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Adaptation of GIS-Based LRI Study on Crop Suitability for Jackfruit and Lemon in the Guida-Kantabahal Micro-Watershed, Deogarh District

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Abstract

Land evaluation through GIS-based soil resource inventory plays a pivotal role in sustainable agricultural planning and resource management. In this context, a comprehensive study was conducted to assess the land suitability for cultivating Jackfruit (*Artocarpus heterophyllus*) and Lemon (*Citrus limon*) within the Guida-Kantabahal micro-watershed, situated in the Reamal block of Deogarh District, Odisha. This region, characterized by varied topography and soil diversity, was selected to explore its potential for high-value horticultural crops. The study adopted the Land Resource Inventory (LRI) approach, following standard protocols, to ensure systematic assessment of soil and land characteristics. A total of 20 representative soil profiles were identified and analysed to capture the spatial variability across the watershed. These profiles were subjected to detailed physico-chemical analysis, evaluating key parameters such as soil texture, depth, pH, organic carbon content, cation exchange capacity, base saturation, and drainage conditions. These factors are known to significantly influence the growth and yield of perennial fruit crops like Jackfruit and Lemon. The land suitability evaluation was carried out using classification criteria established by the Food and Agriculture Organization (FAO, 1976) and the Indian Council of Agricultural Research - National Bureau of Soil Survey and Land Use Planning (ICAR-NBSS&LUP). Based on these guidelines, each soil unit was rated and categorized into different suitability classes—ranging from highly suitable (S1) to not suitable (N). The analysis revealed that approximately 41.32% of the micro-watershed area falls under the 'moderately suitable' (S2) category for the cultivation of both Jackfruit and Lemon. These areas exhibit favourable characteristics such as moderate soil depth, acceptable pH levels, and good drainage. However, limitations like suboptimal nutrient availability or minor textural issues slightly reduce their suitability. On the other hand, more than 53% of the area was found to be 'not suitable' (N) for cultivation due to significant constraints including high soil acidity, shallow soil depth, moderate to severe erosion, and high gravel content. These limitations pose considerable challenges to root establishment and water/nutrient retention, adversely affecting plant growth. Geospatial analysis through Geographic Information System (GIS) was integral to the study, enabling precise mapping and visualization of land suitability classes across the micro-watershed. The use of GIS tools allowed for the spatial correlation of soil parameters with land characteristics, thereby enhancing the accuracy of the evaluation and facilitating targeted interventions. The findings of this study provide valuable insights for local planners, farmers, and agricultural development agencies. By identifying suitable and constrained areas, it recommends appropriate soil and crop management strategies such as liming acidic soils, improving organic matter content, adopting erosion control measures, and selecting suitable crop varieties. These recommendations aim to optimize land use, improve productivity, and ensure the long-term sustainability of agricultural practices in the region.

Keywords: Soil survey, GIS, crop suitability, Jackfruit, Lemon, land evaluation, LRI

1. Introduction

Land use planning plays a pivotal role in achieving sustainable agricultural development by integrating the evaluation of land and water potential with socio-economic and environmental considerations. With increasing pressures on land due to population growth, urbanization, and climate variability, the need for efficient and sustainable land use strategies has become more urgent than ever (Verburg *et al*., 2013) [23]. This is particularly critical in agrarian economies like India, where land serves as the primary livelihood resource. Geospatial technologies such as Geographic Information Systems (GIS) and remote sensing (RS), combined with detailed soil surveys, offer advanced tools for land suitability analysis. These technologies enable spatial assessment of key land characteristics and facilitate informed decision-making in crop planning (Rossiter, 1996; Zolekar & Bhagat, 2015) [16, 23]. GIS-based Land Resource Inventory (LRI) techniques are especially valuable in identifying optimal cropping zones, minimizing resource wastage, and enhancing agricultural productivity. In Odisha, the need for resource-efficient horticultural development has gained traction in recent years due to the state's agro-climatic diversity and growing demand for high-value crops. The Government of Odisha has recently initiated digital crop surveys using GPS and GIS technologies to accurately map cultivation areas, highlighting the significance of spatial data for agricultural planning. In addition, soil fertility mapping using geospatial approaches in Odisha has shown promising results in guiding nutrient and crop management (Patra *et al*., 2023) [15]. This study focuses on the Guida-Kantabahal micro-watershed within the Reamal sub-watershed of Odisha. The main objective is to evaluate the land suitability for two economically significant horticultural crops—Jackfruit (*Artocarpus heterophyllus*) and Lemon (*Citrus limon*). These crops are not only climate-resilient but also have substantial market potential and nutritional value. Employing GIS-based LRI methods, the study will assess soil and terrain parameters to determine the most suitable areas for cultivation, thereby supporting sustainable land use planning and improved livelihood outcomes for local farmers.

