Land Suitability Evaluation & Regional Potential Mapping

Development of Agriculture, Livestock, Fisheries, & Forestry Commodities Região Administrativa Espesial Oe-Cusse Ambeno (RAEOA)

LAND SUITABILITY EVALUATION AND REGIONAL POTENTIAL MAPPING FOR THE DEVELOPMENT OF AGRICULTURE, LIVESTOCK, FISHERIES, AND FORESTRY COMMODITIES IN RAEOA

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FOREWORD

MINISTER OF AGRICULTURE, LIVESTOCK, FISHERIES, AND FORESTRY OF TIMOR-LESTE

With gratitude to God Almighty, we proudly welcome the publication of the book titled *"Land Suitability Evaluation and Mapping of Regional Potential for Agricultural, Livestock, Fisheries, and Forestry Commodites Development in RAEOA, Timor-Leste."* This book is a tangible result of the collaboration between the Ministry of Agriculture, Livestock, Fisheries, and Forestry (MAPPF) of Timor-Leste and the Faculty of Agriculture at Udayana University, supported by funding from the Government of Timor-Leste through Contract No. 24/MAPPF/IV/2024.

As a country rich in natural resources, Timor-Leste faces significant challenges in optimizing land use amidst limited resources and the impacts of climate change. This book aims to address the urgent need for land resource management focused on food security, environmental sustainability, and poverty alleviation. Through a data-driven approach, this research has successfully mapped the regional potential for the development of food crops, plantations, horticulture, and forestry commodities, and formulated relevant strategies to support rural economic growth and create new employment opportunities.

Covering the four main Sub-Regions of RAEOA area Nitibe, Oesilo, Pante Macassar, and Passabe. this book offers strategic guidance in utilizing the dryland areas that dominate RAEOA region. The proposed land suitability zoning approach provides solutions to challenges such as land degradation, erosion hazards, and soil fertility decline. Furthermore, the book emphasizes the importance of integrating environmental conservation and modern technology to support sustainable land productivity.

We believe that the recommendations presented in this book will not only provide direct benefits for food security in Timor-Leste, particularly in RAEOA region, but will also contribute to the achievement of the Sustainable

Development Goals (SDGs), particularly in relation to hunger eradication (SDG 2), climate action (SDG 13), and biodiversity protection (SDG 15).

I invite all stakeholders—from government, academia, to the broader public—to use this book as a reference in land resource management and agricultural sector development planning. Through synergy and close collaboration, we can ensure that agricultural development in Timor-Leste progresses in line with the preservation of natural resources, ecosystem sustainability, and the improvement of community welfare.

Finally, I would like to express my gratitude to all those who have supported the realization of this book. May this work serve as a significant milestone in Timor-Leste's journey toward strong food security, inclusive economic development, and environmental sustainability.

Sincerely,

Eng. Marcos da Cruz, MAgSt
Minister of Agriculture, Livestock
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EXECUTIVE SUMMARY

A. GENERAL OVERVIEW OF THE STUDY AREA

This chapter presents an overview of the ***Região Administrativa Especial de Oecusse-Ambeno*** **(RAEOA)** as an important background for evaluating land suitability and the potential for the development of agricultural, plantation, horticultural, and forestry commodities. The information presented includes demographics, soil types, land use, and existing field conditions, with a data-driven and comprehensive approach.

1. Demographics: Foundation of Human Resource Potential

RAEOA encompasses four Sub-Regions: Nitibe, Oesilo, Pante Macassar, and Passabe. As of the end of 2022, the population was recorded at 80,726 people, with an average population density of 99 people/km².

2. Soil Types: Basis for Land Suitability Evaluation

Each administrative region within RAEOA has a dominance of different soil types, which requires a management approach tailored to the local data and conditions. The identified soil orders in RAEOA include Entisol, Vertisol, Inceptisol, and Alfisol.

3. Geological Formation

The distribution of geological formations in RAEOA region shows diversity. The Bobonaro Complex (60.76%) and Maubisse Formation (13.17%) dominate the region, followed by Alluvial (10.99%), Viqueque Formation (6.03%), Dartoullu Limestone (5.58%), and Borolalo Formation (0.93%).

4. Land Use: Ecosystem Dynamics and Human Activities

Land use in the ***Região Administrativa Especial de Oecusse-Ambeno*** **(RAEOA)** is predominantly dryland agriculture (48.58%), followed by forests (26.76%) and settlements (23.60%). Dryland agricultural areas are spread across the Sub-Regions, with the highest proportion in Pante Macassar, while the largest forest areas are found in Pante Macassar and Nitibe. This land use pattern shows a balance between the ecological function of forests and the agricultural production potential, although integrated management is necessary to optimize its contribution to food security.

5. Slope Gradient: Risks and Potential

The topography of RAEOA is dominated by steep slopes (25–45%) and moderately steep slopes (15–25%), covering more than half of the region. Flat to gently sloping areas (<15%) are relatively limited. These conditions pose a high risk of erosion and limit intensive agricultural land use, requiring land management approaches that focus on conservation practices such as terracing, cover crops, and surface flow control engineering.

6. Agroclimatic Zones: Regional Potential Classification

RAEOA region falls within agroclimatic Zones A, B, and C, characterized by a monomodal rainfall pattern. Zone A (18.40%) experiences a rainy season lasting 4–5 months, Zone B (49.92%) has a rainy season of 5–6 months, and Zone C (31.69%) has a rainy season of 6–7 months. These agroclimatic characteristics are suitable for agroforestry and seasonal dryland agriculture, although the dependence on a single main rainy season requires strict adaptation strategies to climate variability.

7. Field Conditions: Issues and Potential

RAEOA faces significant challenges in developing the agricultural sector due to its complex topography. The hilly terrain with steep slopes makes the area vulnerable to erosion and landslides. Additionally, the Pante Macassar Dam, which serves as the main source of irrigation for rice fields, is at risk of flooding when water levels rise significantly.

8. Utilization of Chromolaena odorata: From Challenge to Opportunity

Chromolaena odorata, or siam weed, is an invasive weed that has spread widely across Timor-Leste since the 1980s. This plant threatens agriculture by forming dense thickets that compete for nutrients and poses a danger to livestock due to the presence of toxic pyrrolizidine alkaloids. Ecologically, this weed invasion inhibits the regeneration of native vegetation and increases the risk of land fires. However, *C. odorata* has potential for utilization, including as a traditional medicinal plant, organic fertilizer, and vermicompost. Appropriate management approaches are required to mitigate its negative impacts while optimizing the value of its biomass.

B. RESEARCH METHOD

This study adopts a survey method, including field observation, interviews, and laboratory analysis, to comprehensively evaluate land suitability. The research uses Homogeneous Land Units (HLU) as the basis for delineating regions based on thematic map data, such as land use, soil types, climate, geology, and slope. Data analysis is supported by Geographic Information System (GIS) technology to produce accurate and informative map visualizations.

Research Procedures

1. **Soil Sampling**
    a) Soil samples were collected **compositely** at the following depths:
        - **0–30 cm** for annual crops.
        - **0–60 cm** for perennial crops.
2. **Laboratory Analysis**

    Physical and chemical soil parameters analyzed include:

    a) **C-organik *(%)***: *Walkley dan Black method*.
    b) **Total N *(%)***: *Kjeldahl method*.
    c) **Soil Texture:** *pipette method*.
    d) **Soil pH:** *potensiometer* (H_2O *1:2.5)*.
    e) **Available P & Available K (ppm):**
        - *Bray-1 method* for pH < 7 (converted to mg/100 g).
        - *Olsen method* for pH > 7 (converted to mg/100 g).
    f) **Salinity:** *dS/m with potentiometer (*H_2O *1:2.5)*.
    g) **Cation Exchange Capacity (CEC)** (*cmol/(mg/100g)*) and **Base Saturation (BS)** (%) *dengan* NH_4OAc *1N pH 7*.
    h) **Total Phosphorus (mg/100 g)** and **Total Potassium (mg/100 g)** determined using the 25 % HCl method.
    i) **Total Zinc (ppm)** determined using the DTPA extraction method and **Available Zinc (ppm)** determined using the HNO^{3-}:$HClO_4$ digestion method.
    j) **Total Sulfur (ppm) and Available Sulfur (ppm)** determined using the spectrophotometric method.
    k) **Soil Fertility Status:** Based on PPT Method *(1995)*.
    l) **Erosion Risk:** Field observations and *Universal Soil Loss Equation* (USLE) model.

Land Suitability Classification Steps

1. Actual Land Suitability:
   The initial classification is conducted to assess the land suitability under existing conditions without improvements.
2. Land Improvement Recommendations:
   Improvement measures are identified to address limiting factors, including the management of inputs such as fertilizers and soil and water conservation techniques.
3. Potential Land Suitability:
   Suitability assessment is carried out after considering improvements to maximize the land's potential.
4. Commodity Development Potential Zoning:
   Zoning is determined by integrating the Agroecological Zones of RAEOA, based on land suitability and specific agroecosystems.

C. CHARACTERISTICS OF AGRICULTURAL AND FOREST LAND

1. Temperature

Air temperature is a key indicator in land suitability assessment, analyzed through a combination of field data and Digital Elevation Model (DEM SRTM) using the Braak approach. In RAEOA region, annual temperatures are predominantly above 26°C. This thermal condition directly influences agricultural potential and the types of commodities that can optimally grow in the area.

2. Rainfall

According to CHIRPS data, RAEOA region shows an uneven annual rainfall pattern, ranging from less than 1,000 mm to approximately 2,000 mm. This variability reflects differences in microclimatic conditions across Sub-Regions. This information is crucial for land use planning and sustainable water resource management. Understanding rainfall distribution is fundamental in determining the suitability of areas for agriculture, fisheries, and forestry.

3. Dry Months

The distribution of dry months in RAEOA reflects the differences in water availability across Sub-Regions, with most areas experiencing a dry season lasting more than six months. This condition indicates the dominance of a dry climate, which impacts water availability for cultivation activities. The consequences are particularly felt in the agricultural and forestry sectors, which require adaptive approaches.

4. Drainage

The variation in land drainage characteristics across RAEOA is evident between Sub-Regions. Nitibe and Passabe Sub-Regions exhibit good drainage conditions, facilitating smooth water flow. In contrast, Pante Macassar Sub-Region has suboptimal drainage, increasing the risk of waterlogging. This difference is an important factor in determining land use strategies based on local hydrological conditions.

5. Coarse Fragments

The distribution of coarse fragments in RAEOA region shows dominance of low to very low levels, with less than 5% spread across the Pante Macassar Sub-Region. Meanwhile, Nitibe Sub-Region is dominated by soils containing coarse fragments between 3% and 15%. This variation reflects differences in soil texture across regions, which affects water retention capacity and the suitability of plant types.

6. Effective Depth

The distribution of effective soil depth across RAEOA shows variation between Sub-Regions. Pante Macassar Sub-Region generally has deep soils, ranging from 90 to 120 cm, which supports the growth of deep-rooted plants. In contrast, Nitibe Sub-Region is dominated by shallow soils, which may limit the types of plants and cultivation systems that are suitable.

7. Surface Rocks

The distribution of surface rocks across RAEOA shows significant variation between Sub-Regions. Pante Macassar Sub-Region is dominated by surface rocks less than 5%, indicating relatively smooth land conditions for cultivation. In contrast, Passabe Sub-Region and parts of Nitibe Sub-Region have surface rock coverage between 15% and 40%, which may hinder soil cultivation and root growth.

8. Rock Outcrops

The distribution of rock outcrops in RAEOA shows notable variation between Sub-Regions. Pante Macassar Sub-Region is dominated by rock outcrops less than 5%, indicating relatively clean land surfaces free from rocks. Medium rock outcrops (15–25%) are scattered across Nitibe and parts of Pante Macassar, while Passabe Sub-Region shows dominance in this category. High rock outcrops (>25%) are found only in a small portion of RAEOA area.

9. Flood Risk

The flood risk potential across RAEOA shows varying vulnerability between Sub-Regions. Nitibe Sub-Region is dominated by areas categorized as "no flood," indicating a low risk of waterlogging. In contrast, Pante Macassar Sub-Region and parts of Nitibe have areas with high to very high flood risk levels.

10. Soil Texture

RAEOA region exhibits variation in soil texture, reflecting differences in geomorphological conditions and soil formation processes across Sub-Regions. Nitibe and Oesilo Sub-Regions are dominated by clayey soils with high water and nutrient retention capacity. Conversely, Pante Macassar and Passabe Sub-Regions have more clay soils, with physical characteristics that support cultivation but vary in terms of stickiness and drainage.

11. Soil pH

Soil pH levels in RAEOA show variation across Sub-Regions, ranging from 6.81 to 7.80. This range reflects soils that are generally neutral to slightly alkaline, which typically supports the availability of nutrients for plants. The pH values within this range are generally suitable for most agricultural commodities.

12. Total Nitrogen

The total nitrogen content (N-total) in RAEOA is low to very low, ranging from 0.10% to 0.16%. Oesilo and Passabe Sub-Regions show very low N-total levels, while Pante Macassar and Nitibe are considered low. The low nitrogen content is generally due to leaching, low organic matter, or slow weathering processes.

13. Available Phosphorus

The availability of phosphorus (P-Available) in RAEOA is very low, with concentrations ranging from 0.99 ppm to 1.60 ppm. These values indicate that soils in most of the region have limited capacity to provide sufficient phosphorus for plant growth. Low phosphorus content can hinder vegetative growth and land productivity. This condition is generally influenced by soil type, acidity levels, and low organic matter.

14. Available Potassium

The availability of potassium (K-Available) in RAEOA is classified as low to moderate. Pante Macassar and Nitibe Sub-Regions show moderate levels, which still support functional plant growth. In contrast, Passabe and Oesilo Sub-Regions have low available potassium content, which could potentially decrease land productivity if not managed with appropriate nutrient

15. Salinity/Toxicity

Soil salinity levels in RAEOA are within a safe range for agricultural activities. Passabe Sub-Region records very low salinity levels, while Pante Macassar, Oesilo, and Nitibe fall within the low salinity category. Low salinity supports optimal water and nutrient absorption by plants. This factor is an important indicator in the evaluation of land suitability for agriculture.

D. SOIL FERTILITY STATUS

The distribution of soil fertility levels in RAEOA region shows a diverse composition, reflecting agronomic challenges that need to be addressed strategically. Of the total land area, approximately 48.06% or 391.00 km² is categorized as having low fertility. On the other hand, land with high fertility accounts for 21.78% of the total area, indicating better cultivation potential. Meanwhile, very low fertility is found on 16.18% of the land, and moderate fertility occupies 13.99%. This distribution suggests that the majority of the land is in a suboptimal condition, requiring land management strategies tailored to local characteristics to achieve efficiency and sustainable production.

Spatial distribution across Sub-Regions shows significant differences. Nitibe Sub-Region is dominated by very low fertility land, covering 103.34 km² or 12.70% of the total RAEOA area. Oesilo and Pante Macassar Sub-Regions each have the largest areas categorized under low fertility, whereas Passabe Sub-Region shows more favorable agronomic conditions, with a dominance of land classified as high fertility.

E. EROSION AND AGROFORESTRY BASED CONSERVATION

1. Soil Erosion

Soil erosion plays a crucial role in land suitability evaluation and the sustainability of land use. RAEOA region experiences erosion levels ranging from very light to very severe. Very light erosion is found in Pante Macassar, which is due to the presence of flat areas. Flat land is typically more stable. In contrast, areas with very severe erosion are found in Passabe. This region is dominated by Inceptisols. Inceptisols are highly prone to erosion because they possess various soil structures such as blocky, granular, and massive types, which are vulnerable to rainfall erosion. Additionally, these soils have a clayey texture, which results in low water absorption capacity.

The main factors contributing to erosion in this region include:

- Topography: Steep to very steep slopes.
- Soil Type: Inceptisols.
- Rainfall: High rainfall intensity leads to severe to very severe erosion.
- Lack of Vegetative Cover: Contributes to the loss of topsoil due to surface runoff.
- Anthropogenic: Management practices that do not adhere to conservation principles accelerate erosion.

2. Agroforestry-Based Conservation

Agroforestry-based conservation is the primary effective approach to address soil erosion in RAEOA. Agroforestry integrates forest trees, food crops, and livestock to provide ecological benefits and sustainable land productivity. This approach focuses on:

- **Increasing Vegetative Cover:** Reduces surface runoff and maintains soil moisture.
- **Enhancing Soil Fertility:** Through the contribution of organic matter from leaves and roots.
- **Sustainable Water Management:** By retaining water in the soil layers through deep-rooted systems.

The main benefits of agroforestry in soil and water conservation include:

1. **Erosion Mitigation:** Trees and plants act as natural barriers to prevent soil from being washed away by surface runoff.
2. **Increased Water Infiltration:** The root systems of trees enhance the soil's ability to absorb water.
3. **Biodiversity Enhancement:** The combination of food crops and trees creates a more diverse and stable ecosystem.
4. **Increased Agricultural Productivity:** Through the combination of agroforestry components that support diverse crop yields.

3. Agroforestry Implementation in RAEOA

The agroforestry systems implemented in RAEOA vary according to the agroecological zones. Examples of effective agroforestry-based conservation systems include:

- **Alley cropping**: Planting crops between rows of trees on steep slopes to control erosion.
- **Live Fences:** Using erosion-resistant plants such as vetiver to strengthen slopes.
- **Live Terracing:** Utilizing perennial plants like *leucaena* to prevent erosion, combined with crops like pepper and other climbing plants.
- **Layered Planting**: A combination of trees, shrubs, and ground cover plants to stabilize soil and reduce runoff.
- **Silvopastoral System:** Integrating forest vegetation with livestock to manage erosion in grazing areas.

4. Conservation Recommendations

- **Enhance Agroforestry Practices** in Erosion-Prone Zones.
- **Spatial Data-Based Management** to Identify Priority Conservation Areas.
- **Capacity Building for Farmers** through Training and Adoption of Modern Agroforestry Techniques.
- **Strengthening Soil Conservation Policies** with Agroecological Approaches in Region Planning.

F. AGRICULTURAL LAND SUITABILITY

1. Land Suitability Evaluation

a) Nitibe Sub-Region

- Food crops for development include irrigated rice, upland rice, sorghum, and cassava.
- Horticultural Crops vegetables such as shallots, chili, and broccoli can be developed on land with a moderately suitable suitability class. Additionally, fruit crops such as mango, soursop, and pineapple show potential in the Sub-Region Nitibe, as well as flower crops such as rose, aster, and sunflower.
- Spices and medicinal plants such as lemongrass and turmeric can be developed.
- Industrial Crops such as kapok are considered moderately suitable. The development of forestry species like Agathis is deemed highly suitable for cultivation.

b) Oesilo Sub-Region

- Dryland food crops such as upland rice, mung beans, and corn, as well as horticultural vegetable crops like shallot, broccoli, eggplant, and tomato vegetable, is suitable. Fruit crops such as orange, watermelon, papaya, and rambutan, as well as flower crops like rose, aster, and sunflower, are considered moderately suitable for the land and have good development potential.
- Spices and medicinal plants such as cardamom and galangal can be developed in the Oesilo Sub-Region.
- Industrial Crops like tobacco and sugarcane have good suitability for cultivation.
- Forestry species such as teak can be developed in the Oesilo Sub-Region.

c) Pante Macassar Sub-Region

- Pante Macassar Sub-Region has significant potential for several food crops, such as irrigated rice, upland rice, rainfed rice, and cowpea, which are classified as moderately suitable.
- In the industrial sector, tobacco can be developed in Pante Macassar Sub-Region. Forestry species such as Melaleuca have a moderately suitable land suitability class (S2).
- Horticultural vegetable crops, such as shallots, broccoli, and cucumber, have great potential with a moderately suitable suitability class (S2). Fruit crops like orange, snakefruit, and rambutan also show promising potential. Flower crops like rose, aster, and sunflower can also be developed.
- Spices and medicinal plants such as cardamom and turmeric show fairly good potential.

d) Passabe Sub-Region

- Passabe Sub-Region has potential for the development of tobacco and cotton.
- Food crops such as upland rice, sorghum, and corn also have a moderately suitable suitability class.
- In the horticultural sector, vegetable crops like broccoli, chili, and tomato vegetable show good development potential. Fruit crops such as breadfruit, orange, snakefruit, and pineapple are also

moderately suitable for cultivation. Flower crops like rose, aster, and sunflower can also be developed.

