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Using Geospatial-Driven Territorial Planning and Land Suitability Analysis for Sustainable Coconut Agriculture in Johor, Malaysia

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Abstract

This research assesses land suitability and territorial planning for sustainable coconut agriculture in Johor, Malaysia, using Geographic Information Systems (GIS) and remote sensing technologies. The study aims to generate a comprehensive coconut land suitability map, evaluate land viability using Weighted Overlay Analysis (WOA) and Principal Component Analysis (PCA), and develop territorial plans that consider soil suitability, climate conditions, and environmental impacts. Key variables analyzed include digital elevation model (DEM), soil bulk density, land use/land cover, soil moisture, NDVI, soil pH, annual rainfall, temperature, soil type, and soil water content. Each of these factors was reclassified and assigned weights through Weighted Overlay Analysis (WOA) and Principal Component Analysis (PCA) to produce detailed suitability maps. The final maps classified areas into suitability categories: very suitable, suitable, moderately suitable, unsuitable, and very unsuitable, based on a predefined scale. These results clearly show that there is a significant loss of suitability regarding coconut cultivation from 2018 to 2024 due to driving factors like urbanization, degradation of land, and fluctuating environmental conditions. Therefore, key areas that were found highly suitable for coconut farming include Pontian, Muar, Batu Pahat, and Kota Tinggi, while areas of lower suitability include Pulau Tioman. The study thus concludes that adaptive land management strategies and continuous monitoring are needed to promote sustainable coconut agriculture, hence optimizing land use in Johor.

1. Introduction

Environmental issues are both a consequence and a potential solution due to the intimate linkage between agriculture, climate change, and loss of biodiversity [1-3]. For instance, it becomes increasingly important that countries like Malaysia are concerned about sustainable agriculture in ensuring food security and protection of the environment, as their economy heavily relies on the agricultural industry to sustain the growing population. This urgency is further composed by challenges such as population increase, environmental degradation, and the pervasive impacts of climate change. Hence, sustainable agriculture, which extends beyond mere crop production, has gained prominence due to increased awareness of the detrimental effects of conventional farming practices on the environment [3]. In a nutshell, it embodies a set of principles that seek to harmonize economic viability, social equity, environmental conservation, production efficiency, and food security [4].

Agriculture might be considered one of the most closely linked factors with both climate change and biodiversity loss, but at the same time, it represents challenges and opportunities in terms of offering environmental solutions [5-6]. For Malaysia, where agriculture plays a crucial role in the economy and food security, the practice of sustainable agriculture becomes quite important in order to address various challenges that emerge from the increasing population growth, environmental degradation, and climate change. As a result, sustainable agriculture aims to balance economic, social, and environmental goals, moving beyond traditional farming methods that often harm the environment and impact the food security of the nation [7]. The coconut industry in Johor provides employment opportunities and supports local economies, supplying raw materials for various products, including coconut oil, desiccated coconut, and coconut-based beverages. Johor, in particular, is a significant producer of coconuts, providing employment opportunities and supporting local economies. The coconut industry supplies raw materials for various products, including coconut oil, desiccated coconut, and coconut-based beverages, which are integral to both domestic and export markets. Sustainable coconut farming in Johor is crucial to ensuring food security, enhancing income generation for farmers, and promoting economic stability in the region.

Thus, the complexity of sustainable agriculture demands the integration of cutting-edge technologies [8-9] to ensure innovative resource conservation, advanced irrigation systems, enhanced crop varieties, and improved soil quality [10]. These imperatives are then responded to in the present research, which has been done on land suitability determination for agriculture and the development of territorial plans to foster sustainability [11-12]. Geographical Information Systems (GIS) appear as a handy tool for thorough land analysis and spatial planning [13-14], integrating geospatial data to assess topography, soil conditions, climate, and vegetation indices through multi-criteria approaches [15]. This approach ultimately provides refined insights into specific land use opportunities and constraints, optimizing land use and crop selection for long-term food security and environmental sustainability [16-17]. In addition, effective land use strategies and efficient management, facilitated by GIS, will surely contribute to improved land production and a sustainable ecosystem [18].

Throughout the centuries, advancements in technology have been key to achieving sustainability. Consequently, software like Geographic Information Systems (GIS) is crucial for inspecting land suitability, managing resources, and improving agricultural practices [19-21]. Hence, GIS helps evaluate factors such as soil, climate, and topography, leading to better land use decisions and enhanced crop selection [22-23]. In the specific context of Peninsular Malaysia, this research extends its focus to the coconut agriculture sector, aiming to assess land suitability and map out territorial plans for sustainable coconut cultivation. Territorial planning, a tool for geographical and political structure, is necessary for determining and implementing primary plans that consider ecological and socioeconomic factors [11]. The national documents outlining this plan provide insights into optimal land use within legal constraints, balancing ecological and socioeconomic considerations [24-26]. Comprehensive territorial planning, supplemented by GIS, enables land management that is sustainable through systematization of land use, allocation, and policies, which may support food security and environmental conservation. In this respect, the synergy between GIS-based land valuation, sustainable agriculture, and comprehensive territorial planning forms the bedrock of this work. It thus becomes comprehensive in providing a strategic approach to the multi-complex problems emanating from agriculture and the environment within Peninsular Malaysia. By aligning environmental preservation and food security objectives, the study thus provides a strong framework tailored to the unique context of Peninsular Malaysia that should promote a balanced and sustainable land use practice, contributing to the overarching goals of environmental conservation and food security.

Moreover, this study aligns with the United Nations Sustainable Development Goals (SDGs). Specifically, it contributes to SDG 2 (Zero Hunger) by ensuring food security through sustainable agricultural practices, SDG 13 (Climate Action) by promoting climate-resilient farming methods, and SDG 15 (Life on Land) by encouraging sustainable land management to prevent degradation. By integrating Geographic Information Systems (GIS) and land suitability analysis, this research provides a strategic approach to optimizing land use while maintaining ecological balance. The findings of this study are particularly relevant for policymakers, agricultural planners, and stakeholders who aim to enhance Johor's coconut industry while ensuring long-term sustainability.