2. Materials and Methods

The Guida-Kantabahal micro-watershed lies in the Reamal block of Deogarh District and spans approximately 725 hectares. It encompasses the villages of Kantabahal, Patharaanjari, Lakshmipur, Guida, Ratakhandi, and Hadasanhara. The topography ranges from hilltops to valleys, influencing soil characteristics and water retention capacity.

Land Use and Land Cover

The land use and land cover analysis of the study area reveals a predominance of scrublands, which account for approximately 49.08% of the total geographical area (TGA). Agricultural lands constitute 33.22%, indicating the primary land use activity in the region. Forest cover occupies 10.9% of the area, contributing to ecological balance and biodiversity conservation. Habitation areas make up 2.46%, reflecting the rural settlement pattern, while wastelands and orchard plantations represent 1.25% and 1.10% of the area, respectively. The significant proportion of scrublands and relatively low extent of orchard plantations suggest an underutilization of land for horticultural purposes. This land use distribution highlights a considerable scope for crop diversification and expansion of horticultural crops such as Jackfruit and Lemon. By integrating suitable land units into productive horticulture, the region can enhance its agricultural sustainability, improve farmers' incomes, and support better land resource management.

Soil Survey and Sampling

A detailed soil survey was carried out employing a transect-based approach, strategically aligned with the natural terrain features of the study area. This method facilitated a systematic investigation of soil variability across different physiographic units such as uplands, midlands, and lowlands, which are characteristic of the Guida-Kantabahal micro-watershed. The transects were designed to traverse the landscape in a manner that captured the heterogeneity of slope, elevation, drainage, and vegetation cover (Naidu *et al*., 2017; Sehgal, 1996) [13, 18]. A total of twenty soil profile pits were excavated at key locations representing distinct landforms, soil types, and land use patterns. These locations were selected based on preliminary reconnaissance surveys, topographic analysis, and satellite imagery interpretation using GIS tools (Mandal *et al*., 2020) [11]. Each soil profile was examined in situ, and comprehensive field observations were recorded, including soil colour (using Munsell Soil Color Charts), texture (by feel method), structure, consistency, root distribution, depth, presence of concretions or rock fragments, and horizon boundaries (Soil Survey Staff, 2014) [19]. Soil samples were systematically collected from each genetic horizon identified within the profiles. These samples were air-dried, ground, and passed through a 2 mm sieve before being subjected to laboratory analysis. The laboratory investigations included determination of pH, electrical conductivity (EC), organic carbon content, available macronutrients (N, P, K), micronutrients (Zn, Fe, Cu, Mn), cation exchange capacity (CEC), and particle size distribution (Brady & Weil, 2016; Biswas & Mukherjee, 2013) [2, 1]. The use of this terrain-based transect method ensured that the soil sampling captured the spatial variability in soil properties across different land units. Such detailed characterization is essential for land capability classification and for assessing the suitability of land for specific horticultural crops, such as Jackfruit and Lemon, based on their edaphic requirements (Naidu *et al*., 2017; FAO, 2007) [13, 5]. The data generated from this survey formed the foundation for developing a geospatial soil database, which was later integrated with GIS to prepare soil maps and perform land suitability analysis.