- Spices and medicinal plants such as galangal and cardamom can be recommended.
- Forestry species such as mahogany have a moderately suitable land suitability class (S2).

2. Agricultural Commodity Development Zones in RAEOA

This study aims to evaluate the potential and land suitability for various land use types in RAEOA region, Timor-Leste, as a basis for sustainable land management planning. The analysis is conducted by reviewing the biophysical aspects, topography, soil types, as well as the ecological and economic functions inherent in each land use category.

a) **Dryland Agriculture,** this area covers 316.64 km² (38.92%) and is located at elevations of 100–900 m with gentle to steep slopes. The commodities include upland rice, corn, sorghum, cassava, legumes, horticulture, as well as industrial crops and spices. Mixed cropping systems, strip cropping, and crop rotation are recommended to maintain productivity and prevent erosion.

b) **Rainfed Rice Fields**, the land area covers 8.39%, scattered at elevations of 10–100 m or more, with the largest area in Pante Macassar Sub-Region. The main commodities are upland rice, corn, and legumes. Productivity is highly influenced by rainfall, requiring water storage ponds, drought-resistant varieties, and water efficiency measures.

c) **Irrigated Rice Fields**, this covers about 3.80%, located on slopes of 0–15% with a predominantly monomodal climate zone of types A, B, and C. The main commodities are irrigated rice, cassava, and legumes. These areas are found in Nitibe and Pante Macassar Sub-Regions.

d) **Grazing Area,** grazing land covers 1.38%, predominantly in Pante Macassar Sub-Region. Although small, it is important as a source of livestock feed. Management is directed through pasture rotation and integration with agroforestry. Elephant grass, Setaria, and legumes are the main forage crops to support sustainable livestock farming.

G. FORESTRY IN RAEOA

The forest areas in RAEOA include agroforestry, protected forests, and mangroves. Agroforestry is located on slopes of 10–30%, with a mixed cropping pattern of 70% forestry and 30% agriculture, including crops such as corn, teak, mango, and banana. Mangroves cover only 0.06% of the area in Nitibe and Pante Macassar Sub-Regions, playing a role in carbon storage, erosion control, and coastal habitat.

H. LIVESTOCK POTENTIAL IN RAEOA

This study aims to evaluate land suitability for the development of livestock feed crops (HPT) and the ecological suitability for livestock farming in RAEOA, Timor-Leste. The analysis supports efforts to increase feed availability, food security, and strengthen the local economy through the livestock sector. The study focuses on three main areas:

1. **Land Suitability for Livestock Feed Crops (HPT),** The areas of Nitibe, Oesilo, Pante Macassar, and Passabe have potential for developing HPT such as elephant grass, Setaria, legumes, and grazing lands. However, limiting factors include total nitrogen (N), available phosphorus (P), available potassium (K), slope, erosion, surface rock outcrops, and dry months. Technical improvements can be made through NPK fertilization, organic matter addition, terracing, sprinkler irrigation, and land clearing. The presence of surface rock outcrops is a permanent factor that cannot be corrected.
2. **Ecological Suitability for Livestock**, RAEOA region covers an area of 81,836.68 ha, of which 39,594.86 ha is identified as suitable for livestock development. Sub-Region Nitibe and Pante Macassar are the most dominant for the development of beef cattle, dairy cattle, and pigs. Oesilo Sub-Region is suitable for beef cattle, dairy cattle, and pigs, but is limited for sheep and buffalo due to rainfall conditions. Passabe Sub-Region is suitable for sheep, beef cattle, dairy cattle, and pigs, but not suitable for buffalo. Poultry is highly suitable due to its high adaptability to various environmental conditions.
3. **Socio-Economic Aspects of Livestock Farming**, the extensive farming system (free-range grazing) is still dominant. The advantages of this system include low labor requirements, but its weaknesses include difficulty in

controlling nutrition, disease risks, livestock theft, and damage to crops. Limited capital, low breeding practices (natural mating, no artificial insemination), minimal feed management, and limited market access (only live animals) are challenges faced by farmers. Solutions that can be offered include breeding and livestock management education, including the application of artificial insemination technology, provision of credit/loans to improve livestock population and quality, and the development of marketing channels for processed products to increase market value.

I. FISHERIES AND AQUACULTURE POTENTIAL IN RAEOA

This study aims to evaluate land suitability for aquaculture development in RAEOA, Timor-Leste, as part of efforts to support food security, improve nutrition, and strengthen the local economy. The methodology used includes geographic information system (GIS) analysis, field observations, and water quality measurements to map actual and potential land suitability. Two main locations represent the primary centers for aquaculture activities, each reflecting different ecosystem characteristics:

1. **Costa Village (Pante Macassar Sub-Region),** this area has a fish seed center with high-quality freshwater sources, which is highly suitable for freshwater aquaculture such as gourami, catfish, carp, and tilapia. However, the pH is slightly acidic, there are slope gradients, and the dry season lasts for an extended period. Proposed solutions include the application of pH management techniques (zeolite/water exchange), the construction of stepped ponds, and the creation of water storage ponds or rainwater harvesting ponds to mitigate the impacts of the dry season.
2. **Sacato Village (Coastal Area),** this area has brackish-marine water characteristics, making it very suitable for the cultivation of high-value marine species such as milkfish, grouper, mangrove crab, and vannamei shrimp. However, it requires an aquaculture management system that meets marine aquaculture standards. Proposed solutions include the implementation of salinity control systems, utilization of tidal movements, and the use of plastic ponds with proper seawater supply management.

Based on the evaluation of actual and potential suitability, a pilot project is recommended in Costa Village (Pante Macassar Sub-Region) for freshwater aquaculture development (catfish, gourami, carp, tilapia) using earthen or flat tarpaulin ponds with simple recirculation/biofloc systems. Meanwhile, Sacato Village is directed to become a center for brackish/marine aquaculture with an integrated pond system that is adaptable to high salinity conditions.

J. RESEARCH RECOMMENDATIONS

1. Agriculture Recommendations

RAEOA region has significant potential for the development of sustainable agricultural systems, including irrigated rice fields in Villages Lela-Ufe, Bene-Ufe, Nipani, Cunha, Lalisuc, and Naimecco, as well as rainfed rice fields in Usi-Tacae, Costa, and Usi-Taco. The main commodities include food crops such as corn, cassava, upland rice, legumes, as well as a variety of horticultural crops and fruits, supported by forest vegetation, industrial commodities like coconut, robusta coffee, and betel, and the availability of livestock feed across the entire Sub-Region. However, the main challenges across all Sub-Regions include limited farmer knowledge, dependence on rainfall, pest attacks, low fertilizer availability, and weak market access. The development of water storage ponds, piped irrigation technology, the application of organic fertilization, land conservation, and road infrastructure improvements are essential to enhance agricultural productivity and resilience in this region.

2. Livestock Recommendations

Based on geospatial analysis, the *Centro Produção Animal* (CPA) Makelap in Village Taiboco has great potential as a breeding center for high-quality livestock for region distribution. The high land suitability and availability of quality livestock feed are key factors in ensuring optimal nutrition for livestock growth. Supporting ecological conditions such as stable temperatures, adequate water sources, and gentle topography minimize heat stress and facilitate effective sanitation and housing management. The genetic potential of local livestock, which has already adapted to the region, can be strengthened through a genetic selection program, making CPA Makelap a strategic location for animal food security and regional livestock development.

3. Fisheries Recommendations

To support the development of productive and sustainable aquaculture in RAEOA, the government needs to strengthen basic infrastructure such as the provision of clean water, micro-irrigation systems, and road access to production sites. Investment in the development of integrated ponds and appropriately designed technology for ponds should be increased to boost production capacity. Integrated technical training and field school modules for farmers in Costa and Sacato are important, along with the formation of Fish Farmer Groups (Pokdakan) to facilitate access to technical and financial assistance. Permanent extension agents or NGO partners should be assigned as technical advisors, while a spatial data-based aquaculture development roadmap and land suitability mapping should be developed to set production targets and priority locations. Partnerships with the private sector should also be developed to strengthen marketing and cold chain supply chains.

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I. INTRODUCTION

New Context: ASEAN, SDGs, and the Special Status of RAEOA

The country of Timor-Leste is now officially part of the Association of Southeast Asian Nations (ASEAN). Timor-Leste's accession was confirmed during the 47th ASEAN Summit held in Kuala Lumpur, Malaysia.

In this new era, Timor-Leste strives to achieve food self-sufficiency through optimal natural resource management. The agricultural sector, as the backbone of the economy, must be able to adapt to sustainability challenges. This aligns with the Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger).

RAEOA (*Região Administrativa Especial de Oé-Cusse Ambeno*), with its special administrative status, plays a strategic role in supporting national food security from the western part of Timor-Leste.

Social, Cultural, and Geographical Uniqueness of RAEOA

RAEOA possesses strong socio-cultural uniqueness rooted in traditional agricultural systems, as reflected in the annual harvest festival centered in Pante Macassar, which serves as an expression of gratitude for agricultural yields while reinforcing cultural identity and social solidarity. Geographically, its position surrounded by Indonesian territory provides strategic opportunities for agricultural development and cross-border trade, with lowland areas utilized for food crops and hilly regions suitable for coffee and horticultural cultivation, supported by proximity to markets in East Nusa Tenggara. Within the framework of national development, the designation of RAEOA as a Special Social Market Economic Zone (ZEESM) underscores its strategic role as a growth center based on infrastructure development, tourism, and sustainable agriculture.

Regional Focus: Significant Potential Under Geological Challenges

RAEOA (comprising the Sub-Region of Nitibe, Oesilo, Pante Macassar, and Passabe) holds a key advantage in terms of soil quality, which greatly supports agricultural productivity.

However, this large potential is counterbalanced by significant geological challenges. Over 60.76% of the area is dominated by the Bobonaro Complex, which has a stable structure but is highly susceptible to erosion. Other formations, such as Viqueque and Aitutu, also show low slope stability.

Thus, the development narrative in RAEOA is centered around maximizing the potential of fertile soils while managing erosion risks through strict conservation approaches.

Technical Basis: Fertile Soil Capital vs. Erosion Risks

The characteristics of RAEOA are defined by these two main factors:

1. **Soil Capital (Edaphic):** he region has a diverse and productive soil capital:
   - **Inceptisols (65.57%):** Dominating the area, this soil type (according to local data) has good water retention capacity and is highly suitable for growing food crops such as rice.
   - **Alfisols (26,95%):** High-quality soils highly suitable for main food crops such as corn, soybeans, and wheat.
   - **Vertisols (7,28%):** Ideal for rice cultivation in irrigated fields.
2. **Geological Challenges:** Alluvial deposits (10.99%) in the lowlands are fertile for intensive agriculture. However, the dominance of bedrock that is vulnerable to erosion and exhibits low slope stability requires agricultural practices in RAEOA to be carefully managed and based on risk mitigation.

Opportunities for Integrated Sector Development (Four Pillars)

To balance potential and risks, the strategy for RAEOA should include four integrated pillars:

1. **Agricultural Sector:** This is the main pillar. The focus should be on optimizing the use of irrigated rice land (on Inceptisols and Vertisols) and diversifying crops (corn, soybeans on Alfisols). The implementation of water-efficient irrigation technologies is highly recommended.
2. **Forestry Sector:** This is a key pillar, not only for risk mitigation but also for economic opportunities. Historically, the Oé-Cusse Ambeno region has been known as one of the world's best producers of sandalwood (Santalum album). This heritage is a valuable resource that must be explored and developed again. Implementing agroforestry systems on sloping land is not only vital for controlling erosion from the Bobonaro Complex, but also provides an opportunity to re-cultivate sandalwood and other valuable forestry species.

3. **Livestock Sector:** There is significant potential for integrated development with agriculture, utilizing local feed resources and improving community welfare.

Management Challenges and the Objective of This Evaluation

Despite the region's large soil potential, the main challenge in RAEOA is the risk of land degradation due to unsustainable farming practices in vulnerable geological areas. The limited irrigation infrastructure and market access also pose challenges.

Therefore, this research aims to evaluate land suitability and map the potential for agricultural sector development in RAEOA. The main focus is on optimizing the use of **irrigated rice land** and **diversifying crops**, while mitigating risks through **agroforestry**.

This book is expected to provide strategic recommendations for the government and other stakeholders to design inclusive and sustainable development policies in RAEOA, supporting Timor-Leste's national food security.

II. GENERAL OVERVIEW OF THE AREA

2.1 DEMOGRAPHY

The Special Administrative Region of Oé-Cusse Ambeno, commonly referred to as RAEOA, is an exclave of Timor-Leste located in the western part of Timor Island and surrounded by Indonesian territory, specifically East Nusa Tenggara Province. The area covers approximately 813.6 km^2 with a population of 80,726 (2022). Its administrative capital is Pante Macassar, which also serves as the center of trade, government, and culture. The exclave position gives RAEOA demographic characteristics that differ from other Districts in Timor-Leste, as cross-border interactions with communities in Indonesia are relatively intensive.

RAEOA consists of 4 Sub-Regions: Nitibe Sub-Region, Oesilo Sub-Region, Pante Macassar Sub-Region, and Passabe Sub-Region. Geographically, RAEOA borders the Sawu Sea to the north; to the east, Wini and Benus Villages, North Central Timor Regency (Kefamenanu City), Indonesia; to the south, Nunpene and Haumeni Ana Villages, North Central Timor Regency, Indonesia; and to the west, Oe-poli Village, Kupang Regency, East Nusa Tenggara, Indonesia. Astronomically, it is located at 9°12′23.0″ S and 124°21′46″ E. The administrative map of RAEOA is presented in **Figure 2.1.**

One important tradition in RAEOA is the annual harvest festival, which is usually centered in Pante Macassar. The celebration expresses gratitude to ancestors and nature for agricultural yields, particularly maize, upland rice, and tubers. During the festival, communities perform the likurai dance, play traditional music with small drums, and conduct rituals offering agricultural produce. This tradition reinforces cultural identity and strengthens social solidarity among residents.

The distinctiveness of RAEOA lies in its position enclosed by Indonesian territory. This condition provides certain advantages, particularly in agriculture and cross-border trade. Fertile lowlands are used to cultivate maize, rice, and legumes, whereas mountainous areas are suitable for coffee and horticultural crops. Proximity to markets in East Nusa Tenggara also creates opportunities for the exchange of agricultural products and livestock, while remaining regulated by border policies.

In addition, the Government of Timor-Leste has designated RAEOA as a Special Social Market Economic Zone (ZEESM) to promote infrastructure development, tourism, and sustainable agriculture. This designation demonstrates how the exclave is not only historically important as the site of the first Portuguese landing in Timor in 1,515 but also strategic for the future economy of Timor-Leste.

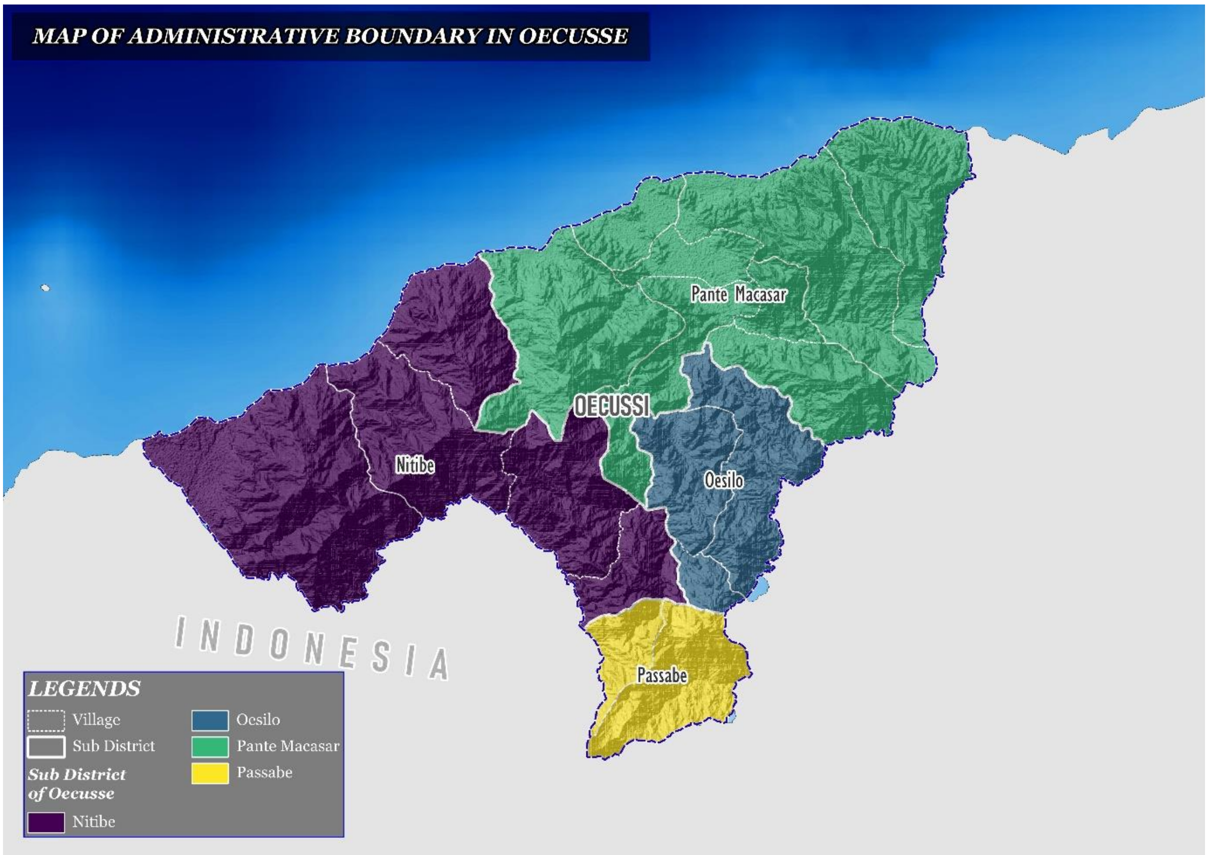


Figure 2.1 Administrative Division in RAEOA

The population in RAEOA at the end of 2022 totaled 80,726, with an average population density of 99 persons km^2 (Minister of Finance of the Democratic Republic of Timor-Leste, 2022). Based on the 2019 Timor-Leste Agricultural Census (TLAC), several indicators, including land area, are presented in **Table 2.1**

Table 2.1 Demographic Data of RAEOA

Sub-Region	Area (ha)
Nitibe	30.036
Oesilo	9.695
Pante Macassar	35.574
Pasabbe	6.057

2.2 SOIL TYPES

The distribution of soil types in RAEOA shows diversity that reflects the complexity of terrestrial ecosystems serving as the basis for land suitability evaluation. Soil mapping in this area provides essential information on physical and chemical characteristics required to support optimal and sustainable natural resource management. Each administrative area has a dominant soil type that requires a data-driven management approach tailored to local conditions. The soil orders identified in RAEOA include Entisols, Vertisols, Inceptisols, and Alfisols. The presence of these four soil types indicates substantial potential for productive and sustainable agricultural development, provided that land management strategies are adapted to soil characteristics and local agroclimatic conditions.