The present research develops strategies for sustainable coconut cultivation and assesses land suitability for coconut agriculture in Peninsular Malaysia. Therefore, there is a need for efficient territorial planning supported by GIS which integrates ecologic and socioeconomic factors for the optimization of land use with regard to environmental and food safety [27-28]. Thus, combining the GIS-based land analysis with sustainable practices indeed forms a comprehensive approach toward agricultural and environmental management in the region.

2. Method

2.1. Study Area

As the main producer of coconuts in Malaysia, Johor was selected as the site of this study. The study concentrated on locations of Johor that are suitable for coconut agriculture, such as areas with coconut plantations currently in place, possible sites found through GIS-driven land suitability studies, and agricultural zones designated to produce coconut seeds. The government's strategic intentions to grow coconut plantations are in line with the choice of Johor as the study region; by 2027, it is expected that 1,325 hectares of coconut plantation will be developed [29].

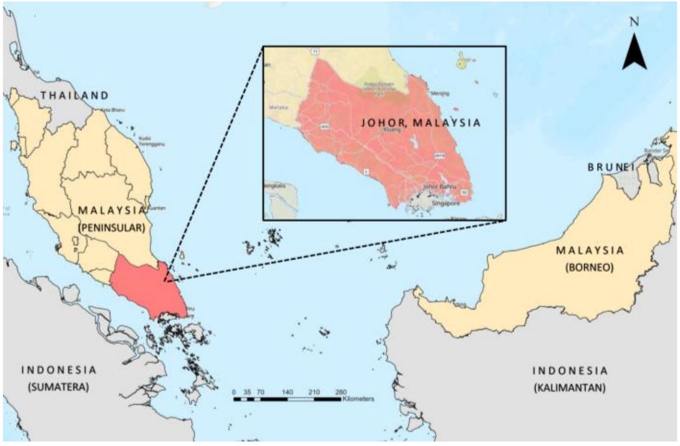


Figure 1. Johor Region Map

Figure 2 illustrates a detailed overview of the methodological flowchart employed in this research. A methodology flowchart is a graphic aid that shows the precise steps or order of tasks required to carry out a project or conduct research. The study design, data collection, analysis, and other significant methodology components are outlined in a straightforward and well-organized manner.

2.2. Data Collection

The data collection for this study involves using a combination of open-access platforms, government databases, and specialized datasets to ensure a comprehensive and accurate analysis of land suitability for sustainable agriculture in Peninsular Malaysia.

This study relies considerably on ERDAS software remote sensing. Data used in this study were taken from Google Earth Engine, which is a cloud-based platform providing users free of cost with the largest satellite image and remote sensing repository. In fact, GEE is a geospatial data platform for accessing and processing satellite remote sensing data, enabling users to achieve both critical and minute degrees of spatial analyses and monitoring of agri-landscapes across seasons and years. Indeed, it hosts several open-source satellite remote sensing datasets, notably MODIS and Sentinel-2 imagery. MODIS provides a broad-scale land cover classification, whereas Sentinel-2 hosts high-resolution images suitable for detailed analysis.

Figure 2. Methodology Flowchart

Further, we integrated the following GIS data layers using GEE: topography, climate, and land cover. From SoilGrids, high-resolution global soil information is available, which significantly enables detailed knowledge about the conditions of the soils. FAO Soil Data allows us to classify the state of soils and their analysis in different regions. We derived critical temperature and precipitation data along with other climatic contributory factors to land suitability from NASA Climate Data. The study boundary was derived using the ESRI Border Data, which is very important in defining the study area, hence giving out actual spatial analysis.

Data included in GeoTanih also contains specific details on soil compendium, which is important for analyzing plantation criteria for various crops such as coconuts. The soil compendium delivers further information on the types of soil, characteristics, and classification based on the soil suitability analysis for agricultural activities.

The dataset was based on the data collected from open sources and government databases. It integrated these into one comprehensive dataset through pre-processing to eliminate anomalies and match data to the geographical scope of this study. Data fusion combines data from remote sensing, GIS layers, SoilGrids, FAO soil, NASA climate, and ESRI border data into one single database. Consequently, land suitability evaluation for coconut cultivation and other agricultural practices through the use of GIS tools in spatial analysis helps to find suitable planting areas and to establish the relationship between variables. In addition, validation results were derived from GeoTanih data, which were cross-checked with remote sensing observation data and SoilGrids data.

Accordingly, by utilizing open access platforms like GEE, supplemented with datasets for SoilsGrids, FAO soil data, NASA climate data, ESRI border data, and government-provided information from GeoTanih, it ensures that this study is vigorously grounded in terms of data collection and analysis. A methodology, hence supportive of a full land suitability assessment, allowing well-informed decisions on sustainable agriculture in Peninsular Malaysia, shall be provided.

2.3. Data Processing

Data processing procedures in this study transformed raw data into actionable insight for land suitability assessment and sustainable agriculture in Peninsular Malaysia. Data were imported from sources like GEE, SoilGrids, FAO soil datasets, NASA climate data, and ESRI border data into compatible formats for analysis. Then, quality assessment for each dataset was handled regarding missing values, anomalies, and inconsistencies. Satellite MODIS and Sentinel-2 imagery were pre-processed for atmospheric distortions, radiometric errors, and geometric misalignments, including atmospheric correction and geometric correction, in order to have seamless image mosaics.

Integration of data was conducted through overlaying spatial layers by ensuring that they were all aligned to the same coordinate system and resolution, matching resolutions of datasets, and converting the dataset to a common coordinate reference system. The various attributes combined include land cover information from MODIS, soil properties from SoilGrids, climate data from NASA, in addition to extra information on economic indicators and agricultural practices as context for land suitability.

Spatial analysis was conducted using GIS tools in analyzing land cover change, assessing the properties of the soil, and finally evaluating the impact of climate variables on land suitability. Land suitability models were developed using Principal Component Analysis and Weighted Overlay Analysis through defining suitability criteria and giving importance weights to the defined criteria, then integrating them to get a land suitability map. Statistical methods were used to evaluate the presence of correlations, trends, and patterns by computing descriptive statistics and conducting inferential statistics that test hypotheses related to variable relationships.