Laboratory Analysis

The collected soil samples were subjected to a comprehensive analysis to evaluate both physical and chemical properties, which are critical determinants of soil quality and crop suitability. The physical parameters assessed included soil texture, effective soil depth, and drainage characteristics. Texture was determined using the hydrometer method, which classifies soil based on the relative proportion of sand, silt, and clay particles (Gee & Bauder, 1986) [6]. Soil depth was measured in the field during profile examination and categorized based on the root-penetrable depth, which directly influences crop rooting and water-holding capacity (Sehgal, 1996) [18]. Drainage status was assessed visually based on field indicators such as color mottles, gleying, and permeability, which are vital for identifying waterlogging potential and aeration conditions (Soil Survey Staff, 2014)[19].For chemical analysis, standard procedures were followed to determine soil pH, electrical conductivity (EC), organic carbon (OC), available macronutrients—Nitrogen (N), Phosphorus (P), and Potassium (K)—and micronutrients such as Zinc (Zn), Iron (Fe), Copper (Cu), and Manganese (Mn). Soil pH was measured in a 1:2.5 soil-water suspension using a digital pH meter, while organic carbon was estimated using the Walkley and Black (1934) [22] rapid titration method. Available nitrogen was analyzed through the alkaline $KMnO_4$ method (Subbiah & Asija, 1956) [20], available phosphorus by the Olsen’s method for neutral to alkaline soils, and available potassium using flame photometry following ammonium acetate extraction (Jackson, 1973) [9]. Micronutrient contents were determined using DTPA extraction followed by atomic absorption spectrophotometry (Lindsay & Norvell, 1978) [10]. To assess the soil's capacity to support sustainable crop production, particularly for horticultural crops like Jackfruit and Lemon, Soil Fertility Indices (SFI) were calculated. These indices integrate multiple nutrient concentrations into a composite score to represent the overall fertility status of the soil (Chien *et al*., 2011) [3]. The SFI approach enables a more objective and quantitative assessment of nutrient adequacy, helping identify both deficiencies and toxicities. The fertility ratings were classified into low, medium, and high categories based on established critical thresholds for each nutrient, as per ICAR guidelines and regional crop requirements (ICAR-IISS, 2020) [8]. This integrated analysis of physical and chemical soil properties, along with fertility indexing, provided essential insights into the nutrient dynamics of the study area. The results were subsequently used in conjunction with GIS to map spatial variability and recommend location-specific interventions for sustainable horticultural planning.

GIS and Remote Sensing Applications

Terrain Mapping Units (TMUs) were delineated using satellite imagery and 5 m contour data. GIS tools were employed to process spatial data, develop soil maps, and visualize suitability classes for Jackfruit and Lemon. The land evaluation followed FAO (1976) [4] guidelines and ICAR-NBSS&LUP criteria, considering climatic and edaphic factors.

3. Results and Discussion

Soil Series Characterization in the Region

A comprehensive soil survey of the study area revealed the presence of seven distinct soil series comprising fourteen soil phases. Among these, the Reamal-Q, Reamal-N, and Reamal-V series were identified as dominant, collectively covering a major portion of the landscape. These soils are largely influenced by the Eastern Ghat Super Group lithology, predominantly consisting of Khondalite and Charnockite rock formations, which significantly affect soil genesis, texture, depth, and drainage characteristics.

1. **Reamal-Q Series (40.75%):** This series constitutes the most extensive coverage, accounting for 40.75% of the area. The soils are: Very deep (>150 cm), Well-drained and characterized by sandy loam texture with slight Gravelines. These soils are ideally suited for agricultural practices due to their favourable drainage and moderate texture, which promote root penetration and aeration. The slight presence of gravel indicates moderate weathering of parent materials and some degree of transport and deposition, possibly by fluvial processes. Their genesis is linked to the weathering of Charnockite and Khondalite rocks, contributing to a sandy mineral composition.
2. **Reamal-N Series (31.1%):** Occupying about 31.1% of the landscape, these soils exhibit: Deep profile (100-150 cm), moderate gravel content and well-drained. These characteristics suggest a relatively mature pedogenic development, with moderate gravel suggesting mechanical weathering of parent material. Their formation is closely associated with in situ weathering of Khondalite rocks, known for their granitic gneiss composition rich in feldspars and quartz.
3. **Reamal-V Series:** This series occurs in the steep upland regions and is characterized by shallow soils (<50 cm) steeply sloping terrain with severe erosion hazards. These soils are less suitable for conventional agriculture due to limited rooting depth and high erosion susceptibility. The topographic setting combined with shallow depth suggests intensive runoff, which accelerates the erosion process, exposing parent material and retarding soil formation. These soils are primarily derived from exposed Charnockite outcrops, which are hard, coarse-grained rocks, resistant to weathering but prone to forming skeletal soils under high erosion pressure.