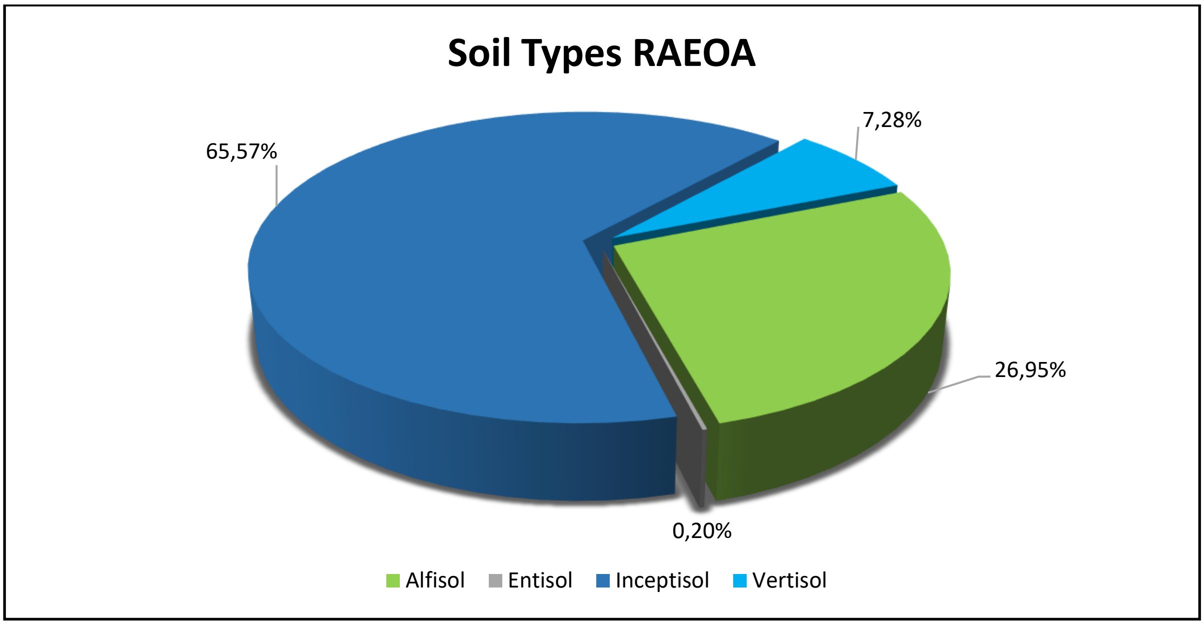


Figure 2.2 Soil Types graphic in RAEOA

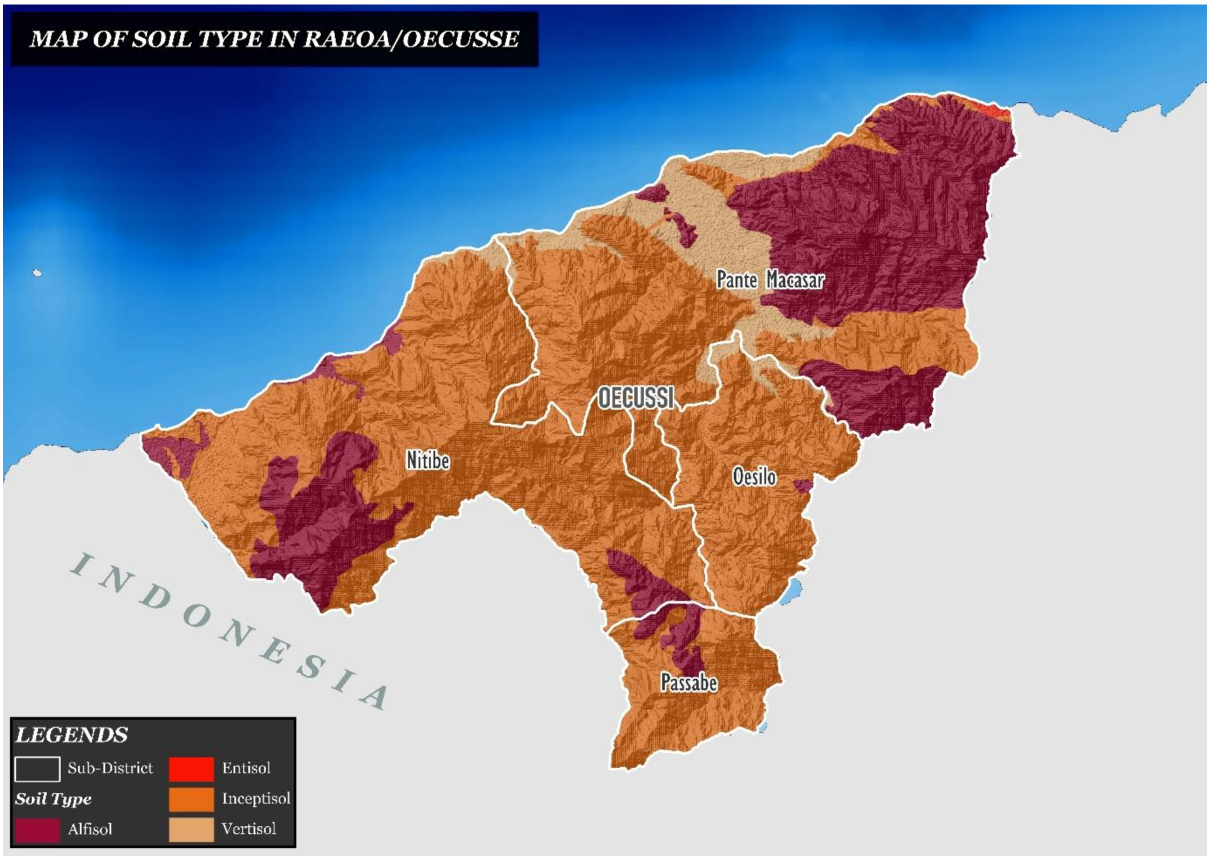


Figure 2.3 Map of Soil Type Distribution in RAEOA

Overall, the soil type that dominates the area is Inceptisols, covering 65,57 % of the total area. These soils show moderate horizon development, characterized by a cambic horizon as an early indication of pedogenic processes. Their physical and chemical properties support the growth of various crops and are therefore suitable for multicultural agricultural development. Crops that can be developed include irrigated rice, upland rice, maize, legumes, vegetables, horticultural crops, and industrial crops. However, because fertility is not always uniform, intensive fertility management is needed through balanced fertilization, organic matter amendments, and appropriate conservation techniques to maintain long-term productivity.

Alfisols occupy 26.95 % of the area and have a distinct argillic horizon. These soils are well suited for staple food crops such as maize, soybean, and wheat. In addition, various horticultural commodities such as tomato, chili, and onion, as well as perennial crops such as citrus, show good growth responses on Alfisols. However, Alfisols are generally acidic, so liming is an important strategy to increase soil pH into the optimal range. The addition of organic fertilizers is also necessary to improve soil structure and stabilize nutrient availability.

Vertisols, which cover 7.28 % of the total area, are characterized by high clay content with strong shrink-swell behavior depending on moisture conditions. This property makes Vertisols ideal for paddy cultivation under irrigation, as these soils can retain large amounts of water when saturated. In addition to rice, Vertisols are suitable for crops such as maize, sorghum, and peanut, as well as horticultural and industrial commodities such as tomato, chili, shallot, papaya, and sugarcane. Soil management on Vertisols must consider appropriate tillage timing, typically when the soil is at optimal moisture, to avoid excessive compaction or soil structure damage.

Entisols cover only 0.20 % of the area and are generally found on steep slopes, young alluvial plains, or areas with high geological activity. These soils have not undergone significant pedogenic horizon development and tend to have low organic matter and nutrient contents. As a result, Entisols have limited agricultural potential and are prone to degradation. Crops that can be developed include upland rice, leucaena, gliricidia, and sesbania. Therefore, land management on Entisols should be preceded by appropriate conservation measures, such as the use of cover crops, terracing, and organic amendments, to improve soil quality before intensive use (Rossiter, 1996).

2.3 GEOLOGICAL FORMATIONS

The distribution of geological formations in RAEOA shows highly complex and significant geological diversity. Each formation contributes uniquely to soil development and influences both the potential and the limitations of land for agricultural development. The analysis indicates that the Bobonaro Complex (60.76 %) and the Maubisse Formation (13.17 %) dominate the area, followed by Alluvium (10.99 %), the Viqueque Formation (6.03 %), the Dartollu Limestone (5.58 %), and the Borolalo Formation (0.93 %), as presented in **Figure 2.4, Figure 2.5**, and **Figure 2.6.**

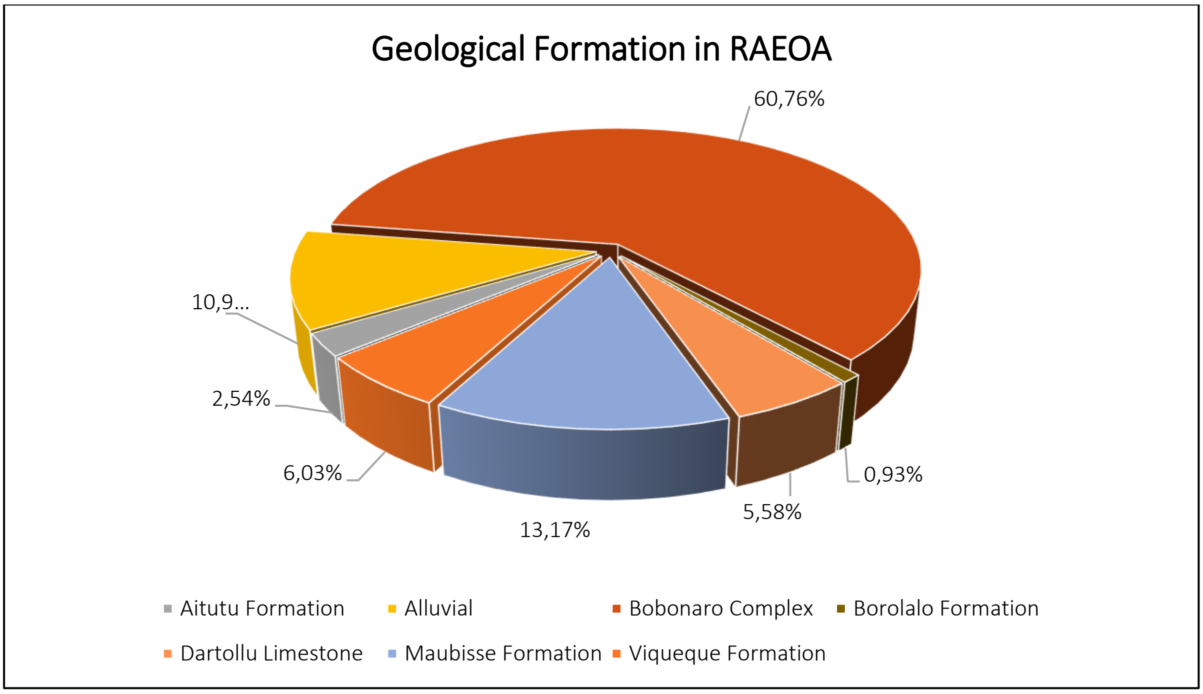
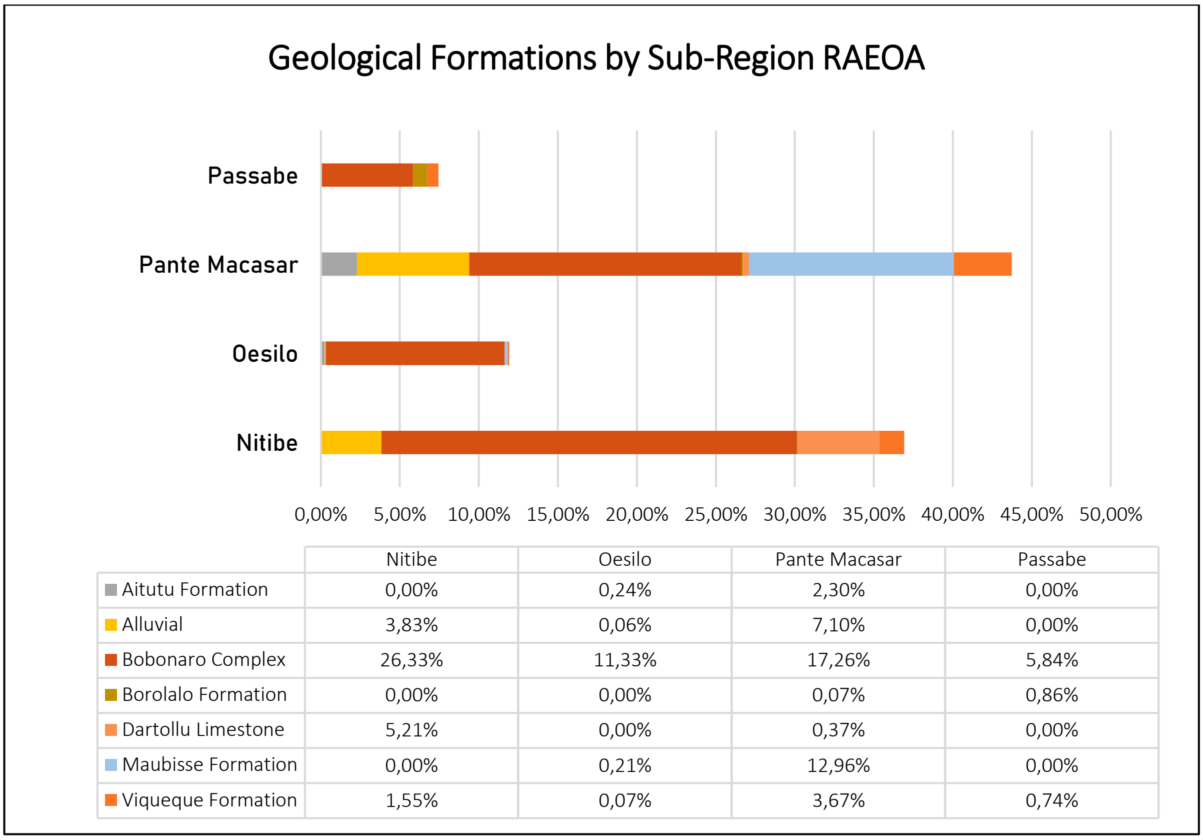


Figure 2.4 Geological Formations in RAEOA



	Nitibe	Oesilo	Pante Macasar	Passabe
Aitutu Formation	0,00%	0,24%	2,30%	0,00%
Alluvial	3,83%	0,06%	7,10%	0,00%
Bobonaro Complex	26,33%	11,33%	17,26%	5,84%
Borolalo Formation	0,00%	0,00%	0,07%	0,86%
Dartollu Limestone	5,21%	0,00%	0,37%	0,00%
Maubisse Formation	0,00%	0,21%	12,96%	0,00%
Viqueque Formation	1,55%	0,07%	3,67%	0,74%

Figure 2.5 Geological Formations by Sub-Region in RAEOA

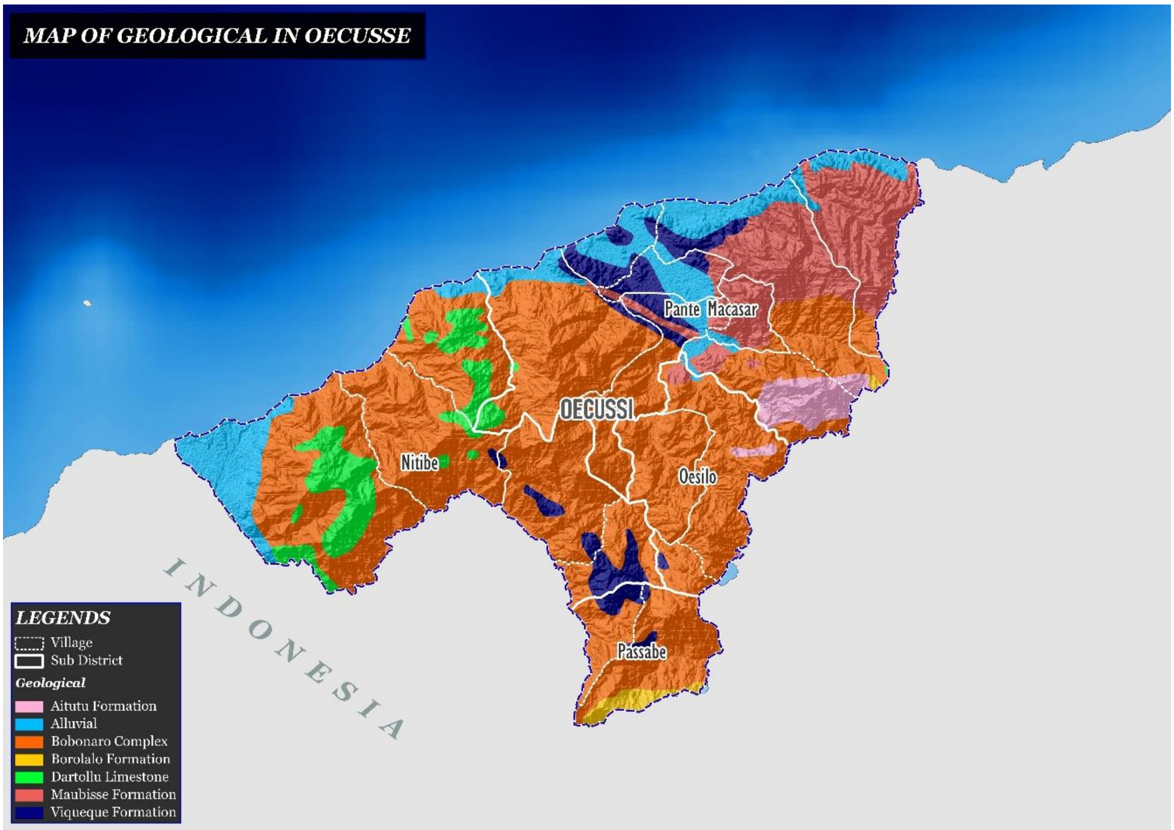


Figure 2.6 Map of Geological Formations in RAEOA

The Bobonaro Complex, the most extensive formation, consists of a clay matrix mixed with large block fragments. These characteristics present challenges in the form of susceptibility to erosion and landslides, particularly on steep slopes. This formation occurs across much of RAEOA, covering 60.76 % of the area with a total of 49,436 ha. It also has substantial potential for soil conservation management, supporting the development of Vertisols, which are known for high water-holding capacity but require careful management to prevent structural damage during the dry season.

The Maubisse Formation covers approximately 13.17 % of RAEOA, equivalent to 10,714 ha. It is distributed in two Sub-Region, namely Pante Macassar (10,542 ha) and Oesilo (171 ha). Geologically, the Maubisse Formation comprises reef limestone, reflecting a biogenic carbonate depositional system formed in shallow tropical marine environments. The residual soils are generally thin, stony, and alkaline, but they have very good drainage. These conditions make the formation more suitable for nonconventional land uses such as perennial crops or drought-tolerant agroforestry systems.

The Viqueque Formation is distributed across all four Sub-Region with a total area of about 4,905 ha. It consists of claystone interbedded with limestone, tuff, and minor other components, reflecting a shallow marine depositional environment with occasional volcanic influence. The dominant clay character indicates high water retention but slow drainage, while the presence of limestone contributes to an alkaline soil reaction. With appropriate management, soils derived from this formation tend to be fertile.

The Aitutu Formation, which covers a total area of approximately 2,070 ha, consists of calcilutite, marl, calcareous shale, and calcarenite. This lithology indicates quiet marine deposition that favors the formation of fine particles with high carbonate content. Marl and calcareous shale contribute positively to soil fertility, but there is a risk to slope stability due to the materials' susceptibility to weathering and plastic behavior when wet.

Alluvium, as a Quaternary geomorphological unit composed of unconsolidated sediments such as clay, sand, and gravel, is distributed in the Sub-Region of Nitibe, Oesilo, and Pante Macassar with an area of 8,943 ha. These conditions contribute to the formation of fertile alluvial soils suitable for irrigation-based land management. In addition, due to its loose nature, this unit is well suited for intensive agriculture, particularly seasonal food crops.

The Dartollu Limestone is a formation composed of calcarenite. It occurs in the Sub-Region Nitibe and Pante Macassar with a total area of about 4,538 ha. Calcarenite is a coarse-grained carbonate rock that generally shows high porosity and good permeability, making it a potential aquifer. However, weathering of this limestone commonly yields shallow, stony soils with coarse structure.

Another formation present in RAEOA is the Borolalo Formation, composed of massive limestone, chert, and calcareous shale. It is distributed in Passabe and Pante Macassar with a total area of 759 ha. These rocks originate from deep-marine environments and have high hardness and low permeability, which result in nutrient-poor residual soils.