Data validation was performed using GeoTanih, complemented by field observation from Google Earth by comparative analysis and error correction. Sensitivity analysis was done to determine the variation in input data that may influence the results obtained from the suitability models, hence ensuring robustness. The findings were matched with existing literature and expert knowledge of the known patterns in sustainable agriculture. These procedures in data processing provided the basis on which accuracy, reliability, and actionability of results for land suitability and sustainable agriculture analysis in Peninsular Malaysia can be achievable, in which raw data was transformed into meaningful insights to inform decision-making and subsequently support sustainable agricultural practices effectively.

2.4. Data Analysis

This section describes the methodology using Weighted Overlay Analysis (WOA) and Principal Component Analysis (PCA) to assess the land suitability for coconut agriculture by synthesizing complex data into actionable insights in land use planning.

2.4.1 Weighted Overlay Analysis (WOA)

WOA is the integration of several criteria into GIS by using weighted scores in the development of suitability maps. In coconut agriculture, for example, a selection of some of the criteria or conditions for suitability may involve soil pH, moisture, temperature, and land cover. Weights represent the relative importance given by experts, literature review, stakeholder input, or other means, as long as the total equals 100% for normalizing. It was followed by the data standardization process, where the values of each criterion were normalized on a common scale and then reclassified into suitability classes such as Very Suitable to Very Unsuitable. The latter step was then followed by the integration of these reclassified criterion layers within a GIS platform, where the application of weights was done along with the computation of weighted scores for each land parcel. A final suitability map produced presented the weighted score to show high, moderate, and low suitability areas. This process of validation of the map entailed field observations or independent data sources, based on which enhancements are made where necessary [30 - 31].

2.4.2 Principal Component Analysis (PCA)

PCA is a statistical procedure applied for data dimensionality reduction and to identify those variables explaining the greater part of variation within a dataset. The initial steps include preparation of the data: quantitative data are collected on variables such as soil density, moisture, temperature, and rainfall; standardization of these variables was carried out so that each variable contributed equally to the PCA [32]. It has to do with computing the covariance matrix of standardized variables that might capture the relationships and variances between different variables. The variance and direction of the captured variance were then represented by the eigenvalues and eigenvectors, respectively, captured from the covariance matrix. The principal components were ranked based on their eigenvalues.

With this ranking, the top-ranking components explained most of the variance and hence selected. The original data were projected onto the selected components to provide principal component scores for each land parcel, representing the transformed data in the new principal component space.

It provided a biplot and a score plot visualizing the results, from which the principal components were analyzed to recognize the key variables that contribute most to the variance in land suitability. Finally, the results of PCA were checked against known assessments of land suitability or actual field observations; the insights from PCA were integrated into an overall assessment of land suitability and informed weighted overlay analysis or other decision-making processes. The study ensures through these procedures a holistic and intensive assessment of land suitability that facilitated informed decision-making for sustainable coconut agriculture.

3. Results and Discussion

3.1. Criteria Identification

The study produced criterion maps (see Figure 3, Tables 1 and 2) showing land suitability for coconut farming in Johor. Key variables influencing suitability included soil pH, moisture content, elevation, and temperature. The suitability classes were categorized into Highly Suitable (S1), Suitable (S2), Moderately Suitable (S3), Unsuitable (S4), and Very Unsuitable (S5) with specific ranges for DEM, soil density, soil type, soil water content, Land Use Land Cover (LULC), Normalized Difference Vegetation Index (NDVI), soil pH, soil moisture, elevation, annual rainfall, and temperature [33].

Table 1. Criteria Table 1

Suitability Class	DEM (m)	Soil Density (g/cm^3)	Soil Type	Soil Water Content (%)	LULC
Highly Suitable (S1)	0-200	1.0-1.2	Loamy soils	15-20	Current croplands and grasslands
Suitable (S2)	200-500	1.2-1.4	Sandy loam or clay loam	10-15	Areas with potential for conversion
Moderately Suitable (S3)	500-1000	1.4-1.6	Sandy or clayey soils	5-10	Areas with mixed land cover or forested land
Unsuitable (S4)	< 1000 + slope < 15%	< 1.6	Highly clayey or sandy soils	> 5	Urban or industrial areas, dense forests, or protected zones.
Very Unsuitable (S5)	< 1000 + slope < 30%	< 1.8	Highly saline or sodic soils	> 0	Areas with critical natural habitats or extensive land degradation

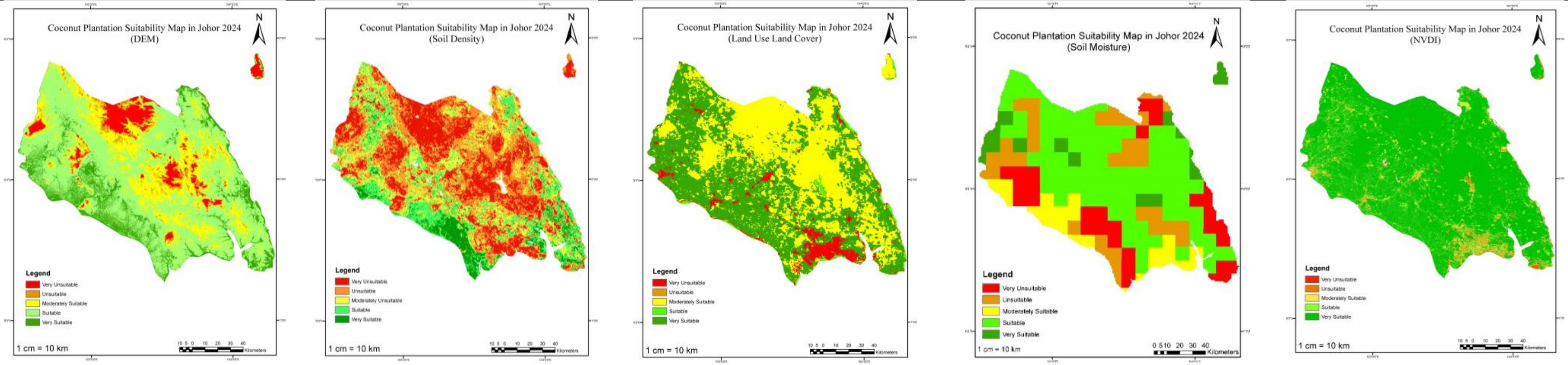
These tables outline the key environmental and soil parameters that determine land suitability for coconut farming. Table 1 focuses on the key physical parameters that influence land suitability for coconut farming. These parameters include soil density, land use classification, and elevation. The findings suggest that regions with loamy soils and moderate elevation (0-200 meters) are classified as highly suitable for coconut cultivation. Conversely, areas with steep slopes or high soil density are less suitable due to drainage and root penetration limitations.