Geological Influence

The rocks, comprising primarily Khondalites (garnet-sillimanite gneiss) and Charnockites (hypersthene-bearing granulites), are metamorphic in origin and play a significant role in soil characteristics in this region. These rocks are ancient, forming part of the Precambrian shield and are known to produce a wide range of soil types depending on their mineralogy, structure, and weathering intensity. According to Murthy *et al*. (1981) [12] and Sehgal (1996) [18], Khondalite-derived soils typically show sandy loam to loam textures and moderate fertility, while Charnockite-derived soils tend to be coarse-textured and acidic with lower base saturation.

Suitability classes were defined based on limitations and overall capability index:

Table 1: Land Suitability Classification

Crop	Highly Suitable (S1)	Moderately Suitable (S2)	Marginally Suitable (S3)	Not Suitable (N)
Lemon	-	299.51 ha (41.32%)	9.01 ha (1.24%)	384.78 ha (53.08%)
Jackfruit	-	299.51 ha (41.32%)	9.01 ha (1.24%)	384.78 ha (53.08%)

Based on the provided table, the suitability of land for Lemon and Jackfruit cultivation in the specific area has been classified into four classes: Highly Suitable (S1), Moderately Suitable (S2), Marginally Suitable (S3), and Not Suitable (N).

- **Highly Suitable (S1):** This category represents land that has no significant limitations for the sustained production of the specified crop. The table indicates that there is no land classified as Highly Suitable (S1) for either Lemon or Jackfruit in the area under consideration.
- **Moderately Suitable (S2):** This category represents land that has limitations which in total are moderately severe for sustained production of the specified crop. These limitations can usually be overcome with careful management. The table shows that 299.51 hectares (ha), which constitutes 41.32% of the total assessed area, is Moderately Suitable (S2) for both Lemon and Jackfruit. This suggests that a significant portion of the land has some limitations that can be managed to grow these crops successfully.
- **Marginally Suitable (S3):** This category represents land that has limitations which in total are severe for sustained production of the specified crop and so marginal in terms of production. It will only be suitable at acceptable production levels with major improvements. The table indicates that 9.01 ha (1.24%) is Marginally Suitable (S3) for both Lemon and Jackfruit. This small percentage of land has significant limitations that would require substantial investment

and management to achieve even moderate yields.

- **Not Suitable (N):** This category represents land that has limitations which are so severe that they preclude any possibility of successful sustained production of the specified crop. The table shows that 384.78 ha (53.08%) is Not Suitable (N) for both Lemon and Jackfruit. This is the largest proportion of the assessed area, indicating that a majority of the land has constraints that make it unsuitable for cultivating these crops.

For both Lemon and Jackfruit cultivation in the assessed area: 0% of the land is Highly Suitable (S1); 41.32% (299.51 ha) of the land is Moderately Suitable (S2); 1.24% (9.01 ha) of the land is Marginally Suitable (S3) and 53.08% (384.78 ha) of the land are not Suitable (N). This information is crucial for land-use planning and agricultural decision-making. It helps to identify the most suitable areas for cultivating these specific crops, potentially leading to higher yields and more sustainable agricultural practices. The high percentage of not suitable land highlights the importance of understanding the specific limitations present in the area.

