index	10	3
	Total		**100**

Table.2: Classification of suitability

Classifications	area (sq.km)	percentage
Highly not suitable	900.92	16.43
Not suitable	913.22	16.66
Moderate	802.89	14.64
Highly not suitable	1003.2	18.30
Very high	1862.5	33.97
Total	**5482.73**	**100**

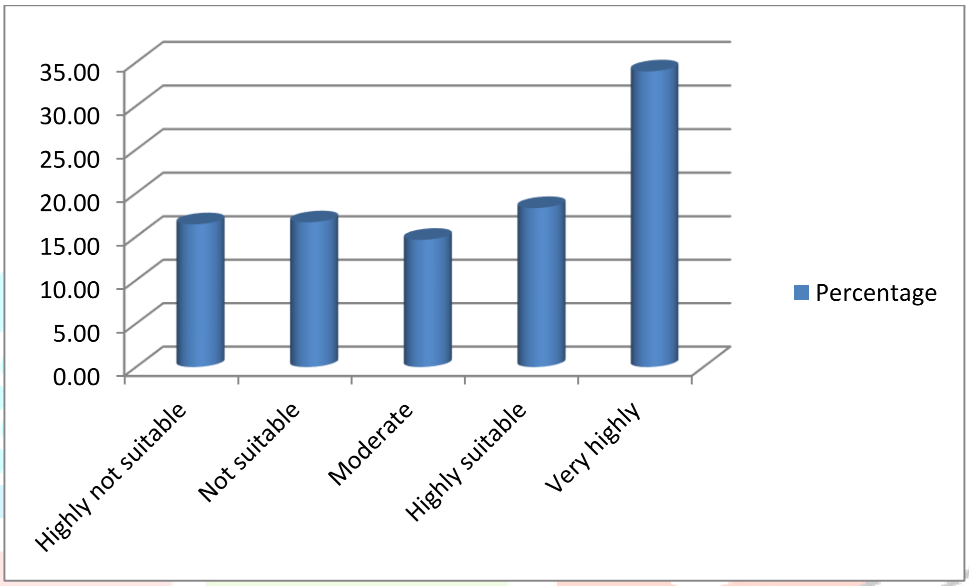


Figure 12: Distribution of sandalwood suitability

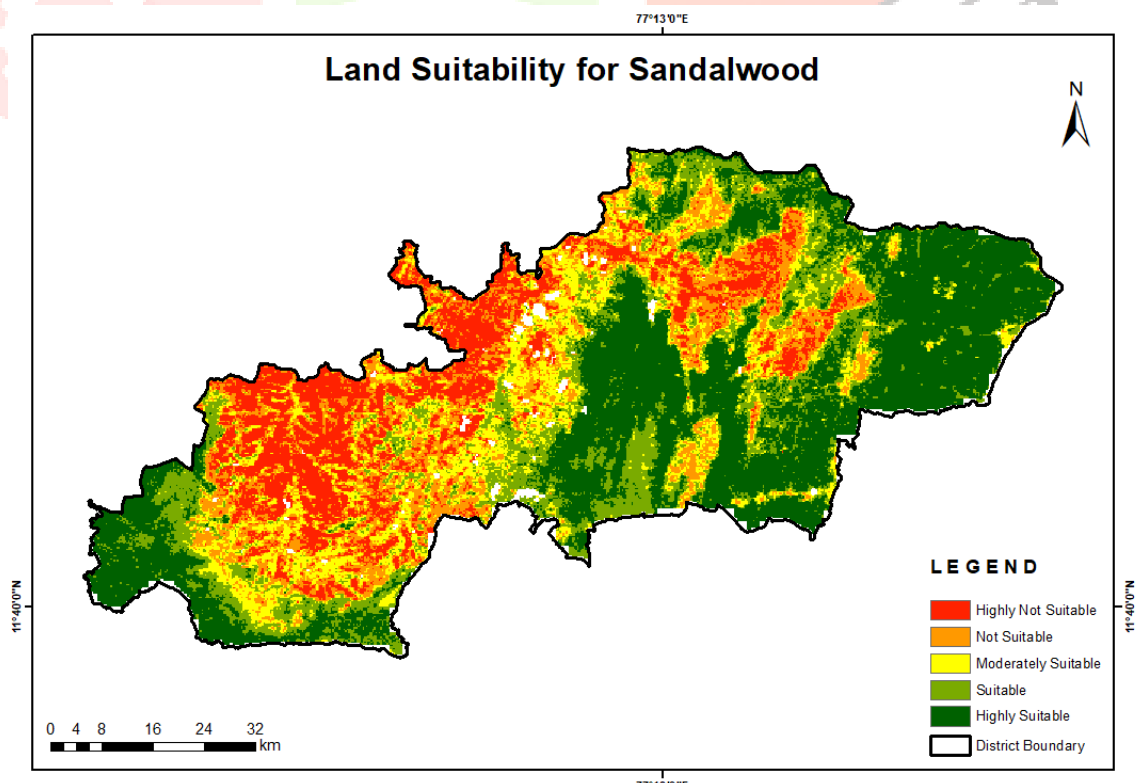


Figure.13: Land suitability map of Sandalwood

5. Discussion

Land areas that belong to the highly suitable places are the best locations for the planting, growth, and development of Sandalwood; the areas that are modestly suitable are also fit, but have some.

Confinements, limitations of the criteria used, and likewise, the just suitable areas. Land areas that are not suitable are plainly impractical to overcome, and they cannot be acceptable for the planting of Sandalwood. The map created for this suitability is the result of the spatial overlay of the given criteria. This project has applied GIS procedures and analyses to identify areas potentially suitable for Sandalwood planting. The development of a GIS-based thematic soil database is imperative for yield analysis and for assessing the suitability of ideal use of accessible resources (Coleman & Galbraith, 2000). Suitability is a function of product requirements and land qualities (Mustafa et al., 2011) to explore the potential area suitable for Sandalwood production. This combined-criteria model meets the criteria for Sandalwood; however, other factors could have been taken into consideration, such as labor availability. This analysis method considered detailed driving elements, for example, temperature, slope, climate, access to road, access to railway, availability of water supply, availability of host plant, and soil type in the criteria, which are the determinants used as part of the decision-making process for determining suitability for the proposed Sandalwood site. The climate, soil quality, and topography of an area are the most important factors in assessing land suitability. The GIS-based model identified areas suitable for Sandalwood production. This indicated that the areas deemed suitable were acceptable when all the criteria were met.

6. Conclusion

The study concludes that GIS and AHP-based multi-criteria analysis provide an effective and reliable approach for identifying suitable areas for sandalwood cultivation. Environmental variables such as rainfall, soil moisture, elevation, soil fertility, vegetation cover, and land use significantly influence sandalwood growth potential. The eastern and south-central forested regions of Chamarajanagar district offer the most favorable conditions for sustainable sandalwood cultivation. In contrast, the agricultural plains of the central and northern regions are largely unsuitable. The suitability map generated through GIS can serve as an important decision-support tool for plantation planning, agroforestry development, resource conservation, and policy formulation. Overall, the integration of GIS and spatial modeling is a powerful approach for sustainable sandalwood resource management and future plantation expansion in the district.

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