2.4 LAND USE

The distribution of land use in RAEOA comprises various categories according to their respective functions, providing a basis for the development of agricultural commodities and other high-value commodities. Data on area and the land-use maps are presented in **Figure 2.7, Figure 2.8**, and **Figure 2.9.**

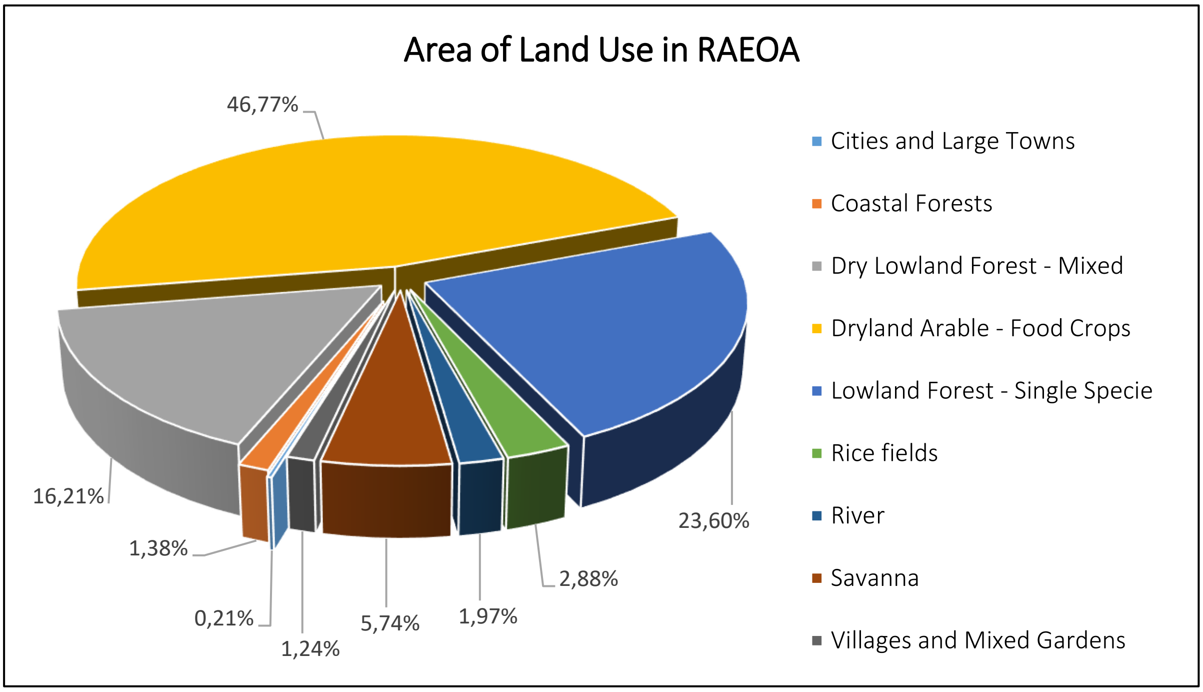
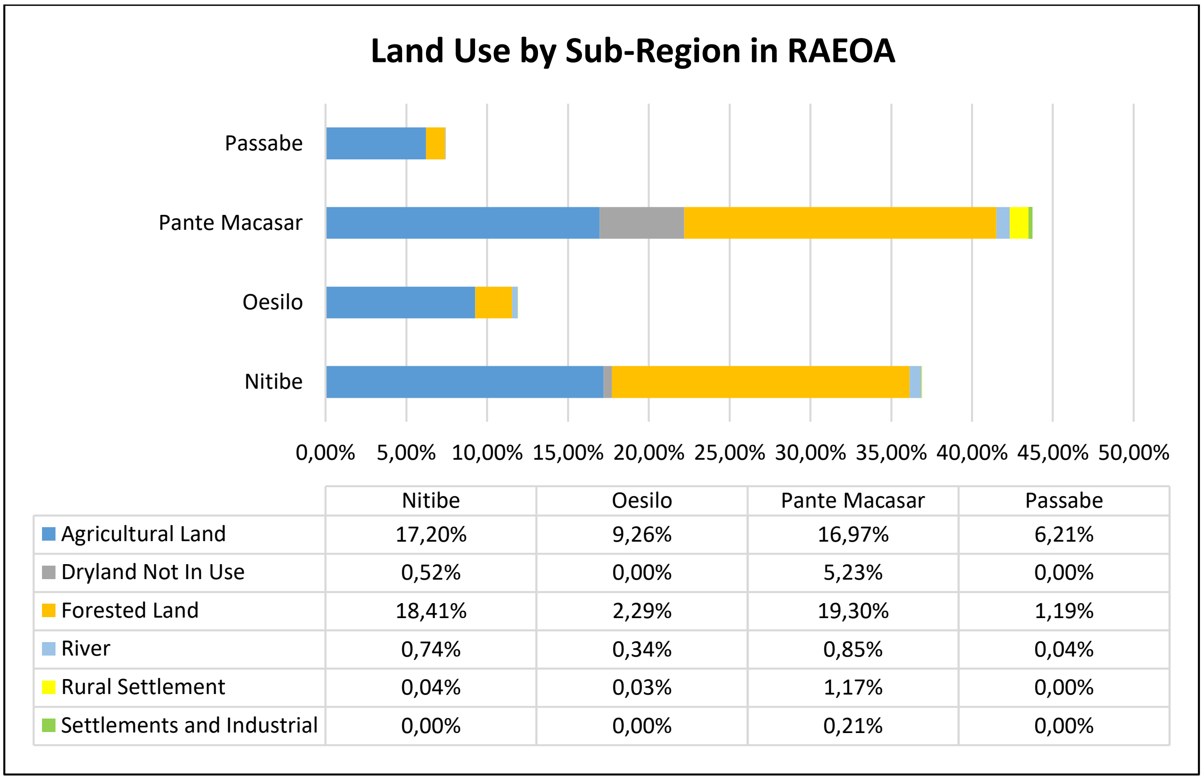


Figure 2.7 Area of Land Use in RAEOA



	Nitibe	Oesilo	Pante Macasar	Passabe
Agricultural Land	17,20%	9,26%	16,97%	6,21%
Dryland Not In Use	0,52%	0,00%	5,23%	0,00%
Forested Land	18,41%	2,29%	19,30%	1,19%
River	0,74%	0,34%	0,85%	0,04%
Rural Settlement	0,04%	0,03%	1,17%	0,00%
Settlements and Industrial	0,00%	0,00%	0,21%	0,00%

Figure 2.8 Graph of Land Use Area in RAEOA

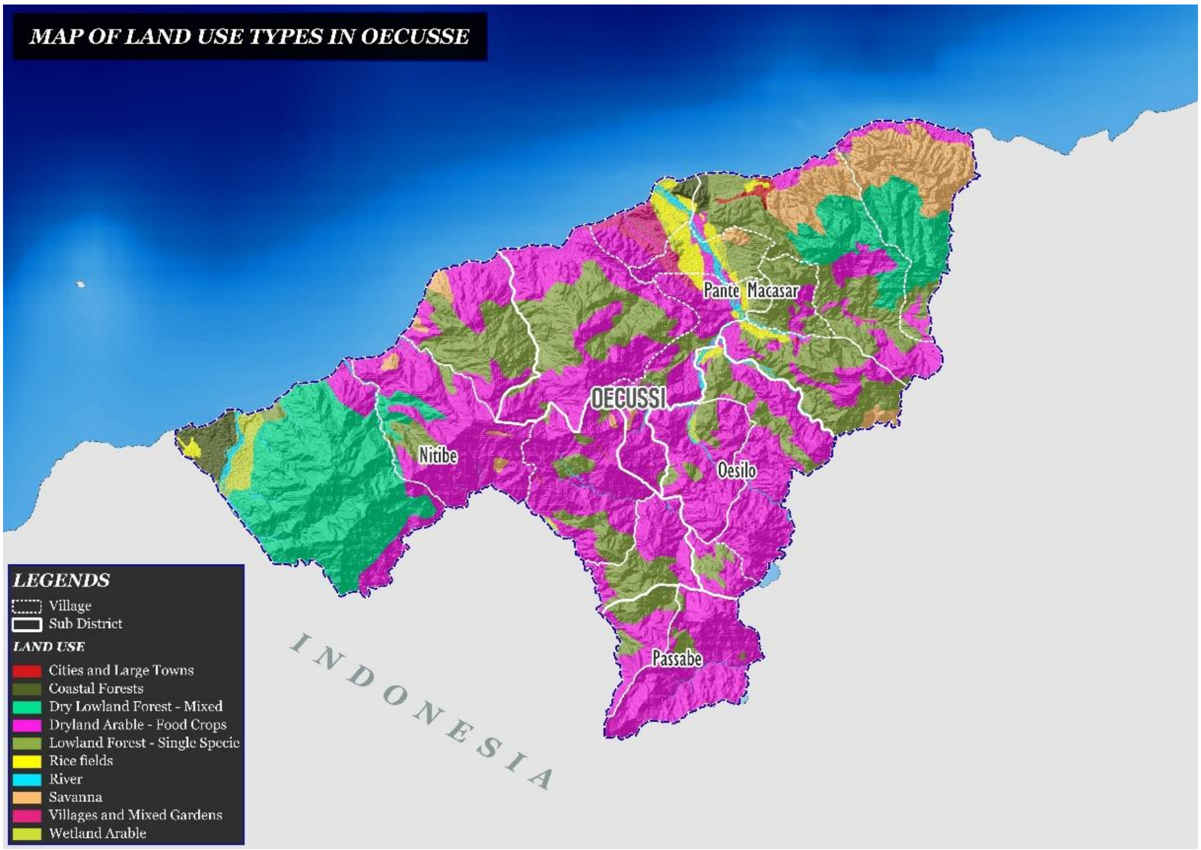


Figure 2.9 Map of Land Use in RAEOA

Agricultural land accounted for 48.58 % of the total area of RAEOA, consisting of dryland arable for food crops at 46.77 % and rice fields at 2.88 %. Dryland was widespread across all Sub-Regions, with the highest proportions in Pante Macassar (16.97 %) and Nitibe (17.20 %), while Oesilo and Passabe accounted for 9.26 % and 6.21 %, respectively. Although rice fields covered a smaller share, 2.88 % of RAEOA, they are an important component supporting food security in lowland areas.

Unutilized dryland comprised 6.96 % of the total area and was concentrated primarily in the Pante Macassar Sub-Region (5.23 %), with a smaller portion in Nitibe (0.52 %). This category includes savanna distributed in the Pante Macassar and Nitibe Sub-Regions that functions as seasonal grazing land important for traditional livestock systems. This land type indicates potential for development for agriculture, forestry, or conservation, depending on local biophysical and socioeconomic conditions.

Forest covered 26.76 % of the area, consisting of mixed dry lowland forest at 16.21 %, coastal forests at 1.38 %, and single-species lowland forest at 9.17 %. Forests were most widespread in the Pante Macassar (19.30 %) and Nitibe (18.41 %) Sub-Regions, indicating important ecological roles and potential for agroforestry. Coastal forests accounted for 1.38 %, and other areas such as mixed gardens have important ecological value, particularly for disaster mitigation and biodiversity conservation.

Areas classified as rivers occurred across all Sub-Regions, with the largest share in Pante Macassar (0.85 %), followed by Nitibe (0.74 %), Oesilo (0.34 %), and Passabe (0.04 %). Rivers play an important role in meeting water needs for communities and ecosystems.

Settlements comprised several categories: cities and large towns at 23.60 %, rural settlement at 1.38 %, villages and mixed gardens at 5.74 %, and settlements and industrial areas at 0.21 %. Most of these activities were concentrated in the Pante Macassar Sub-Region, which functions as the center of government and public services.

2.5 SLOPE GRADIENT

The distribution of slope gradients in RAEOA, Timor-Leste shows substantial variation and provides important topographic information with implications for land management, soil erosion risk, and natural resource conservation. Based on the available data, slope gradients in RAEOA were grouped into five categories: flat (0 to 8 %), gently sloping (8 to 15 %), moderately steep (15 to 25 %), steep (25 to 45 %), and very steep (>45 %), as presented in Figure 2.10. This variation reflects the area's complexity, which affects both opportunities and constraints for agricultural land management. The slope map for seven areas in Timor-Leste is presented in Figure 2.12.

The 0 to 8 % class covered 13.59 % (110.53 km^2) of RAEOA. This zone is flat and has high potential for infrastructure development, settlements, and intensive agriculture. The largest extent was in the Pante Macassar Sub-Region at 7.97 % (64.82 km^2), followed by Nitibe at 3.93 % (31.94 km^2), Oesilo at 1.39 % (11.33 km^2), and Passabe at 0.30 % (2.44 km^2). Flat topography facilitates land preparation, irrigation, and the use of agricultural machinery, with minimal erosion risk.

The 15 to 25 % class occupied 28.51 % (231.76 km^2). Nitibe had the largest extent in this class at 11.72 % (95.29 km^2), followed by Pante Macassar at 9.40 % (76.41 km^2). These slopes can still be used for agriculture with the application of soil conservation techniques such as terracing.

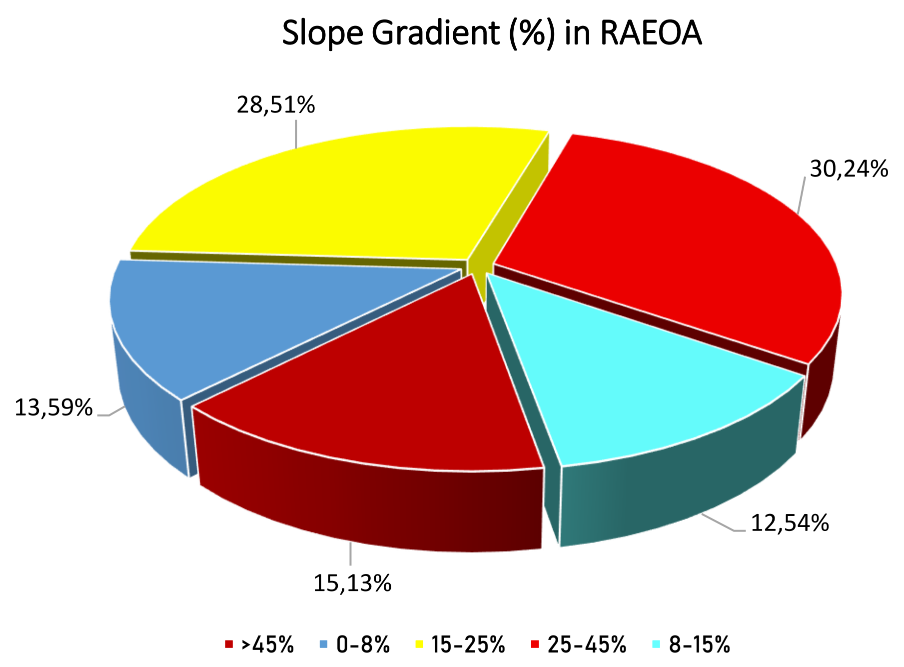
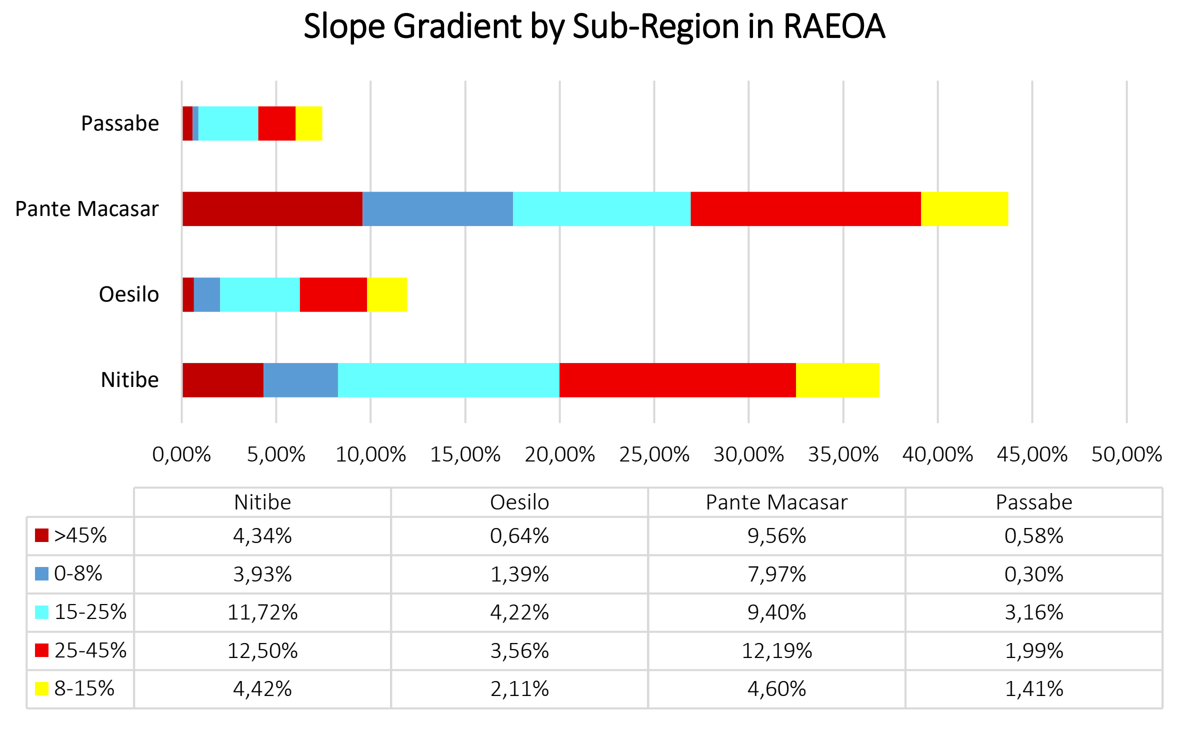


Figure 2.10 Diagram of Slope Gradient (%) in RAEOA



	Nitibe	Oesilo	Pante Macasar	Passabe
>45%	4,34%	0,64%	9,56%	0,58%
0-8%	3,93%	1,39%	7,97%	0,30%
15-25%	11,72%	4,22%	9,40%	3,16%
25-45%	12,50%	3,56%	12,19%	1,99%
8-15%	4,42%	2,11%	4,60%	1,41%

Figure 2.11 Slope Gradient by Sub-Region in RAEOA

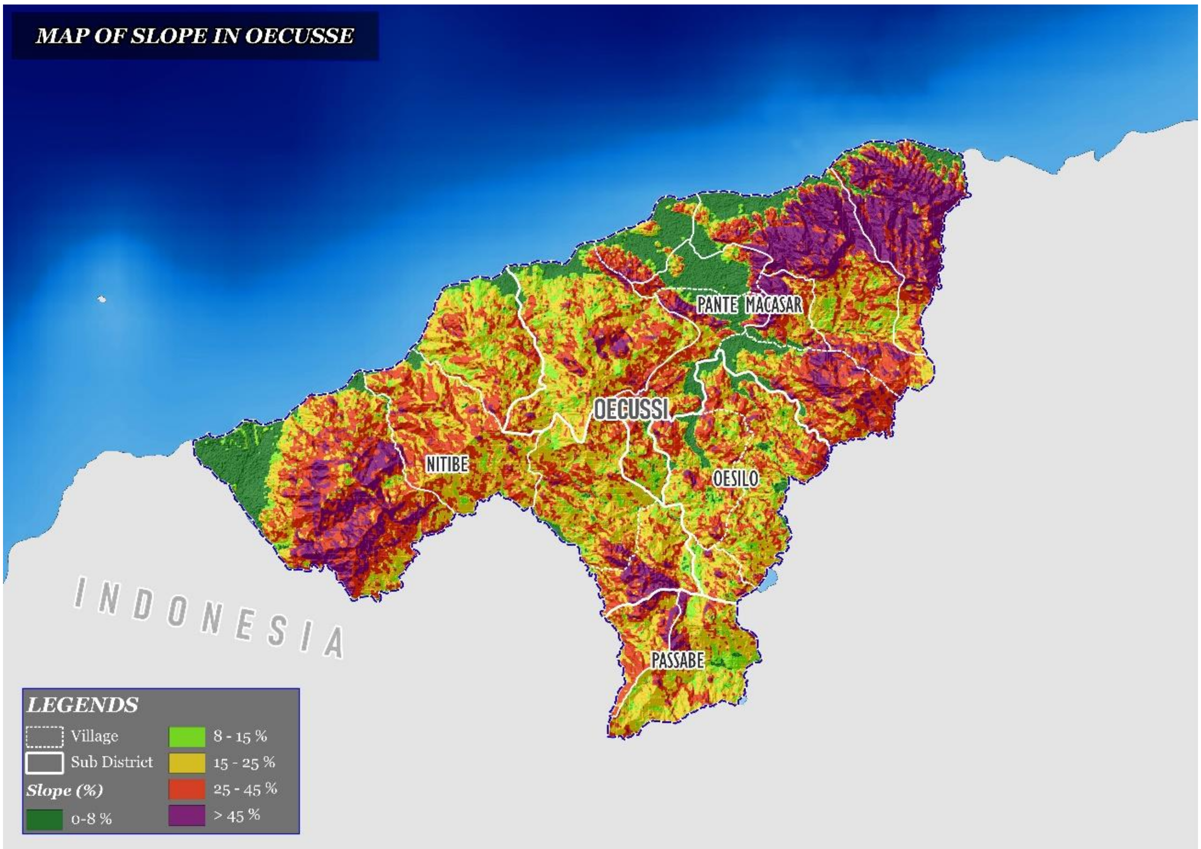


Figure 2.12 Slope Gradient Map of RAEOA

The 25 to 45 % class was the most extensive, covering 30.24 % (245.83 km^2). It was distributed across nearly all Sub-Region, with the largest proportions in Nitibe at 12.50 % (101.64 km^2) and Pante Macassar at 12.19 % (99.14 km^2). These areas are generally more suitable for conservation-oriented uses, such as agroforestry, to reduce erosion and land degradation risks.