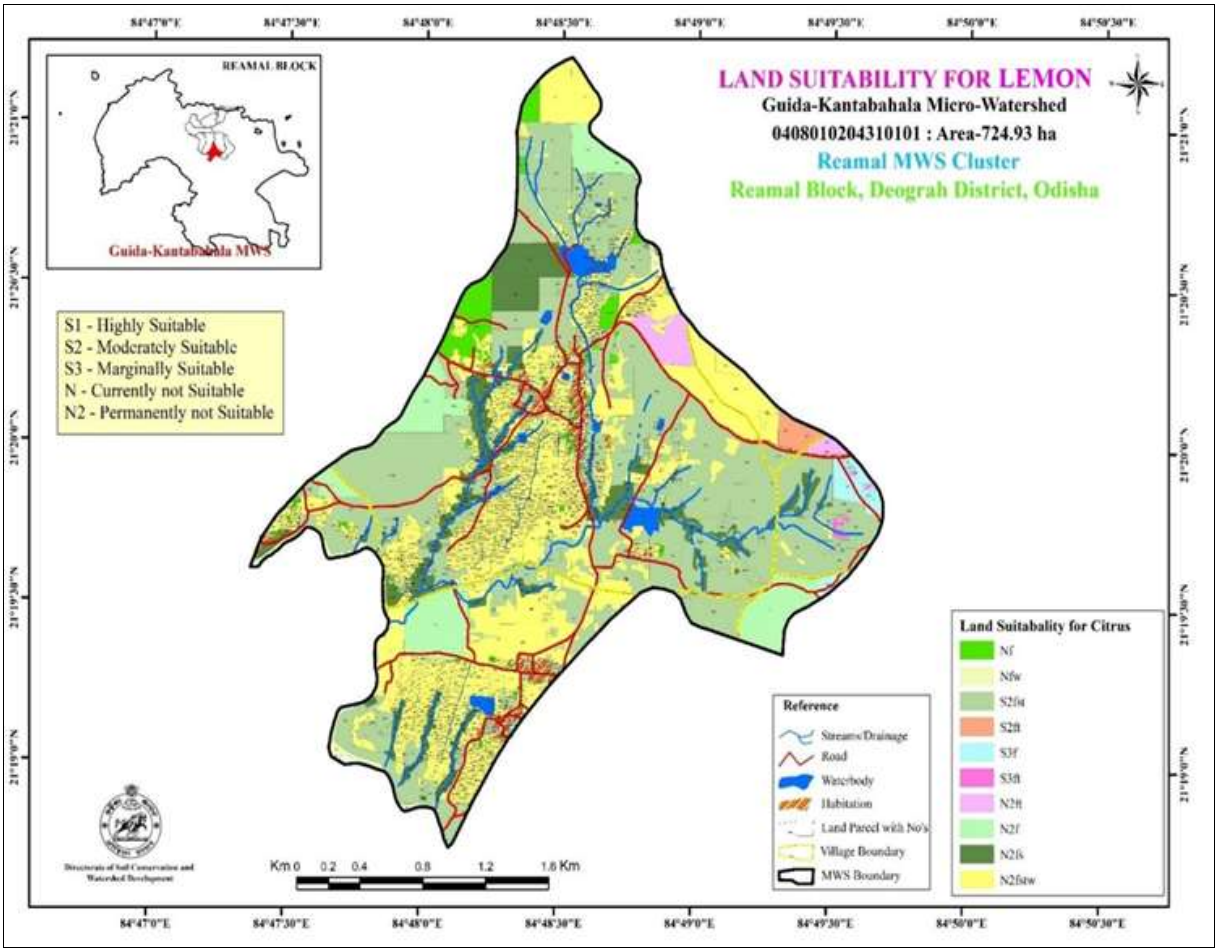
Table 2: Constraints and Management Options

Soil Phase	Suitable Crop	Constraints	Recommendations
RmlM3bD3g2	Jackfruit, Lemon	Soil erosion, shallow depth, acidity	Liming, micro-irrigation, high-input management
RmlO4bB1g1	Jackfruit, Lemon	Low fertility, acidity, gravelliness	Agroforestry, soil amelioration, lime application