Table 2 presents soil moisture, NDVI (Normalized Difference Vegetation Index), and climate conditions as key variables influencing coconut plantation viability. The study indicates that regions with moderate to high soil moisture (15-20%) and NDVI values between 0.6-0.9 exhibit optimal conditions for coconut growth. Furthermore, annual rainfall within the range of 1500-2000 mm and temperatures between 25-30°C contribute to the highest suitability classification.

Table 2. Criteria Table 2

Suitability Class	Soil Moisture (%)	NDVI	Soil pH	Annual Rainfall (mm)	Temperature (°C)
Highly Suitable (S1)	15-20	0.6-0.9	6.0-7.0	1500-2000	25-30
Suitable (S2)	10-15	0.4-0.6	5.5-6.0 or 7.0-7.5	1000-1500	20-25 or 30-35
Moderately Suitable (S3)	5-10	0.2-0.4	4.5-5.5 or 7.5-8.0	800-1000	15-20 or 35-40
Unsuitable (S4)	> 5	> 0.2	> 4.5 or < 8.0	> 800	> 15 or < 40
Very Unsuitable (S5)	> 0	> 0.1	> 4.0 or < 8.5	> 0	> 10 or < 45

Digital Elevation Model (DEM) Map	Soil Bulk Density Map	Land Use Land Cover	Soil Moisture	NVDI



Soil pH	Annual Rainfall	Temperature	Soil Type	Soil Water Content

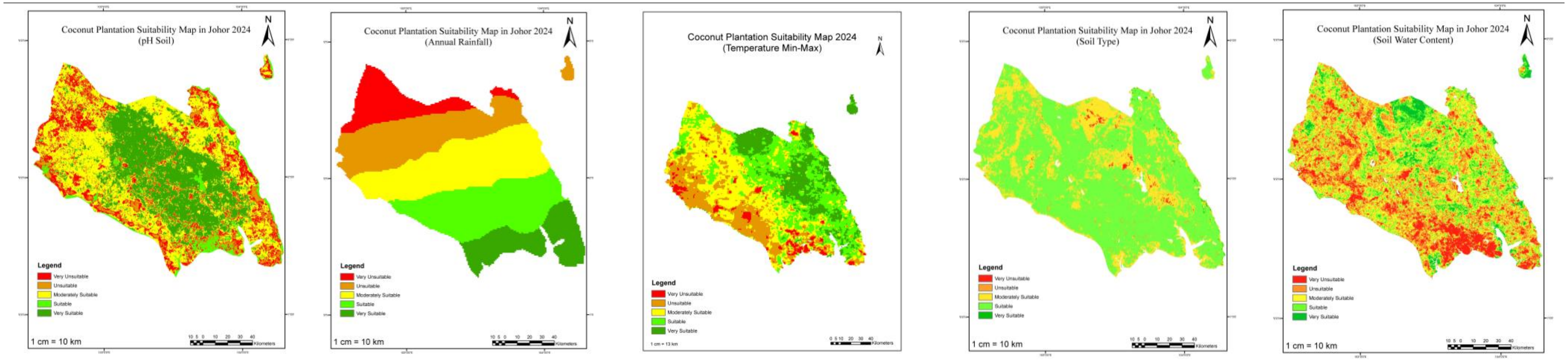


Figure 3. Criterion Maps

3.2 Coconut Plantation Suitability Map

One of the key deliverables for this study is the Coconut Plantation Suitability Map, which is intended to address the comprehensive assessment of areas in Johor, Malaysia, that are suitable for coconut cultivation. This assessment applies two major methods of analysis for generating suitability maps, namely the Weighted Overlay Analysis (WOA) and Principal Component Analysis (PCA), which present different standpoints on land suitability, integrating various environmental and soil parameters to indicate optimal locations for coconut farming.

3.2.1 Weighted Overlay Analysis Map

WOA provides a basis for evaluating and ranking land suitability for coconut plantations, integrating multiple environmental and soil parameters. It assigns weights to each parameter based on the relative importance for coconut cultivation and thereafter combines these weighted parameters to come up with a composite suitability map. Finally, the Weighted Overlay Analysis map shows three distinct suitability categories for coconut cultivation in Johor, Malaysia (see Table 3 and Figure 4):

3.2.2. Principal Component Analysis (PCA) Map

Principal Component Analysis is a statistical procedure for reduction of dimensionality, retaining most of the information about variance. In this context, PCA is performed for integration and analysis of various environmental and soil parameters to generate composite suitability maps based on principal components.

The PCA suitability map highlights areas of high, medium, and low suitability for coconut plantations (see Table 4 and 5). Table 4 categorizes land suitability based on Weighted Overlay Analysis (WOA), identifying zones as suitable, moderately suitable, or unsuitable. The analysis reveals that green-labelled areas (highly suitable zones) possess the most favourable environmental conditions for coconut plantations, ensuring maximum productivity. Table 5 further refines the classification through Principal Component Analysis (PCA), which assigns weighted importance to different variables. The study finds that southern and southeastern regions of Johor show high suitability, while the northwestern parts face limitations due to poor soil quality and drainage issues.