Very steep slopes (>45 %) accounted for 15.13 % (122.99 km^2). The largest share was in Pante Macassar at 9.56 % (77.75 km^2), while the other Sub-Region were much smaller: Nitibe at 4.34 % (35.31 km^2), Oesilo at 0.64 % (5.20 km^2), and Passabe at 0.58 % (4.73 km^2). This class is highly susceptible to erosion and land degradation and therefore has major limitations for intensive agriculture.

The distribution of slope gradients provides a critical basis for land-use planning tailored to local conditions. Land with flat to gently sloping gradients is ideal for intensive agriculture and infrastructure development. In contrast, steep to very steep areas require strict soil conservation strategies, such as cover crops, terracing, and water-control structures, to reduce high erosion risk. Slope classes strongly influence erosion potential, particularly on unstable soils. This information is also important for selecting crop types appropriate to slope conditions to support sustainable land management in Timor-Leste.

2.6 AGROCLIMATIC ZONES

The agroclimatic zones in RAEOA were classified based on elevation and rainfall patterns using the Agriculture Land Use Information System (ALGIS), which adopts the framework of Fox (2003). RAEOA is divided into three main zones, A, B, and C, each characterized by distinct rainfall and wet-season durations. The total area by agroclimatic zone is shown in **Figure 2.13**, and the distribution by Sub-Region is presented in **Figure 2.14**. This approach is relevant for natural resource management and provides a scientific framework for sustainable land suitability evaluation (Molyneux *et al.*, 2013; Williams *et al.*, 2017).

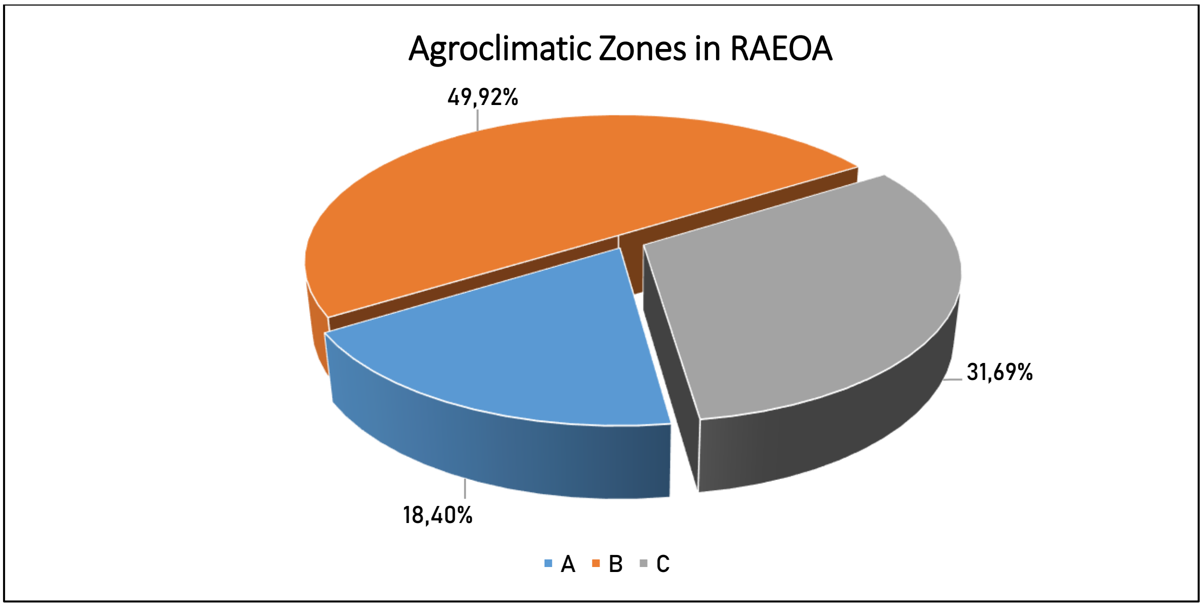
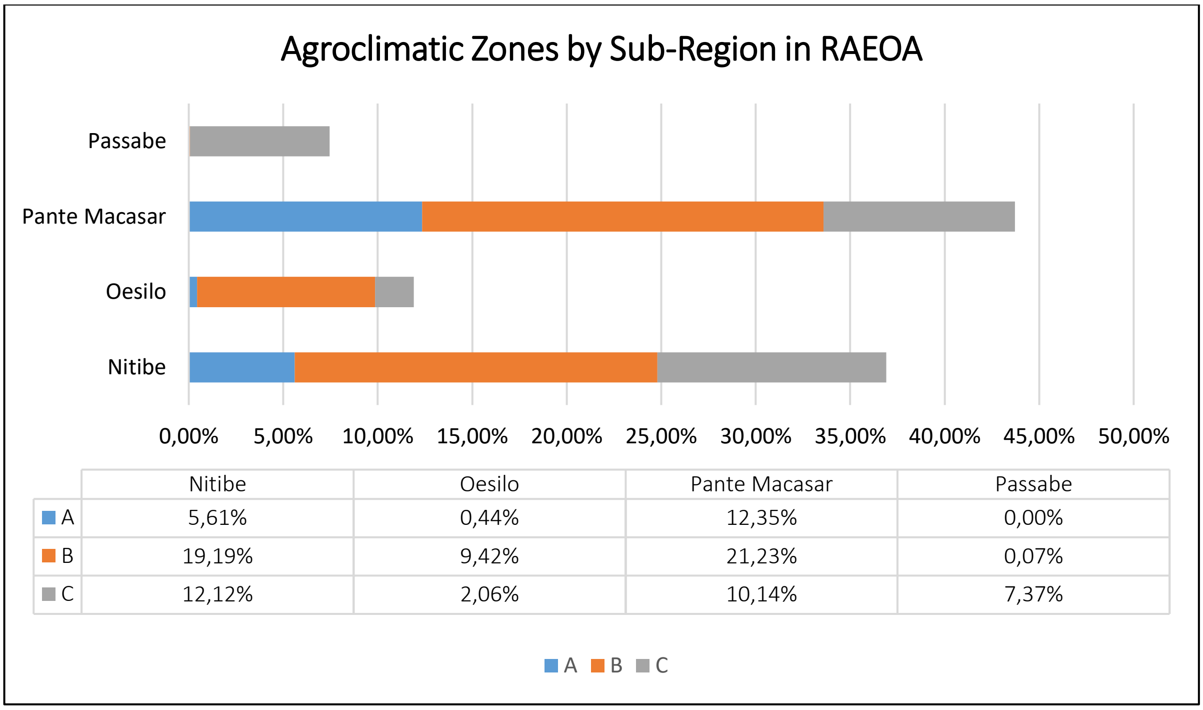


Figure 2.13 Diagram of Agroclimatic Zones in RAEOA



	Nitibe	Oesilo	Pante Macasar	Passabe
🟦 A	5,61%	0,44%	12,35%	0,00%
🟧 B	19,19%	9,42%	21,23%	0,07%
⬜ C	12,12%	2,06%	10,14%	7,37%

Figure 2.14 Graph of Agroclimatic Zones by Sub-Region in RAEOA

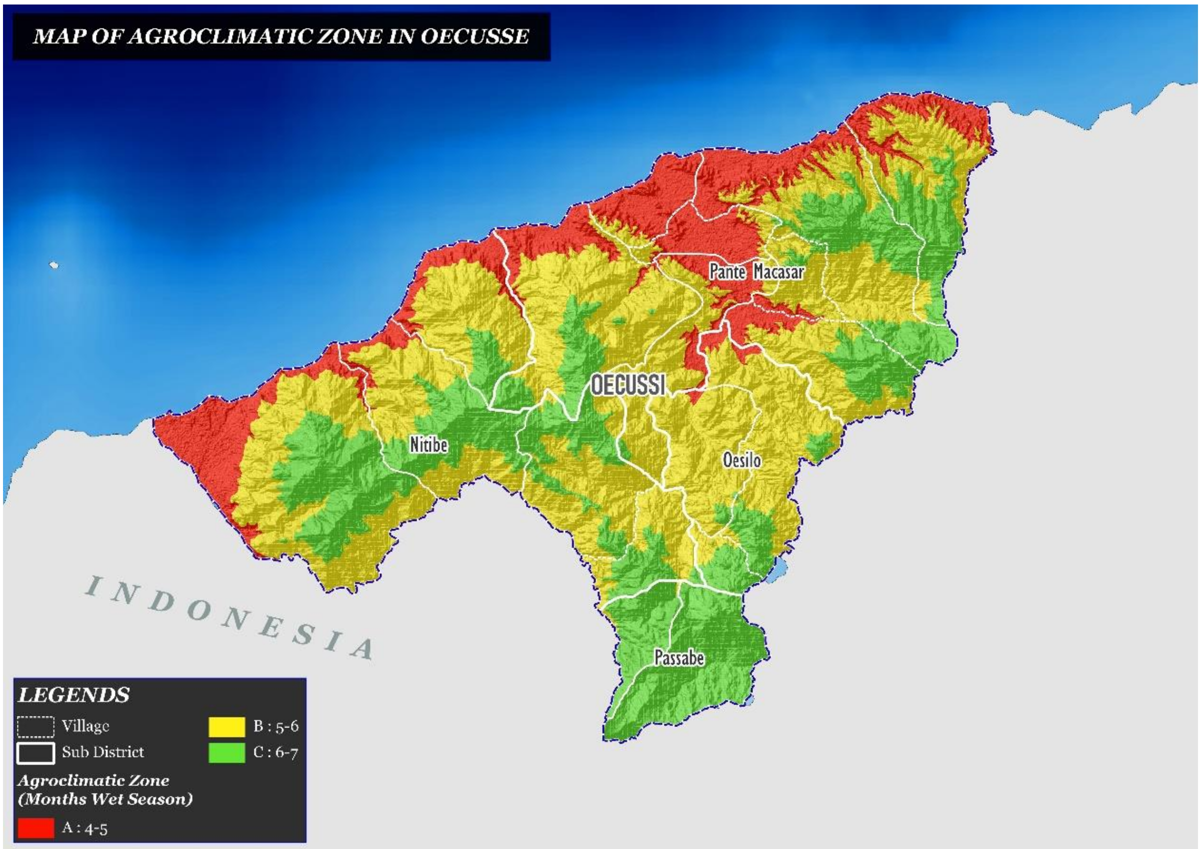


Figure 2.15 Map of Agroclimatic Zones by Sub-Region in RAEOA

Zone A was the smallest, covering 18.40 % (149.67 km^2) of RAEOA. The largest extent was in the Pante Macassar Sub-Region at 12.35 % (100.47 km^2), followed by Nitibe at 5.61 % (45.61 km^2) and a small area in Oesilo at 0.44 % (3.59

km^2), while Passabe had no Zone A area. Rainfall is monomodal and influenced by the northwest monsoon, with a rainy season lasting 4 to 5 months from November to March. Previous studies by Molyneux *et al.* (2013) indicated that rainfall variability is a major challenge affecting yields, requiring water-conservation technologies and adaptive agronomic practices.

Zone B was the most extensive agroclimatic type, covering 49.92 % (406.13 km^2). Rainfall is also monomodal, with a relatively stable rainy season lasting 5 to 6 months (October to March). This zone was dominant in the Pante Macassar Sub-Region at 21.23 % (172.77 km^2) and Nitibe at 19.19 % (156.13 km^2), while Oesilo and Passabe accounted for smaller proportions at 9.42 % (76.64 km^2) and 0.07 % (0.60 km^2), respectively. Williams *et al.* (2017) reported that farming systems in this zone combine food-crop production with livestock, although limited access to modern agricultural technology remains a key constraint to production optimization.

Zone C covered 31.69 % (257.82 km^2) and was distributed across nearly all Sub-Region. Nitibe had the largest share at 12.12 % (98.61 km^2), followed by Pante Macassar at 10.14 % (82.50 km^2), Passabe at 7.37 % (59.98 km^2), and Oesilo at 2.06 % (16.73 km^2). Rainfall is monomodal with a longer rainy season of 6 to 7 months (October to April). According to Molyneux *et al.* (2013), this zone has strong potential for coffee-based agroforestry that supports environmental sustainability and food security.

2.7 EXISTING CONDITIONS

Figure 2.16 Grazing Land and Livestock Feed Conditions
(Source: Researcher documentation, 2025)

RAEOA has substantial potential in agriculture and livestock. Efforts to increase food-crop production, particularly rice, face different constraints depending on the cropping system and geographic setting. Irrigated lowland rice requires consistent water management and reliable irrigation infrastructure. Rainfed rice in Abani Village depends heavily on variable rainfall. In highland areas such as Bobometo Village and Usi-Tacae Village, upland rice cultivation is constrained by low soil fertility and limited production inputs. These three rice systems contribute to regional food security, but their development requires approaches tailored to local conditions and support from adaptive agricultural technologies.

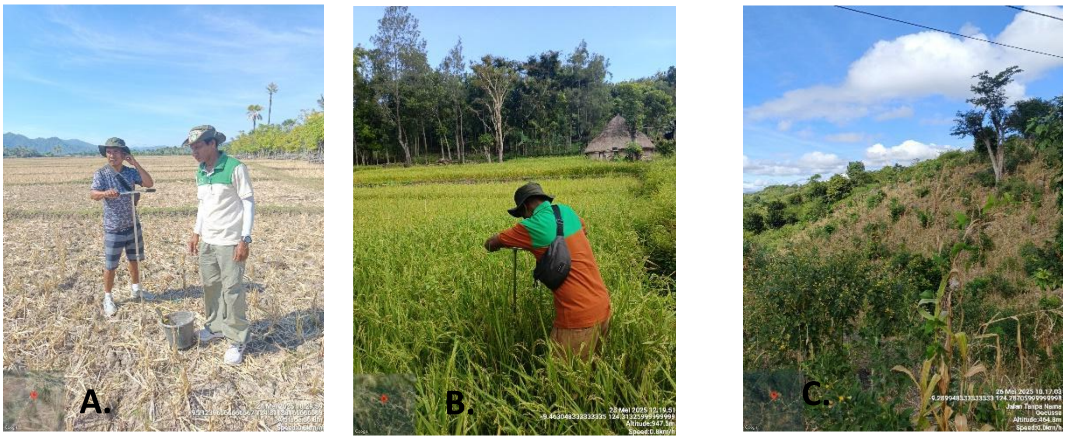


Figure 2.17 Rice Field Conditions: A) Irrigated Lowland;B) Rainfed Lowland Rice; C) Upland Rice
(Source: Researcher documentation, 2025)

RAEOA also has strong potential for livestock development, supported by extensive grazing land and the availability of forage resources. These natural conditions make livestock a leading sector with the potential to become a pillar of the local economy if managed optimally and sustainably. In Abani Village and Lalisuc Village, grazing areas are relatively extensive but face physical challenges, including stony surfaces, high coarse fragment content, and erosion risk.

To address these constraints, technical solutions are needed, such as constructing low bund terraces to attenuate surface runoff and applying vegetative conservation using terrace-reinforcing species such as vetiver and citronella. In addition, to maximize existing resources, the quality and quantity of forage should be enhanced through the introduction of improved grasses, development of integrated fodder-cropping systems, and farmer training focused on feed management and efficient land use. This approach strengthens the foundation of the livestock sector in RAEOA and supports an environmentally sound, climate- and market-adaptive agro-pastoral system.

RAEOA faces significant challenges in agricultural development due to complex topography. Hilly land with steep slopes is prone to erosion and landslides during the rainy season, threatening the continuity of farming. The Pante Macassar Dam, the primary source of irrigation water for irrigated rice fields, also poses flood risks when water discharge surges, potentially damaging irrigation systems and reducing yields. Disaster-mitigation strategies are therefore necessary, including terracing, land conservation, and strengthening irrigation infrastructure to maintain stable agricultural operations.

Figure 2.18 Conditions of Flooded Rice Fields and Erosion Land
(Source: Researcher documentation, 2025)

Pante Macassar Sub-Region is a priority area for the development of irrigated lowland rice in RAEOA. Its main advantage is abundant water availability, enabling intensive and sustainable use of land for irrigation-based agriculture. However, water use optimization remains focused on rice, while opportunities for diversification into horticultural commodities such as vegetables, fruit, and other high-value crops have not been fully utilized. Diversification could increase farmer income, expand the local market, and enhance regional food security.

An example of successful production is found in Lifau Village, which has achieved 4 to 6 t ha^{-1} of rice using urea, SP36, and pesticides efficiently. This Village demonstrates strong agricultural performance and has become a focal point for local government productivity programs. In addition, Naimeco Village has irrigated rice fields yielding 2 to 3 t ha^{-1}, with potential for improvement through irrigation optimization from the Sungai Utama. The dry season has not been fully utilized, even though local farmers recommend horticultural commodities such as watermelon, melon, eggplant, chili, and soybean. As support, the government has distributed Amo fertilizer, which is expected to increase yields and serve as a model for other Villages to manage agricultural land more efficiently.

Figure 2.19 Irrigated Lowland Rice Field: (Left) Lifau Village; (Right) Naimeco Village (Source: Researcher documentation, 2025)

Highland areas in the Nitibe, Passabe, and Oesilo Sub-Regions show strong potential for dryland agriculture. Agroclimatic conditions in these areas favor commodities adapted to limited water availability and drier soils. Maize and upland rice are the primary options for dryland systems because they can grow optimally with minimal water inputs. These areas are also suitable for forage-crop development, which supports integration between the crop and livestock subsectors. By optimizing land use according to local characteristics, both in lowlands suitable for irrigation-based agriculture and in highlands suitable for dryland systems, crop development in RAEOA shows balanced progress and opens opportunities for sustainable local economic development.

Figure 2.20 Conditions of Corn, Upland Rice, and Fava Bean on Dryland
(Source: Researcher documentation, 2025)

2.8 *Chromolaena Odorata*

Chromolaena odorata (siam sweed) is a flowering weed in the family Asteraceae that grows in tropical and subtropical regions. The species originates from North America, Mexico, and the Caribbean and later spread widely to Asia, Africa, and Australia through human activities and natural processes (Day *et al.*, 2013). Its spread, particularly in developing countries such as Timor-Leste, has significant environmental and economic impacts. *Chromolaena odorata* has cylindrical, pubescent stems; simple leaves with serrated margins; and compound inflorescences that are bluish when young and turn brown at maturity (**Figure 2.21**). The plant contains bioactive compounds such as flavonoids, tannins, alkaloids, saponins, and essential oils, which have considerable potential as raw materials for traditional medicines for conditions including diabetes, burns, hypertension, and skin infections (Jamatia *et al.*, 2024).

Figure 2.21 Leaf Structure of *C.odorata* in RAEOA
(Source: Researcher documentation, 2025)

In Timor-Leste, *C. odorata* was first recorded in the 1980s and spread rapidly due to slash-and-burn practices and the dry tropical climate. It can grow on various soil types, including nutrient-poor soils, with an optimal elevation of 500 to 2,000 masl. Its invasive growth indicates strong environmental adaptability but poses a serious threat to productive land.