Table-2 outlines the constraints and management options for two distinct soil phases, RmlM3bD3g2 and RmlO4bB1g1, both deemed suitable for cultivating Jackfruit and Lemon in the studied region. The first soil phase, RmlM3bD3g2, is characterized by soil erosion, shallow depth, and acidity, for which the recommended management strategies include liming to neutralize the acidity, micro-irrigation to efficiently manage water in the shallow soil and prevent further erosion, and high-input management suggesting an intensive approach with fertilizers and other inputs to overcome the inherent limitations. In contrast, the second soil phase, RmlO4bB1g1, presents challenges of low fertility, acidity, and gravelliness. To address these issues, the table suggests agroforestry to improve soil health and prevent erosion, general soil amelioration practices to enhance the soil's physical and chemical properties, and lime application specifically to combat the acidity and improve nutrient availability. Thus, the table emphasizes that while Jackfruit and Lemon are suitable crops for both soil phases, the specific constraints of each necessitate tailored management approaches to ensure successful cultivation. Soil acidity and poor fertility were the major biophysical constraints, affecting nutrient uptake and root development. Application of lime and organic amendments is recommended to neutralize soil pH and improve soil structure.

Implications for Crop Diversification

The presence of "moderately suitable zones," despite their inherent limitations as detailed in Table-2, presents a significant opportunity for enhancing agricultural productivity and resilience through crop diversification and horticultural intensification in the region. This implies moving beyond reliance on a limited number of traditional crops and exploring a wider array of cultivable species, including high-value horticultural crops. The successful implementation of this diversification hinges on the strategic introduction of adaptive varieties, which are specifically bred or selected to tolerate the existing constraints such as soil acidity, shallow depth, low fertility, or gravelliness. These varieties would be better equipped to thrive in these conditions compared to conventional ones, leading to more stable and potentially higher yields. Furthermore, the adoption of agroforestry systems offers a holistic approach to land management that can simultaneously address multiple limitations. Integrating trees and shrubs with crops can improve soil health through increased organic matter, enhanced nutrient cycling, and reduced soil erosion. The tree components can also provide shade, conserve moisture, and potentially offer additional sources of income through timber, fruits, or fodder. This diversification within the farming system not only enhances ecological sustainability but also reduces economic risks associated with monoculture. Finally, the implementation of water-saving irrigation techniques, such as micro-irrigation as suggested in Table-2, is crucial for maximizing the productivity of these moderately suitable zones, especially considering potential issues like shallow soil depth and gravelliness which can impact water retention. Efficient water management ensures that the limited water resources are utilized optimally, reducing water stress on crops and improving overall water use efficiency. By combining adaptive crop varieties, integrated agroforestry systems, and precise irrigation methods, these moderately suitable zones can be transformed into productive and diversified agricultural landscapes, contributing to enhanced food security, economic opportunities for farmers, and greater resilience to environmental challenges in this region.