Table 3. WOA Suitability Table

Class	Descriptions
Green (Suitable)	Represents areas where the combined influence of all criteria indicates optimal conditions for coconut plantations. These regions meet the desired thresholds for factors such as soil properties, climate conditions, and other environmental variables. The green areas on the map suggest that these locations are well-suited for coconut cultivation and are likely to support healthy growth and high yields.
Yellow (Moderate)	Indicates regions where the suitability for coconut cultivation is moderate. These areas meet some of the criteria for coconut farming but may fall short in one or more aspects, such as soil quality or climate conditions. While these regions can support coconut cultivation, they may require additional management practices or improvements in certain factors to enhance suitability. The yellow areas highlight potential locations for coconut farming, with some constraints that need to be addressed.
Red (Unsuitable)	Denotes areas that are deemed unsuitable for coconut plantations based on the combined analysis of all criteria. The red regions fail to meet critical thresholds for key factors such as soil bulk density, pH, water content, and other essential parameters. These areas are likely to face significant challenges, such as poor soil conditions or an adverse climate, which would impede successful coconut cultivation. The red areas are recommended to be avoided for new coconut plantation projects due to their unfavourable conditions.

Table 4. Composite Bands

Class	Descriptions
Unsuitable Areas (Red)	These are in the northwestern and central parts of Johor, and the conditions in these areas are not suitable for coconut farming. Among unsuitable factors are poor soil fertility and lack of enough water.
Suitable Areas (Green)	Extensive areas in the southern and south-eastern regions have been identified as highly suitable. Such zones are considered to have optimum conditions for coconut growth with respect to soil type and climatic conditions.
Moderately Suitable Areas (Blue)	These regions, scattered across Johor, indicate areas that can support coconut plantations with some agricultural interventions. Practices such as soil enhancement and irrigation could enhance the suitability of these areas.

Table 5. Stretched Bands

Class	Descriptions
High Suitability Areas	These are shown in green, mostly appearing in the Southern and South-eastern parts of Johor. They have been selected as having the most ideal conditions from both the environmental and soil point of view for coconut plantations.
Low Suitability Areas	Indicated in red, these areas are less suitable for coconut farming. Significant low suitability zones are found in the northwestern region, likely due to limitations such as poor soil quality or inadequate drainage.

The mapping was conducted for two different approaches of PCA and visualized the most promising locations for farming coconut with regard to several environmental and soil characteristics [32 - 33]. Hence, high suitability areas were mapped in bright green, while on the other hand, areas with low suitability were mapped in a range from yellow to orange to red colour, indicative of less suitable conditions (see Figure 5). The method provides a nuanced view of suitability by considering the integrated effects of all factors on stakeholders' decision-making in land use and coconut farming practices.

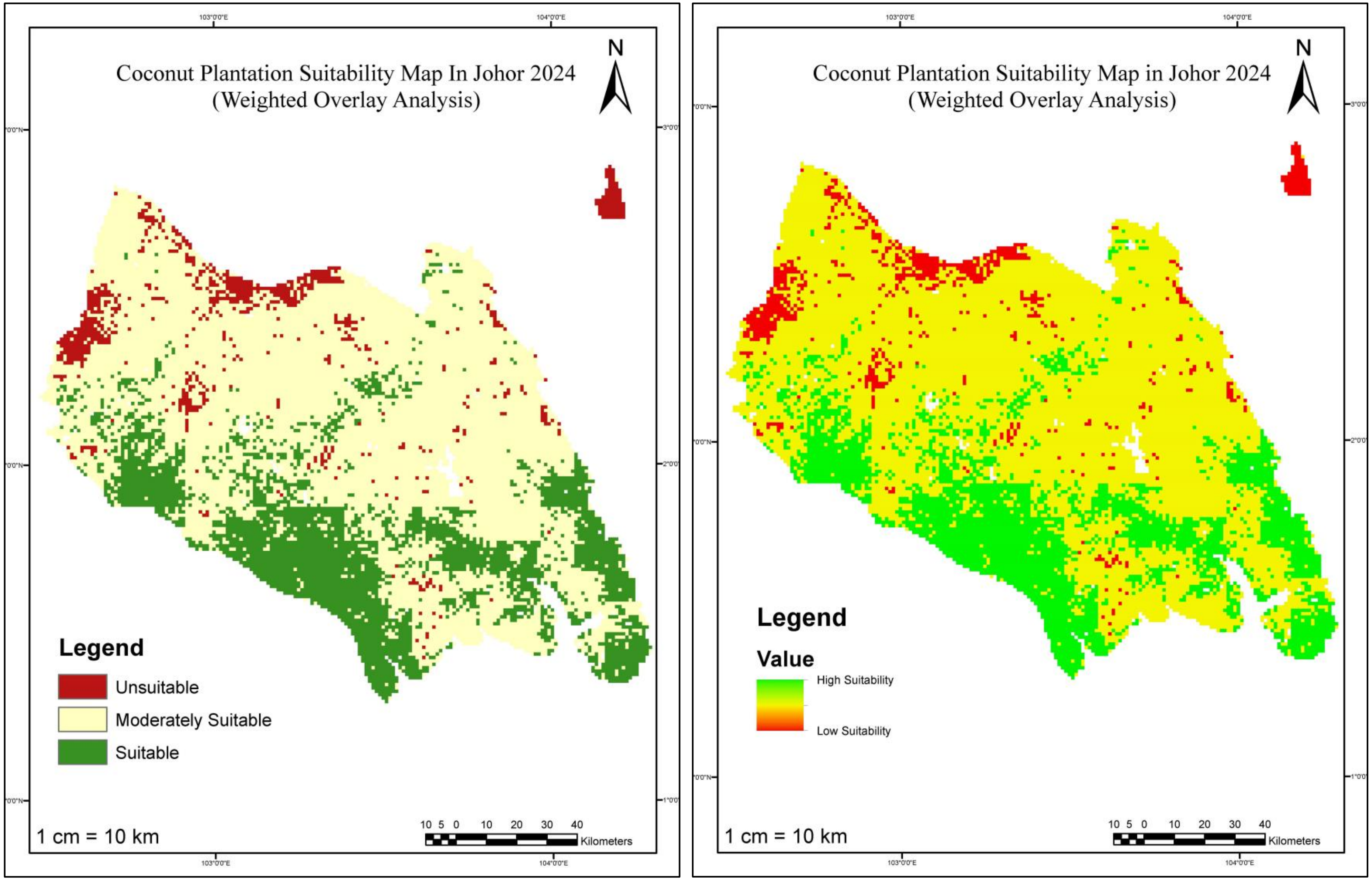


Figure 4. Coconut Plantation Suitability Map in Johor 2024 (Weighted Overlay Analysis – Stretched & Classified).