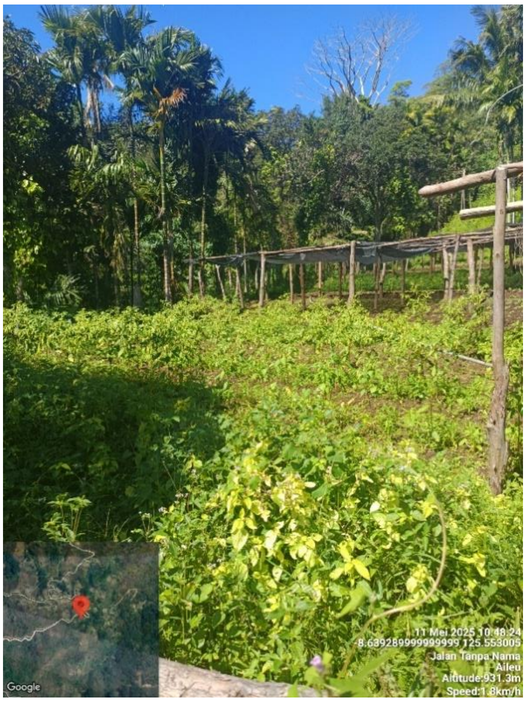


Figure 2.22 *C.odorata* Plants in RAEOA
(Source: Researcher documentation, 2025)

A. Threats of *Chromolaena odorata*

Chromolaena odorata has negative impacts on agriculture, livestock, and ecology. This weed can form dense thickets that suppress the growth of cultivated plants. In addition, its deep root system and extensive branching allow rapid uptake of soil nutrients compared with crops, resulting in unfavorable nutrient competition (Mugwedi, 2020). Consequently, land productivity declines sharply, exacerbating local food security challenges.

In the livestock sector, leaves of *C. odorata* contain pyrrolizidine alkaloids that are hepatotoxic and can cause liver damage in livestock when consumed in large quantities (Day *et al.*, 2013; Jamatia *et al.*, 2024). The dominance of this weed in grazing areas also reduces the availability of forage grasses, lowers carrying capacity, and indirectly affects the livelihoods of livestock keepers in Timor-Leste (Westaway *et al.*, 2018).

Ecologically, invasion by *C. odorata* disrupts ecosystem balance by dominating native vegetation and inhibiting the regeneration of trees and native plants important for biodiversity (Mugwedi, 2020). Its easily dried biomass increases the risk of land fires during the dry season in tropical regions such as Timor-Leste, accelerating land degradation and lowering environmental quality, including declines in soil nutrient content.

B. Potential of *Chromolaena odorata*

Chromolaena odorata has potential as an indicator of improving soil fertility. Mixing its biomass with farmyard manure can increase phosphorus levels in sandy soils and support the growth of cultivated crops such as shallot (Peniwiratri and Arbiwati, 2021). Its high organic content also makes it a candidate feedstock for environmentally friendly organic fertilizers.

From an ethnopharmacological perspective, *C. odorata* has reported benefits for treating burns, diabetes, hypertension, and skin infections, supported by multiple scientific studies (Jamatia *et al.*, 2024). Its flavonoid and phenolic contents confer notable antioxidant, anti-inflammatory, and antibacterial properties. In Vietnam, *C. odorata* leaves are used to treat soft-tissue wounds and leech bites, while in Africa the plant is used as a natural antiseptic (Mugwedi, 2020; Jamatia *et al.*, 2024). The biomass of *C. odorata* can be processed into high-quality vermicompost through biodegradation using the earthworm *Eisenia fetida* (Ganguly *et al.*, 2022).

III. RESEARCH METHOD

This study was conducted in the Special Administrative Region of Oé-Cusse Ambeno (RAEOA), Timor-Leste, recognized as an area with substantial agricultural potential that supports national food security. The region has extensive agricultural land, making it one of Timor-Leste's principal food-producing areas. Adequate irrigation systems and fertile soils supported agricultural productivity, particularly for major agricultural commodities

Data collection was carried out through field surveys, laboratory analyses, and the use of geographic information systems (GIS). The research took place from May to June 2025 and included direct field observations, soil sampling, interviews with local farmers, and spatial mapping using geospatial technology. Each stage was conducted systematically to obtain accurate information as a basis for planning optimal and sustainable land management.

3.1 RESEARCH DESIGN

A. Methodological Approach

This study adopted quantitative and qualitative approaches. The quantitative approach was used to obtain numerical data for statistical analysis, while the qualitative approach explored farmers insights and experiences regarding agricultural practices in the study area (Trigunasih, 2016). The methods applied included field surveys and laboratory analyses, comprising soil sampling and interviews with farming communities.

B. Sampling Locations

Sampling locations were determined using a Village-based approach that considered factors such as land-use practices, agricultural traditions, and community dynamics. This approach was designed to represent homogeneous land units in the area, thereby producing results that were relevant and accurately reflected field conditions. Soil samples were collected randomly and as composites using the boring method. Each land unit was represented by one composite soil sample, to depths of 0 to 30 cm for seasonal crops and 30 to 60 cm for perennial crops. Each soil sample weighed 1 kg for subsequent laboratory analysis.

C. Soil Morphological Observations

During soil sampling, field observations and recording of soil characteristics were conducted to understand the physical condition of the soil in greater detail. Observed parameters included soil color, texture, structure, consistency, and drainage. For more in-depth analysis, ring samples were taken as undisturbed cores to measure bulk density (BD) and soil porosity, which are important indicators of soil fertility and water-holding capacity (Sukarman *et al.*, 2017).

D. Interviews and Questionnaires

In addition to field observations, interviews and questionnaires were administered to farming communities to obtain further information on agricultural practices in the study area. Respondents were selected using purposive or judgmental sampling, considering farmers experience and expertise in land management (Sekaran & Bougie, 2013). The data collected included cropping patterns, constraints in farming, and land management systems applied in the area.

E. Land Suitability Evaluation

Field survey results, climate data, and laboratory analyses were compiled and evaluated using an agroecosystem land suitability assessment based on the criteria of Ritung *et al.* (2011). The classification method followed the FAO (1976) system with a matching approach, aligning land characteristics with the growth requirements of the analyzed crops. The agricultural commodities evaluated included food crops, horticultural crops, plantation crops, industrial crops, spices and medicinal plants, forestry, forage, and grazing with high economic potential.

3.2 RESEARCH PROCEDURES

A. Literature Review

The initial stage comprised a literature review to compile relevant secondary data to support the analysis. Collected data included administrative maps of the study area, geographic conditions, agricultural land area, and agricultural commodity production. Climate data analyzed included temperature, rainfall, dry months, and relative humidity. Previous studies on land suitability evaluation were also reviewed to strengthen the scientific basis of this research.

B. Land Unit Analysis

Land Unit analysis aimed to delineate land units as the basis for planning field observations. The resulting land units were used as references for soil sampling and for preparing the land suitability map. The LU analysis comprised:

a) Interpretation of Digital Elevation Model (DEM) data to analyze landforms and slope gradients.
b) Analysis of satellite imagery to verify actual land-use patterns, especially in areas that have undergone conversion such as rice fields, settlements, and plantations.
c) Use of supporting data, including slope maps, geological maps, and soil-type maps, to strengthen land-unit delineation.
d) Overlay of thematic maps to produce homogeneous land units that served as the basis for soil sampling.

C. Field Survey

Field surveys were conducted to verify the agreement between sampling locations and actual conditions. When discrepancies were found between land-use interpretations from satellite imagery and field reality, adjustments were made by establishing new sampling points. Sampling locations were determined from satellite-image analysis and the most recent field conditions.

In addition, interviews with local farmers were carried out to obtain supplementary information on agricultural practices and land-management challenges. Observations also covered environmental factors influencing agricultural productivity, including soil drainage, effective depth, erosion risk, flood risk, and surface rock outcrops (Ritung *et al.*, 2011).

Soil sampling was performed by boring to depths of 0 to 30 cm for seasonal crops and 30 to 60 cm for perennial crops. The collected soil samples were analyzed in the laboratory to determine physical and chemical properties that may affect land productivity. Climate data, including temperature, rainfall, and relative humidity, were obtained from local climate stations and presented in tabular form. The results of the land suitability evaluation and the characteristics of each land unit are presented in **Table 3.1.**

Table 3.1 Relationship Between Parameters, Data Acquisition, and Data Sources

No	Parameter	Data Acquisition		Data Source
		Primary	Secondary	
1	Temperature		√	Remote Sensing/ Timor-Leste climatology
2	Rainfall		√	Remote Sensing/ Timor-Leste climatology
3	Dry Month		√	Remote Sensing/ Timor-Leste climatology
4	Humidity		√	Remote Sensing/ Timor-Leste climatology
5	Drainage	√		Field survey
6	Soil texture	√		Field survey
7	Coarse fragments	√		Field survey
8	Efective Soil depth	√		Field survey
9	Cation exchange capacity, CEC	√		Laboratory results
10	Base saturation	√		Laboratory results
11	Soil pH	√		Laboratory results
12	Soil organic carbon, SOC	√		Laboratory results
13	Total-N	√		Laboratory results
14	P_2O_5	√		Laboratory results
15	K_2O	√		Laboratory results
16	Salinity	√		Laboratory results
17	Alkalinity	√		Laboratory results
18	Slope Gradient	√		Field survey
19	Erosion hazard (eh)	√		Field survey
20	Flood hazard (fh)	√		Field survey
21	Surface Rock	√		Field survey
22	Rock outcrops	√		Field survey

D. Laboratory Soil Analysis

The parameters used to determine soil properties from laboratory-analyzed samples were:

a. Soil organic carbon by the Walkley and Black method (%).

b. Total N by the Kjeldahl method (%).

c. Soil texture by the pipette method.

d. Soil pH by potentiometer (H_2O 1:2,5).

e. Available P (ppm) and available K (ppm) by the Bray-1 method when soil pH < 7 and the Olsen method when soil pH > 7, with units converted to mg /100 g

f. Electrical conductivity, EC (dS/m (H_2O 1:2,5).

g. Cation exchange capacity, CEC (cmol) and base saturation (%) using 1 N NH_4OAc at pH 7 as the extractant.
h. Total Phosphorus (mg/100 g) and Total Potassium (mg/100 g) determined using the 25 % HCl method.
i. Total Zinc (ppm) determined using the DTPA extraction method and Available Zinc (ppm) determined using the HNO3-:HClO4 digestion method.
j. Total Sulfur (ppm) and Available Sulfur (ppm) determined using the spectrophotometric method.
k. Determination of soil fertility status based on the PPT (1995) method
l. Erosion hazard estimated using the Universal Soil Loss Equation (USLE).

E. Land Suitability Analysis

Field observations and laboratory results were tabulated into agroecosystem land characteristics/qualities. Agroecosystem land suitability was analyzed by matching land characteristics/qualities with the growth requirements of bamboo, teak, mahogany, pine, coffee, cocoa, and coconut, to obtain land-suitability classes according to Ritung *et al.* (2011). Classification was conducted to the land-unit level.

Land-suitability classes were specified as actual and potential suitability. Actual suitability for each homogeneous land unit was determined by matching land characteristics/qualities with crop requirements without improvement of limiting factors. Potential suitability was determined by considering inputs and management measures applied to each homogeneous land unit, assuming improvements to the limiting factors.

F. Planning for Agricultural Commodity Development

Commodity planning was based on potential land suitability for the agricultural commodities to be developed, using the highest suitability class for each crop as the primary parameter. Other parameters included the dominant current land use within each homogeneous land unit and farm feasibility.

G. Land Use Recommendations

Land-use recommendations were prepared at the land-unit level based on the highest land-suitability class followed by lower classes, together with the treatment of limiting factors and improvement measures for each homogeneous land unit in RAEOA. Preparation of digital maps using a geographic information system facilitated interpretation. The information comprised agroecosystem land suitability, land-use recommendations, and agricultural commodity zoning. The land-suitability map was compiled from homogeneous land units and the results of the agroecosystem land-suitability classification.

Each land-suitability classification was mapped for the evaluated crop groups. Land suitability for commodities was presented as an agricultural commodity zoning map, while land-use planning was presented as a land-use recommendation map. The research flowchart is shown in **Figure 3.1.**

H. Data Analysis Using Geographic Information System Technology

The land-suitability information system comprised spatial data (map of land units) and attribute data (land-suitability classes). Integration of these components produced an information system using QGIS 3.10 that provided land-suitability classes for food crops, horticultural crops, and plantation crops based on the evaluation results. The compiled land-suitability maps, together with the land-resource database and information, were prepared according to land-suitability criteria and evolving uses such as varieties, cultivation technologies, and land management.

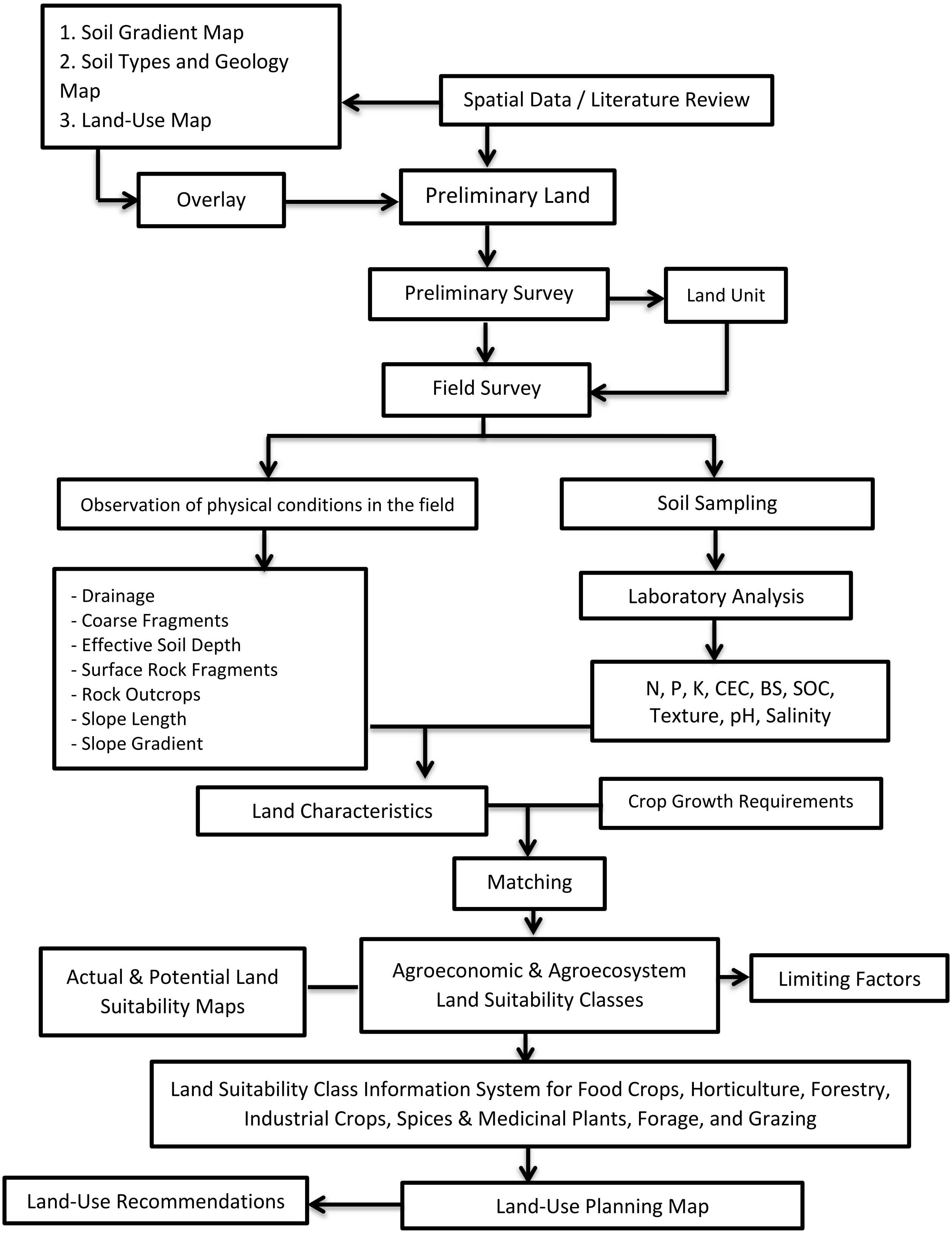


Figure 3.1 Research Process Flowchart

Land-use planning maps were derived from land-suitability classification and commodity zoning. The planning maps were thematic digital maps that provided land-use recommendations for various food, horticultural, and plantation crops. Digital maps resulted from converting primary and secondary data and information from raster and analog sources into digital data. Advantages of digital map data include easier error editing, ease of copying, long-term storage, and the ability to measure distance and area on screen without time-consuming and costly field measurements (Nugroho and Yarianto SBS, 2010). Outputs included digital maps in analog or hard-copy form in JPEG format for printing, and digital maps in DBF or integrated shapefile (SHP) formats that are easy to copy and informative. Map margins presented the map title, author, scale bar, legend box (land units, study area, soil type, slope, and land use), sources, latitude and longitude coordinates, and the geodetic datum used.

3.3 GEOGRAPHIC INFORMATION SYSTEM TECHNOLOGY

Geographic Information System (GIS) is a system that contains spatially referenced data that can be analyzed and converted into information for specific purposes. The definition of GIS includes systems that can:

1. Collect, store, and retrieve information based on spatial location.
2. Identify locations within a given area that meet specified criteria.
3. Explore relationships among various datasets within a given area.
4. Facilitate the selection and distribution of data for specific analytical application models that can estimate the impacts of alternatives for particular regional conditions.
5. Present a given area graphically and numerically, both before and after analysis (Murai, 2006).

Across the various definitions of GIS, several common keywords recur, namely geographically referenced data and the analysis of data (spatial and attribute) to generate information for specific aims and objectives. Accordingly, compared with other systems, GIS has the capability to handle data and information from a geographic perspective. This capability is especially relevant for development planning, which is carried out within the context of a particular region.

The term geographic is part of spatial. These two terms are often used interchangeably, giving rise to a third term, geospatial. In the context of GIS, all

three carry the same meaning. Use of the word geographic conveys issues concerning the Earth: two- or three-dimensional surfaces (Prahasta, 2005).
The term geographic information refers to information about places located on the Earth's surface, knowledge of the position where an object is situated on the Earth's surface, and information about attributes on the Earth's surface whose positions are given or known (Prahasta, 2005).

GIS is a formal entity composed of various physical resources related to objects on the Earth's surface. Thus, GIS is also a type of software that can be used for input, storage, manipulation, visualization, and output of geographic information together with its attributes (Prahasta, 2005).

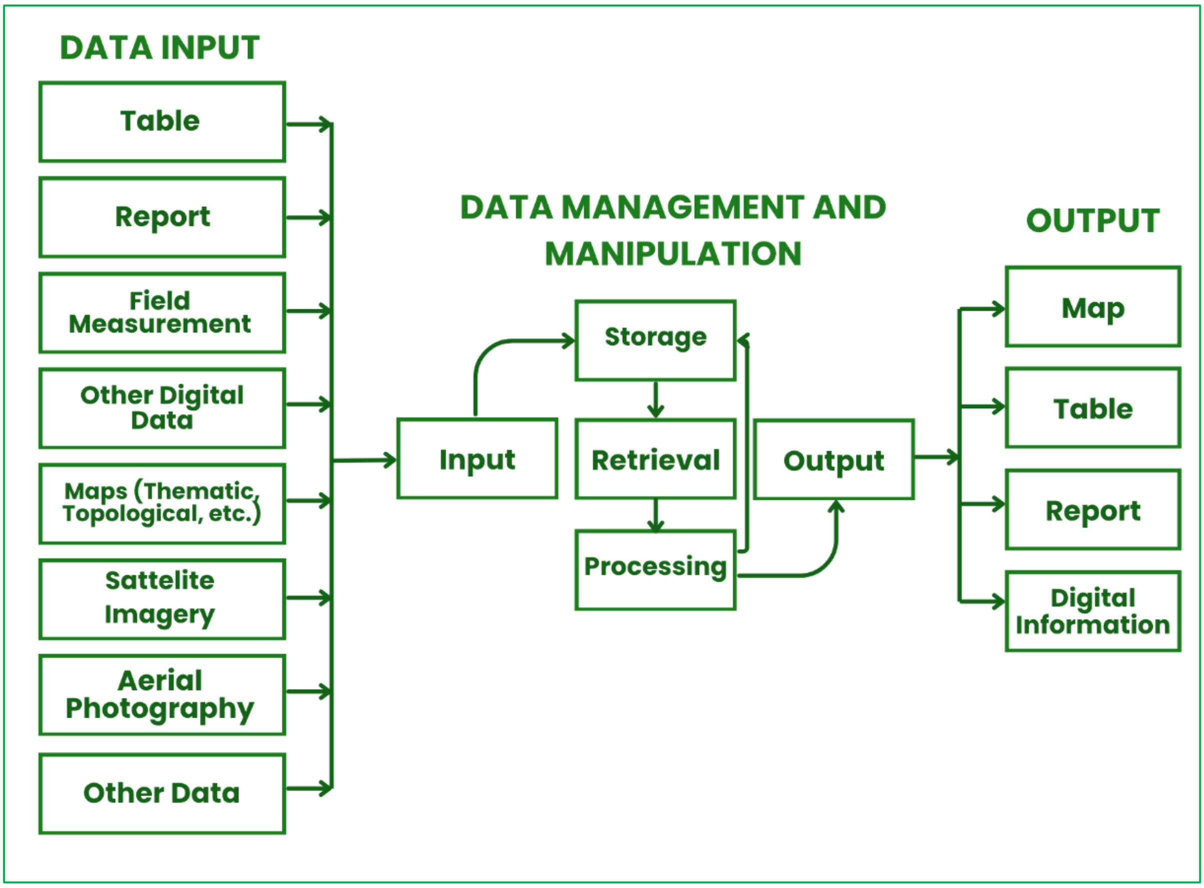


Figure 3.2 Components Costitutuning
(Source: Prahasta, 2005)

Geographic information systems can be applied in various fields. The system's capabilities include (Prahasta, 2005):

1. Cartographic Capabilities

   With this capability, GIS users can create maps and technical figures effectively and efficiently. The cartographic capability comprises digitizing, graphic visualization, interactive line manipulation, and plotting.