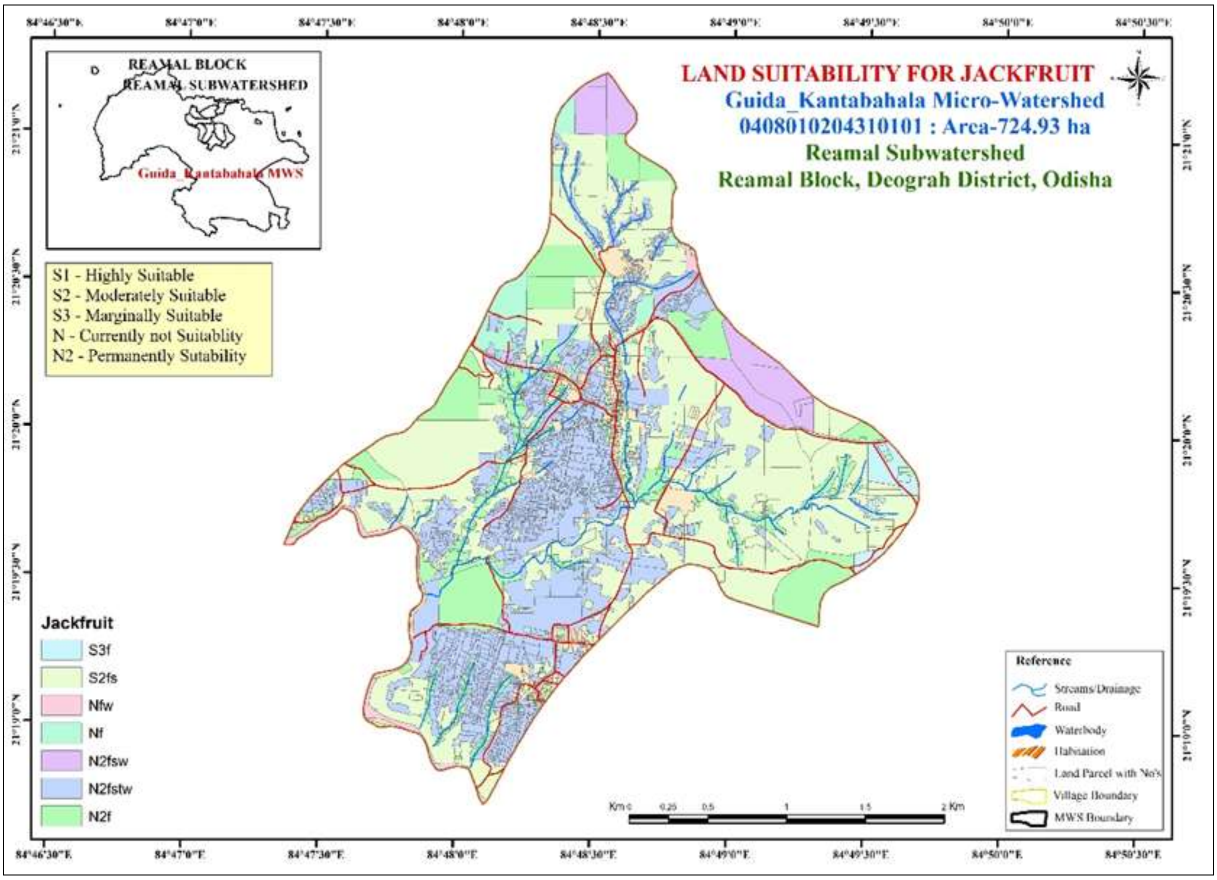


Fig 1: Land Suitability plan for lemon and Jack fruit

4. Conclusion

A GIS-based land suitability assessment conducted in the Guida-Kantabahal micro-watershed, situated within the Reamal block of Deogarh District, Odisha, has revealed that approximately 41.32% of the area is moderately suitable for the cultivation of horticultural crops such as Jackfruit and Lemon. While this presents a promising opportunity for enhancing local agricultural productivity, the study also highlights several biophysical constraints that limit the optimal utilization of the remaining land. These limitations primarily include high soil acidity, susceptibility to erosion, and shallow rooting depth, all of which adversely affect crop performance and long-term soil health. To address these challenges and promote sustainable agricultural development, the study recommends the adoption of targeted, site-specific interventions. One key recommendation is the application of soil amendments, particularly lime, to neutralize soil acidity and improve nutrient availability. Additionally, the implementation of soil conservation practices—such as contour bunding, mulching, and the establishment of vegetative barriers—can play a critical role in reducing erosion and preserving topsoil integrity. For areas that remain less suitable for Jackfruit and Lemon due to inherent soil or topographical limitations, the study suggests exploring crop diversification strategies. Introducing alternative, more resilient crops suited to these marginal conditions can help ensure that no part of the watershed is underutilized. By addressing site-specific constraints with tailored agronomic and conservation measures, the agricultural potential of the entire micro-watershed can be significantly enhanced. Such a comprehensive and adaptive approach not only maximizes land productivity but also supports long-term ecological sustainability and rural livelihood development in the region.

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