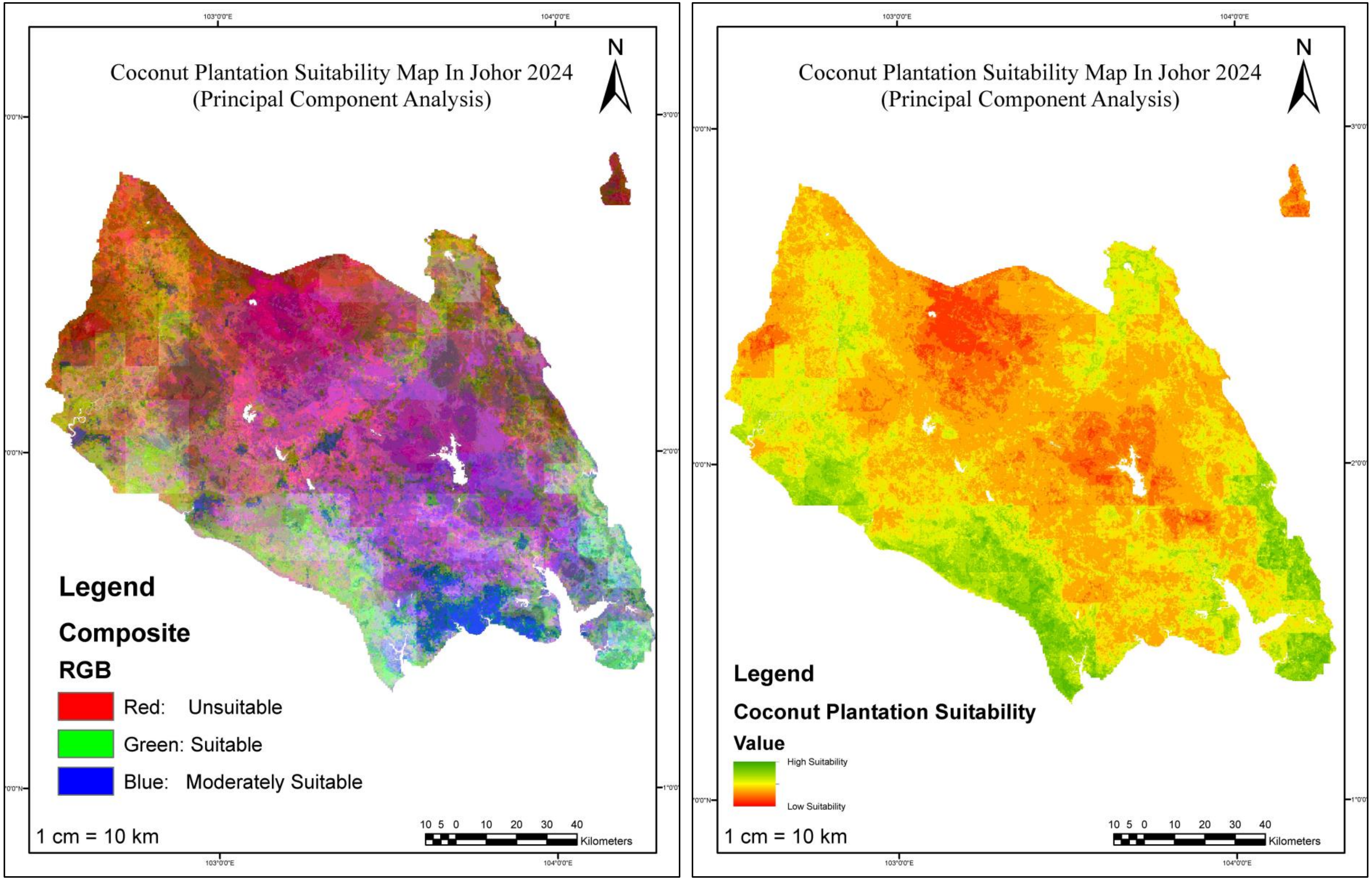


Figure 5. Coconut Plantation Suitability Map in Johor 2024 (Principal Component Analysis – Composite Bands & Stretched).

3.2.3 Territorial Plan Map

The Territorial Plan Map outlines the region of Johor, including Muar, Segamat, Batu Pahat, Kluang, Pontian, Mersing, Pulau Tioman, Kota Tinggi, and Johor Bahru (see Figure 6). This map represents the suitability of these areas for the plantation of coconuts. It can be gathered from this map that the Pontian area is most suitable for coconut plantations as it is mainly green in colour. Muar, Batu Pahat, and Kota Tinggi also show extensive areas in green colour, showing high suitability, while Kluang and Johor Bahru have some green regions, indicating moderate suitability. Mersing and Segamat present a little green, indicating limited suitability; Pulau Tioman is mostly red, hence unsuitable for the coconut plantations.