2. Data Management Capabilities

   GIS can store, process, and manipulate geographically referenced data. This management capability also includes attribute data processing, namely the ability to store and display specific attribute data associated with particular geographic features.

3. Analytical Capabilities

   The analytical capability is the ability to interpret and study collected data and information for specific purposes. It includes analysis of engineering functions, prediction/forecasting, computational operations, demographic analysis, sociocultural analysis, analysis of various regions and Districts, presentation of graphs and tabulations, overlay analysis, logical analysis, and selection analysis.

4. Integration of GIS and Multimedia

   The ability to integrate GIS and multimedia has been developed by local innovators in Bali. Through integration between multimedia systems and GIS, the final display of GIS analysis results becomes more engaging and facilitates reading and understanding of the results.

A. GIS Processes and Components

GIS essentially performs six processes (Prahasta, 2005):

1. Data Input

Before geographic data can be used in GIS, it must be converted to digital format, a process called digitizing. In this study, on-screen digitizing was carried out, in which data conversion can be performed using scanning technology.

2. Data Transformation

The types of data used in GIS may need to be transformed or manipulated in several ways to conform to the system. For example, there may be differences in scale, so before data are entered and integrated they must first be transformed to the same scale. This transformation could be temporary for display purposes or permanent for analytical processing.

3. Editing

The editing stage is the digital correction stage. Corrections may involve adding or removing arcs or features by editing overshoots or adding undershoots. Editing is also performed to add arcs manually, such as creating polygons, lines, or points.

4. Data Management

After spatial data are entered, processing proceeds to descriptive data, which includes annotation (adding text to the coverage), labeling (assigning information to the relevant map), and attributing, namely the stage in which each label ID from the labeling process is assigned additional attributes that provide information about the polygon or arc it represents.

5. Query and Analysis

Query in GIS is essentially an analytical process performed in tabular form. Fundamentally, GIS analysis uses spatial analysis. GIS has many strengths in spatial analysis, with two of the most important being:

a) Proximity Analysis

A geographic analysis based on distances between layers. Questions include, for example, how many houses are located in a watershed. In proximity analysis, GIS uses a process called buffering (creating a support layer around a layer at a specified distance) to determine the nearness of relationships among existing components.

b) Overlay Analysis

The process of integrating data from different layers is called overlay. In simple terms, this can be considered a visual operation, but analytically it requires merging more than one layer. An example of overlay or spatial join is the integration of soil, slope, and vegetation data, or land ownership with assessed land tax values.

6. Visualization

For some types of geographic operations, the best final output is expressed in maps or graphics. Maps are highly effective for storing and conveying geographic information.

B. GIS Components

In general, GIS operates through the integration of five components, namely hardware, software, data, people, and methods, described as follows (Budianto, 2010).

1. Hardware

The computers on which a geographic information system operates. At present, GIS can run on a wide range of hardware types, from centralized server computers to desktop computers used as stand-alone machines or in network configurations.

2. Software

GIS software provides the functions and tools needed to create, process, analyze, and display geographic information, for example:

a. Tools for data input and manipulation.
b. A database management system (DBMS).
c. Tools that support geographic query, analysis, and visualization.
d. A graphical user interface (GUI) for accessing the tools.

3. Data

Data are a critical component of GIS. Fundamentally, GIS works with two geographic data models: the vector data model and the raster data model. The vector data model represents, places, and stores spatial data using points, lines or curves, or polygons together with their attributes. The raster data model represents, places, and stores spatial data using a matrix structure or pixels that form a grid. Each pixel or cell has its own attributes, including its unique coordinates (at a grid corner, at the grid center, or elsewhere). The accuracy of this data model depends strongly on the resolution or pixel size (grid cell) on the Earth’s surface.

4. Human

GIS technology is not useful without people who operate the system and develop plans that can be applied to real-world conditions. As with other information systems, GIS users have different levels, from technical specialists who design and maintain the system to users who employ GIS to support their daily work.

5. Methods

A well-designed GIS aligns a good design plan with real-world rules. Models and implementation methods vary for each problem.

C. Data Processing in GIS

GIS data processing comprised the following activities (Budianto, 2010):

1. Base Map Digitizing

Base map digitizing was performed using the Rupabumi Indonesia map at 1:25.000 scale, which served as the basis for conducting the survey and for map digitizing, including data updating. Conversion to digital format was carried out layer by layer with topology.

2. Import Data

Data import was conducted for satellite imagery whose format differed from the processing software. This format conversion is an initial step commonly performed in image processing.

3. Geometric Correction of Imagery

Geometric correction was required so that satellite imagery had a map reference or coordinate system. Geometric correction can be performed using three methods: image to image (previously corrected imagery), image to ground, in which map coordinates are measured directly in the field using GPS (Global Positioning System), and image to map.

4. Digital Image Processing

Satellite imagery was processed digitally to enhance the standard 25 m spatial resolution of multispectral bands to 15 m color. This was done using an image data fusion model with the Brovey Transform. The process supported visual interpretation of planimetric objects such as transportation networks, rivers, and other planimetric features in the area.

5. Satellite Image Classification

A digital classification process was also carried out, complemented by a knowledge-based approach for extracting spatial information on land use. Classification employed supervised classification and filtering. The digital classification model, which yields grouping accuracy far superior to the human eye, was complemented by visual interpretation of the Brovey-transformed data. Digital classification was performed by grouping assemblages of objects identified as samples (sampling areas). The image-processing software automatically searched for pixel assemblages similar to the sample areas, thus forming distinct classes. The classified imagery was then validated in the field to identify discrepancies and uncertain pixels. Discrepancies found during field validation were not permitted to exceed 3 % of the test area. The classification results were used to update the digitized Rupabumi Indonesia map using the digital light table effect and raster–vector overlay.

6. Updating Spatial Information

Spatial information on maps was updated using raster–vector overlay, complemented by the light table effect for interpreting and analyzing land-use information. Updates to planimetric spatial information were performed with raster–vector overlay. This integration model combined digital image classification with visual image interpretation to obtain accurate updated spatial data. Specific objects deemed important but not clearly visible in the imagery were mapped using GPS during field surveys. The final output of the updating work was digital spatial land-use data in GIS.

7. Field Survey

Field surveys were conducted to correct interpretation errors made in the laboratory, to investigate spatial information for uncertain objects in the imagery, and to plot the positions of important objects that could not be extracted directly from the imagery.

8. Reinterpretation and Editing

This task was performed to improve inaccurate image-interpretation results based on fieldwork findings. It was carried out digitally in the laboratory to obtain final, up-to-date spatial information.

9. Edge Matching

Edge matching was performed to ensure consistency across adjoining map sheets. This process was carried out digitally on all adjacent layers.

10. Digital Cartography and Map Production

Cartographic processing was performed fully digitally to produce standard map layouts in accordance with prevailing cartographic principles. The cartographic model in this work referred to the thematic map cartography model issued by Badan Informasi Geospasial.

11. Database Development and Modeling

Database development was carried out for all resulting GIS spatial datasets, consisting of spatial land-use data, attribute data, and the thematic maps produced.

IV. LAND CHARACTERISTIC

4.1 TEMPERATURE

Air temperature is one of the key factors in land suitability evaluation as it significantly impacts the sustainability of natural resource management and regional development potential. In this study, the temperature distribution was analyzed using a combination of field measurement data and geospatial data based on the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM), with the Braak formula approach. This analysis provides a comprehensive overview of temperature variability, reflecting the complexity of topography, elevation, and microclimates in the Special Administrative Region of Oé-Cusse Ambeno (RAEOA).

RAEOA exhibits a range of temperatures spread across several categories, as shown in the temperature distribution analysis diagram (**Figure 4.1**). The temperature range above 26°C is the most dominant, especially in the Pante-Macassar Sub-Region, reflecting that much of RAEOA experiences relatively high temperatures year-round. This condition places RAEOA in either a wet tropical or dry tropical climate zone, depending on the annual rainfall distribution. Such conditions have the potential to exacerbate seasonal drought, particularly when not balanced by adequate rainfall, thus requiring adaptive approaches such as the use of heat-tolerant crop varieties and efficient water management.

Following the dominant category, the temperature range between 21–24°C is common in the Passabe area, while temperatures between 24–26°C are most prevalent in Nitibe. These two ranges indicate a warm climate. This variation suggests the influence of topography and local microclimates. Physiologically, these temperatures are within the optimal range for most crops, as they support critical processes such as photosynthesis, water absorption, and cell growth (Mildaerizanti & Pangestuti, 2016). The temperature distribution data for RAEOA is presented in **Figure 4.1.**

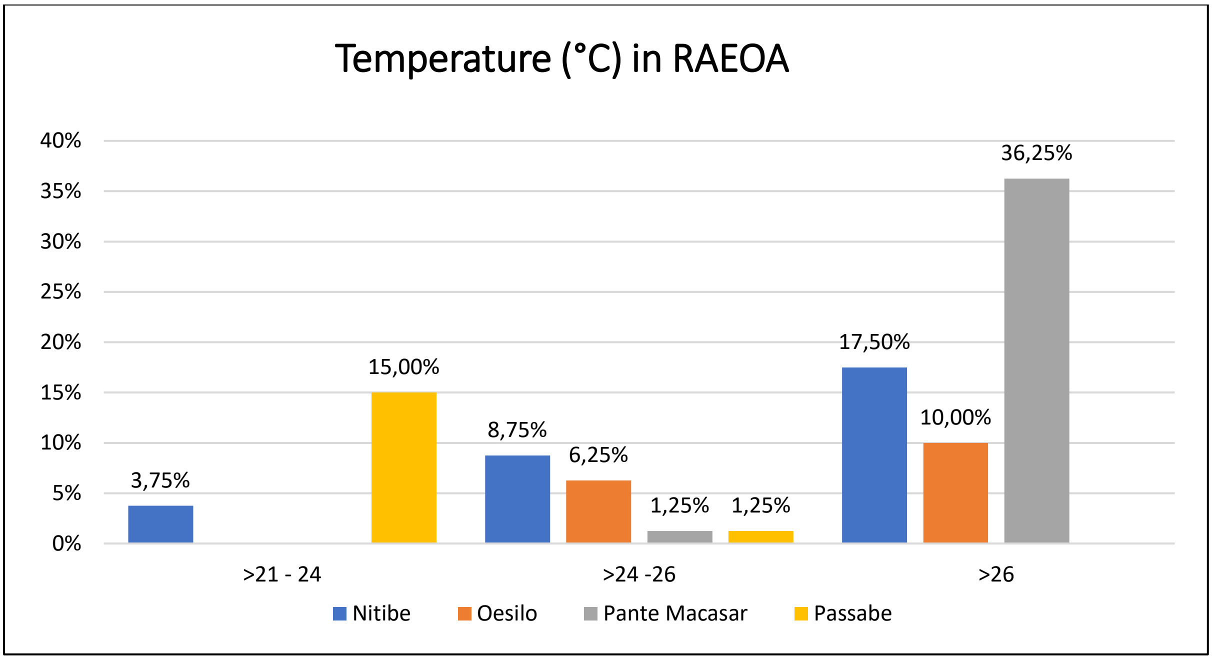


Figure 4.1 Temperature Data (°C) in RAEOA

4.2 RAINFALL

The land characteristics of RAEOA, based on field observations regarding rainfall, dry months, and drainage, show significant variability in annual rainfall, ranging from less than 1,000 mm to up to 2,000 mm. The region with the lowest annual rainfall, under 1,000 mm, is predominantly found in the Pante-Macassar Sub-Region. Meanwhile, the Nitibe and Pante-Macassar Sub-Region experience rainfall between 1,000 and 1,500 mm annually. The Passabe Sub-Region has the highest rainfall, ranging from 1,500 to 2,000 mm/year

The variation in rainfall characteristics across the Sub-Regions leads to differences in water availability. Therefore, each region needs to manage and utilize water resources optimally to support more effective and sustainable agricultural development. Regions with low rainfall (less than 1,000 mm/yr) require water conservation technologies and supplementary irrigation to meet water demands, while areas with moderate rainfall (1,000–2,000 mm/yr) need water management strategies during the dry season. The distribution of rainfall data is presented in **Figure 4.2**.

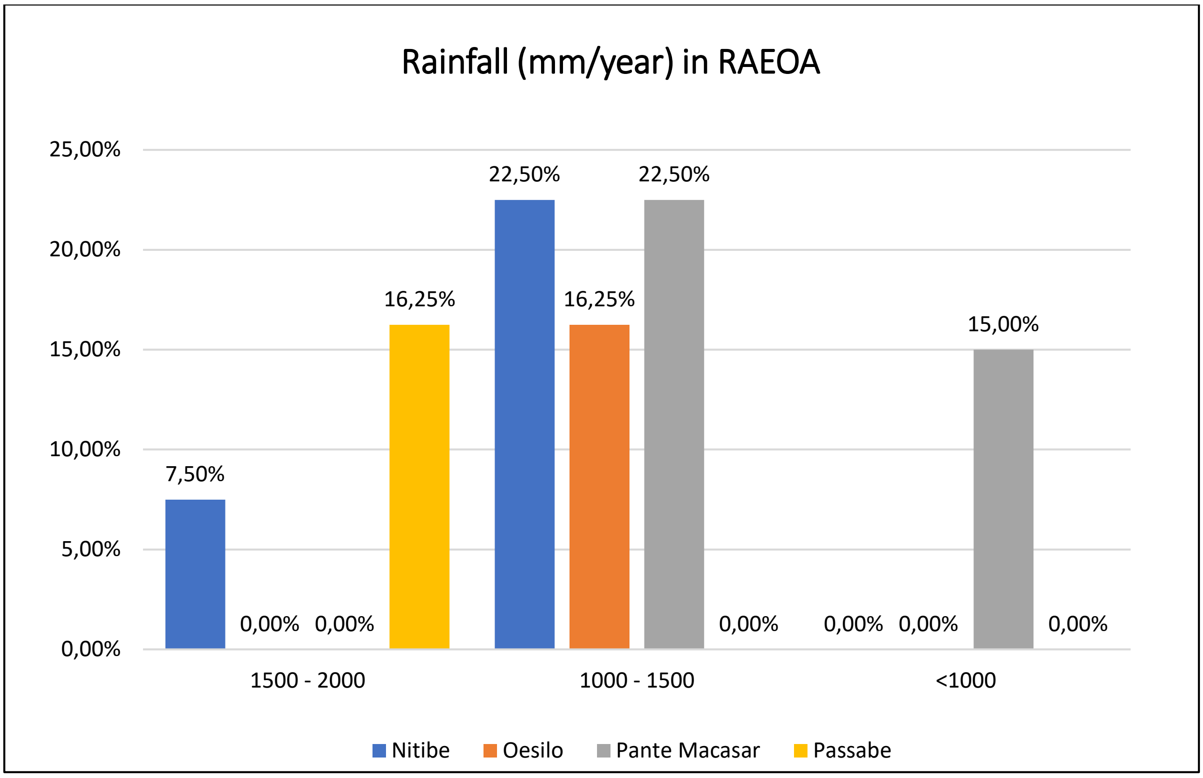


Figure 4.2 Rainfall Data (mm/year) in RAEOA

4.3 ELEVATION

The distribution of elevation in RAEOA shows a dominance of low-lying areas, particularly within the 0–400 m above sea level (masl) range **(Figure 4.3).** Pante Macassar Sub-Region represents the largest share of this distribution, followed by the Nitibe Sub-Region. At these elevations, air temperatures are relatively higher and more stable, while rainfall tends to be concentrated in coastal lowland areas. These conditions make lowland areas more suitable for land-use activities that require warm temperatures and high accessibility, although proper water management remains essential to anticipate potential inundation resulting from rainfall intensity.

In contrast, areas with elevations exceeding 700 masl have a much more limited distribution and are mainly concentrated in the Passabe Sub-Region. At higher elevations, air temperature decreases with increasing altitude, while rainfall tends to be higher due to orographic effects. Consequently, hilly and upland areas are more suitable for conservation functions, water resource provision, and land uses that are adaptive to cooler climatic conditions. However, limited accessibility and erosion risk constitute major constraints to intensive land utilization.

Overall, the elevation distribution in RAEOA indicates a clear differentiation in land suitability that is closely related to variations in temperature and rainfall. Lowland areas are more supportive of intensive land use, whereas highland areas are better suited for ecological and conservation functions. This pattern underscores the importance of land-use planning that accounts for physiographic and climatic conditions, so that a balance between productivity and sustainability can be achieved.