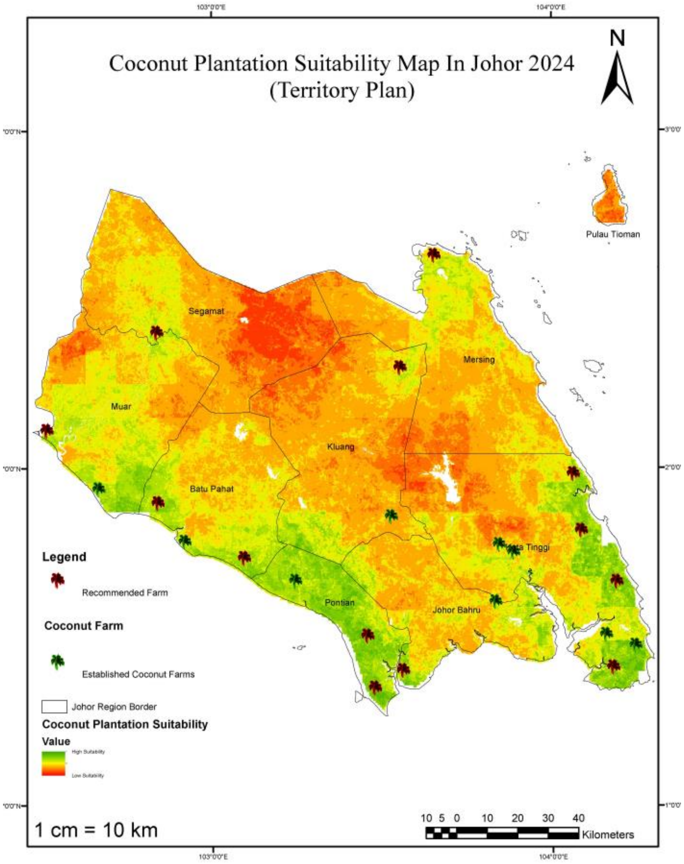


Figure 6. Coconut Plantation Suitability Map in Johor 2024 (Principal Component Analysis – Composite Bands & Stretched).

The plantation effort could be concentrated on highly favourable locations, such as Pontian, Muar, Batu Pahat, and Kota Tinggi, for maximizing the success of coconut plantations in Johor, along with focused intervention in the moderately suitable areas (summarized in Table 6). Productive and long-term sustainability of coconut farming in the region can be built upon the use of technology, improvement of resource management, and integration of sustainable agricultural practices [6, 8,19,-34]. It will be very important before large-scale plantation initiatives are mounted, that the changes likely to be needed, along with possible benefits for places that are less suitable, are carefully assessed [10, 17].

Table 6. Sustainability Analysis

Pontian	With extensive suitable areas, Pontian offers high potential for sustainable coconut plantation development.
Muar, Batu Pahat, Kota Tinggi	These regions also provide good prospects but may require targeted interventions to maximize potential.
Kluang, Johor Bahru	Moderate suitability suggests these areas can support coconut plantations, but with careful planning and resource management.
Mersing, Segamat	Limited suitability means these areas may need significant improvements in soil and water management for successful plantations.
Pulau Tioman	Unsuitable due to predominant red areas, indicating high unsuitability for coconut cultivation.

3.2.4 Comparison of Coconut Suitability Map

The following comparison of land suitability maps for coconut agriculture in Johor, Malaysia, over the years-for instance, from the year 2018 to the year 2024-reveals a few disturbing trends: the land has become less suitable for growing coconuts over the years. This change shows an increment of mismatch in characteristics of land and the requirements of land for coconut agriculture.

In 2018, the land suitability map represented a very fair share that fell within the suitable or moderately suitable classes for coconut cultivation. The favourable properties of the soil, adequate climate, and sufficient availability of water were the main factors behind this, hence laying a good foundation for sustainable coconut agriculture. By 2024, the updated map shows a big decline in these suitable classes. It has been attributed to deteriorating soil conditions, changes in climate patterns, and increased land degradation or competing uses. Either soil fertility could have declined due to high-intensity continuous use of the land or poor management practices. On the other hand, changes in climate conditions-such as more frequent extreme temperatures or altered rainfall patterns-have, had a negative impact on land suitability [1,-25, 28].

Besides this, even broader environmental and socioeconomic changes, such as urbanization or industrial expansion, have encroached upon the suitable agricultural land. This has been exacerbated further by the decline in the availability of water due to changes in infrastructure or land use policies; hence, it is also a contributing factor to decreased land suitability. The comparison done here-after contrasting the future scenarios with baseline shows that immediate and strategic interventions are urgently needed to overcome the decline in land suitability factors. This calls for continuous monitoring, hence adaptive management practices, to reduce negative impacts on coconut agriculture, motivating sustainable land use strategies in Johor.

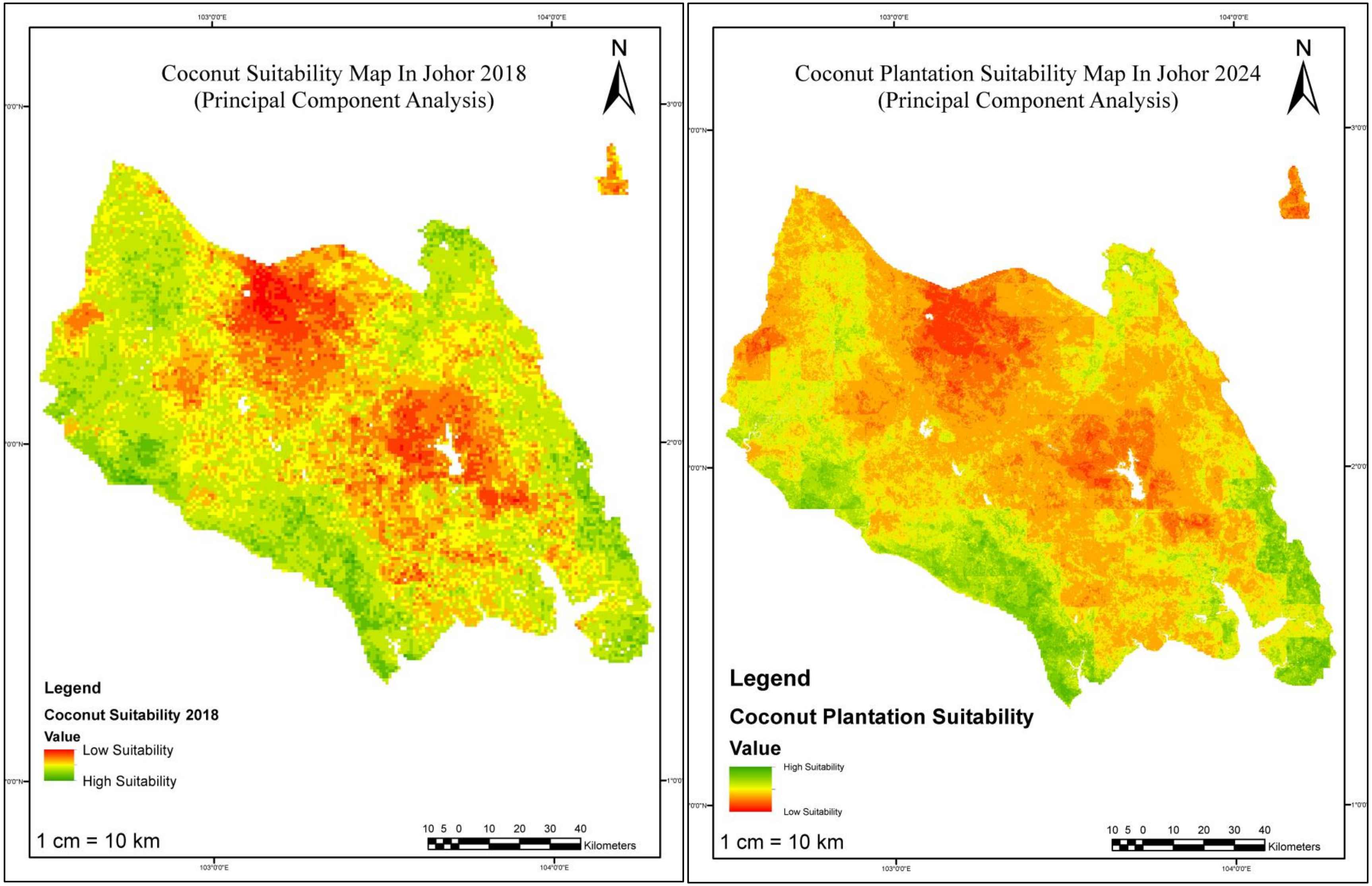


Figure 7. Comparison of coconut suitability map 2018-2024

4. Conclusion

This study has systematically addressed the critical aspects of land suitability for sustainable coconut agriculture in Johor, Malaysia. Through a detailed methodological approach, various data sources and analytical techniques were integrated to assess land potential, determine suitability, and propose a comprehensive territorial plan, emphasizing a balanced approach that considers environmental, economic, and social factors.

4.1. Generating a Comprehensive Coconut Land Suitability Map for Johor

The research successfully provided the results of developing an integrated suitability map for recent coconut land in Johor using remote sensing, GIS, and data from government databases [20, 21]. This integrated map, combining soil properties, climate conditions, and land cover, reflects diverse suitability conditions across Johor with high accuracy; therefore, it provides valid information for stakeholders in decision-making for the identification and prioritization of land that is suitable for coconut agriculture.

4.2. Assessing Land Suitability Using Weighted Overlay Analysis (WOA) and Principal Component Analysis (PCA)

In this study, the suitability of the land for the coconut plantation was evaluated by WOA and PCA. Although WOA can provide a multi-criteria weighted score, PCA can reduce data dimensions to focus on the most influencing variables. These two complementary techniques can be useful in understanding land suitability [38]. Further verification of the results from this analysis confirmed that the approach is sound and reliable for precise insight into coconut plantation suitability in Johor.

4.3. Developing a Territorial Plan for Johor

This study attempted a Johor territorial plan based on determinants of critical factors in soil suitability, climate conditions, and perceived environmental impacts. Having taken into consideration soil health, water availability, and climate variability, the plan indeed postulates a framework that ascertains the practice of sustainable land use in coherence with environmental conservation and agricultural productivity. It provides a pragmatic guide in which stakeholders in land resources can effectively manage and utilize the same for long-term sustainability in coconut farming.

4.4. Recommendation

These findings make crucial contributions to the development of sustainable agriculture and also provide realistic recommendations for the improvement of coconut cultivation without losing environmental integrity. This study focuses on how land suitability assessment must be approached from a multidimensional perspective in devising sustainable agricultural practices and provides a sound basis for future research in food security [35 - 36], farmers and policy reform in the region [37, 7]. Several districts were classified as high suitability for coconut farming namely Pontian, Muar, Batu Pahat, and Kota Tinggi. These locations were selected based on their favourable soil properties, climate conditions, and existing agricultural infrastructure. Based on these conclusions, this study puts forward the following recommendations, essential for the improvement of sustainable coconut agriculture in Johor, Malaysia:

4.4.1 Implementation of Suitability Maps

The result of the coconut land suitability map developed in this study is recommended for use by stakeholders, both governmental and agricultural organizations. This map shall serve to pinpoint the most suitable areas for coconut cultivation, thereby enhancing investment and allocation of resources to specific areas with maximized productivity and sustainability of the coconut plantations through land-use planning integration.

4.4.2 Enhancement of Data Integration and Analysis

Future research should be directed to diversified data sources and techniques, such as Weighted Overlay and Principal Component Analysis, which would be useful for the realization of more precise results in land suitability. Updating and refinement of data and analytical models are needed continuously to cope with changes in environmental conditions and economic circumstances [38-39]. This will also involve cooperation by researchers, government agencies, and local partners in updating the research with new information and knowledge.

4.4.3 Development of Sustainable Agricultural Practices

Farmers and land planners will need to address production methods that promote soil health and efficient use of water at minimal environmental degradation and promoting balance ecosystem [20]. Agroforestry, organic farming, and precision agriculture will enhance the productivity of coconut plantations while reducing impacts on the environment. The territorial plan developed herein underlines the need to consider soil suitability, climatic conditions, and their eventual environmental implications in all aspects of agricultural production.

In a nutshell, these recommendations, if adopted by all the stakeholders and researchers, will further bring in even better effectiveness of land suitability assessments, improve sustainable agricultural practices, and ensure the long-term viability of coconut cultivation in Johor.

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Author contributions

Muhammad Shafiqal Daniel Bin Abdul Rahim: Data processing, analyses and manuscript development, **Siti Aekbal Salleh:** conceptualization, methodology, software, design analyses, **Nabilah Naharudin:** Manuscript review, design analyses, GEE resource, **Nurul Amirah Isa:** Methodology, mapping, manuscript editing **Faezah Pardi:** Vegetative analyses, manuscript review, **Mohamad Fuad Abdullah:** multicriteria analyses, manuscript review**, Nornizar Anuar:** manuscript editing, soil analyses.

Conflicts of interest

The author(s) declare(s) that there is no conflict of interest concerning the publishing of this paper.

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