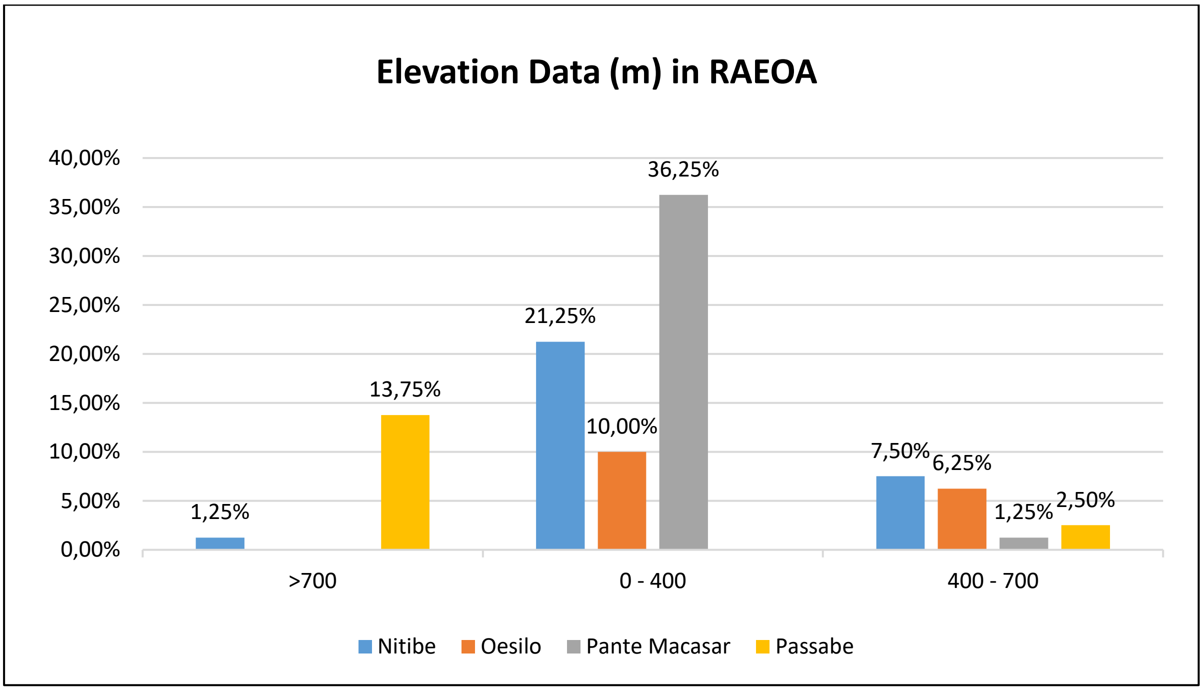


Figure 4.3 Elevation Data in the RAEOA Region

4.4 DRY MONTHS

Land characteristics based on dry months also show variation and differences across the Sub-Regions in RAEOA. The Passabe Sub-Region has the highest number of dry months, ranging from 5 to 6 months, while the Pante-Macassar Sub-Region experiences more than 6 dry months, the highest in the region. These dry-month characteristics indicate that, on average, Sub-Regions in RAEOA experience more than 6 dry months, which significantly affects water availability. Regions with more than 6 dry months experience extended dry seasons, which can negatively impact agricultural activities (Rozci F, 2024). Overall, this data underscores the importance of a zonation-based approach to ensure adaptive land management that is grounded in scientific evidence to address climate challenges in RAEOA. The dry-month data for RAEOA is presented in **Figure 4.4.**

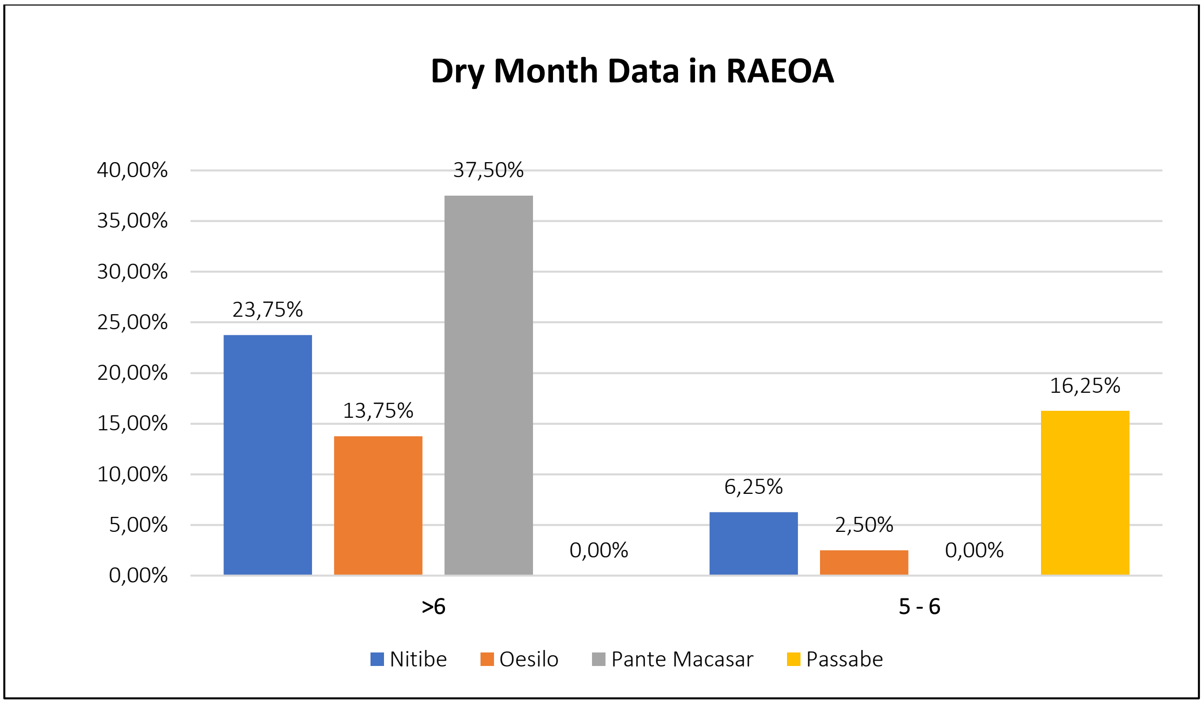


Figure 4.4 Dry Month Data in RAEOA

4.5 DRAINAGE

Land characteristics based on drainage exhibit variation and differences across the Sub-Regions. Nitibe and Passabe Sub-Region have well drained drainage due to land use being predominantly composed of mixed gardens and forests. Mixed gardens, which integrate various perennial and seasonal crops such as fruit trees, woody plants, and shrubs, have a positive effect on the natural drainage system of the area. The diverse root systems of these plants and the less compacted soil structure help enlarge soil pores, allowing rainwater to more easily infiltrate the soil and reducing surface runoff. The deep and spreading root systems of different plant types also help bind the soil, stabilize slopes, and enhance water retention (Bodner, G., Mentler, A., & Keiblinger, K., 2021; Febriyandra, E., 2017).

In contrast, the Pante-Macassar Sub-Region has somewhat Poorly drained drainage due to the widespread use of rice fields. Rice fields have a unique drainage characteristic because they are designed to hold water for a specific period to support rice plant growth. The drainage system in rice fields is not meant to drain water quickly but to regulate the water table height according to the plant's needs, resulting in poorer drainage compared to other land uses (Mujiyo *et al.*, 2018). The Nitibe Sub-Region has moderate drainage, as the land use is primarily mixed gardens. The dense canopy of plants slows the rainfall's impact on the soil, reduces surface runoff velocity, and prevents erosion and waterlogging (Adhitya, F., Rusdiana, O., & Saleh, M.B., 2017). The distribution of drainage across RAEOA is presented **in Figure 4.5.**

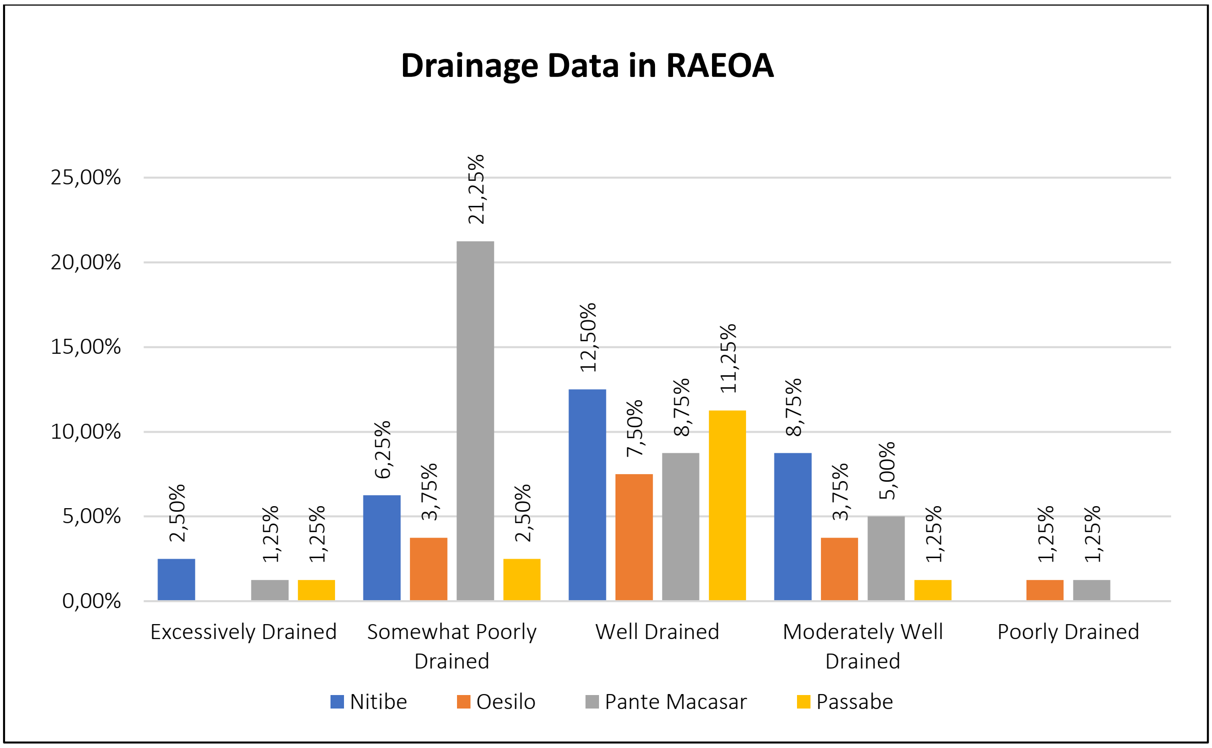


Figure 4.5 Drainage Data in RAEOA

4.6 COARSE FRAGMENTS

Based on **Figure 4.6,** which presents the distribution of coarse fragments across RAEOA, it is evident that the < 5% category is the most dominant, widely distributed in the Pante-Macassar Sub-Region. Coarse fragments in the soil increase capillary porosity and also enhance the soil's ability to retain effective water, although their effect on water retention in saturated conditions is minimal. The presence of coarse fragments in the soil also increases the movement of groundwater or water percolation (Zhongjie *et al.*, 2008).

The next category, with the lowest amount of coarse fragments in RAEOA, is 3%–15%, and it is widely distributed in the Nitibe Sub-Region. In general, as the amount of coarse fragments in the soil increases, the total porosity of the soil also increases. This is because the pores that should be occupied by soil are replaced by the coarse particles, resulting in larger gaps between the soil particles in a given volume, thus increasing the total porosity. This also affects the other pore arrangements, including macro pores and the water retention pores (Mahfut *et al.*, 2015).

Overall, this analysis indicates that RAEOA predominantly has soil with low to very low levels of coarse fragments. This distribution provides valuable insights into various aspects, such as agricultural planning, infrastructure development, and mitigation of erosion and land degradation. Soils with low coarse fragment content tend to be more fertile and better able to retain water, whereas soils with high coarse fragment content often have faster drainage but may not support the growth of certain plants. The coarse fragment data for RAEOA is presented in **Figure 4.6**.

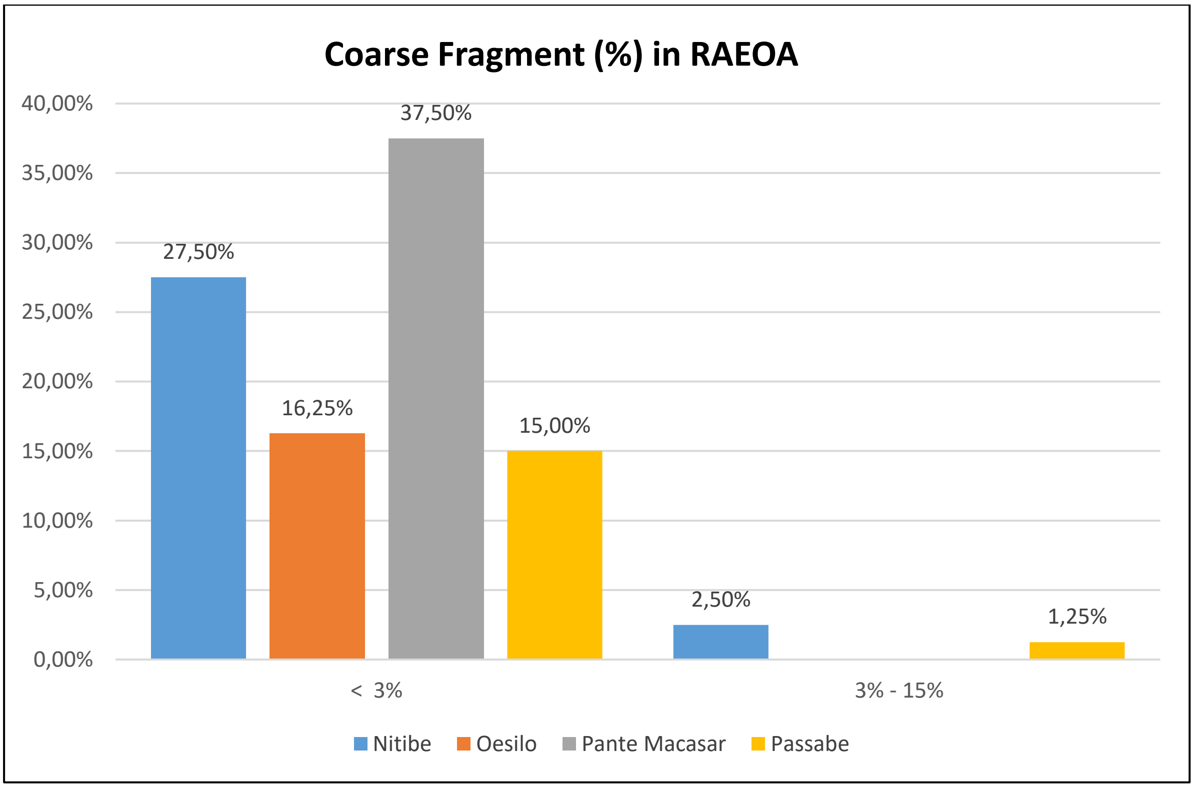


Figure 4.6 Coarse Fragment (%) in RAEOA

4.7 EFFECTIVE SOIL DEPTH

Effective soil depth refers to the depth of soil that can be penetrated by plant roots until reaching a hard layer (Basir, 2019). Effective depth plays a crucial role in the root zone of plants to support plant growth (Baghdadi *et al.*, 2021).

The distribution of effective soil depth in RAEOA shows varied depths. The Pante Macassar Sub-Region predominantly has deep effective soil depths, ranging from 90 to 120 cm. This depth indicates the soil's ability to support the growth of deep-rooted plants, increase groundwater availability, and provide optimal space for nutrient accumulation.

On the other hand, the Nitibe Sub-Region is dominated by shallow effective soil depths, ranging from 30 to 60 cm **(Figure 4.7)**. Soils with limited depth tend to have lower water retention capacity, making them more susceptible to drought and erosion, while also limiting the types of vegetation that can grow optimally. Land management in this zone requires stricter conservation approaches, such as the use of cover crops, terracing, and selecting plants with fibrous roots or short life cycles that are adaptable to shallow conditions.

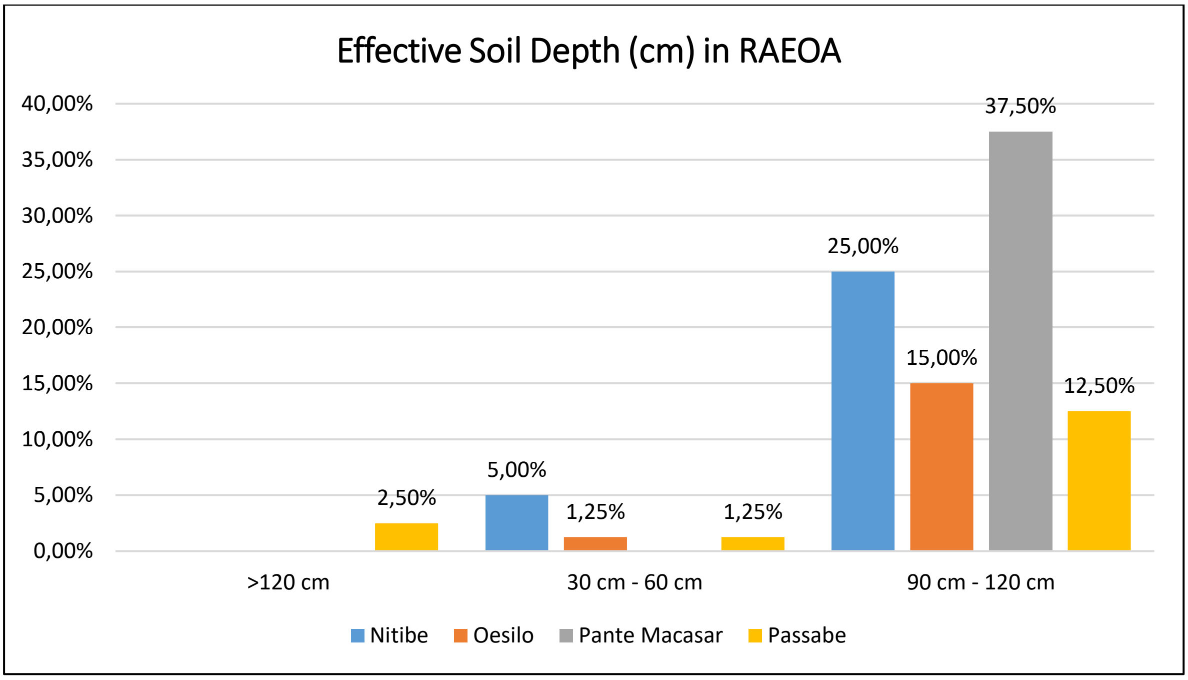


Figure 4.7 Effective Soil Depth (cm) Data in RAEOA

4.8 SURFACE ROCK

Surface rocks with a <5% category are most dominant in the Pante-Macassar Sub-Region. This indicates that most of the Pante-Macassar region has a surface relatively free of rocks, making it more suitable for intensive agricultural activities. The Nitibe Sub-Region also has a high proportion in the <5% category, reflecting land conditions that are relatively free of surface rocks. This is particularly favorable for the establishment and development of rice fields, as rice cultivation requires a flat surface, free from large rocks, and easy to cultivate. However, water conservation management is necessary to support crop water requirements.

On the other hand, the 15–40% surface rock category is most dominant in the Passabe Sub-Region and parts of Nitibe, indicating areas with a relatively high surface rock content. This condition can be an obstacle for conventional land cultivation, requiring a more adaptive approach in land-use planning. One potential solution is the use of deep-rooted plants, which can help stabilize the soil, reduce erosion risks, and utilize the gaps and spaces between the rocks (Vannoppen *et al.*, 2017). The distribution of surface rock percentages in RAEOA is presented in **Figure 4.8**.

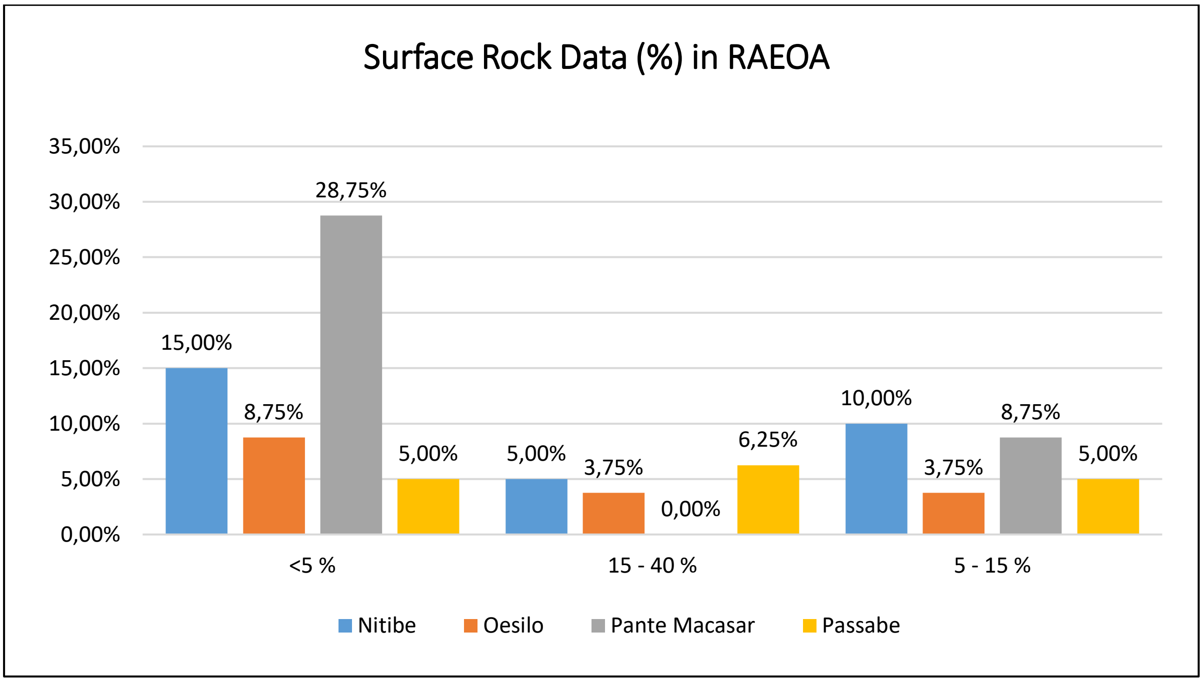


Figure 4.8 Surface Rock Data (%) in RAEOA

Surface rocks in the 5–15% category are relatively evenly distributed across all four Sub-Regions, indicating a transition zone between open land and rocky land. Regions with 5–15% surface rocks are categorized as moderate, and these areas are still suitable for various land uses, especially if managed with an adaptive approach.

This information is crucial for land-use planning and natural resource management. Areas with low surface rock content can be utilized for agriculture and settlements, while regions with high surface rock content are more suitable for conservation or infrastructure development aligned with local geological conditions. Therefore, further mapping of surface rock distribution can provide deeper insights to support sustainable development in RAEOA.

Figure 4.9 Surface Rocks in RAEOA
(Source: Researcher documentation, 2025)

4.9 ROCKS OUTCROPS

The RAEOA region exhibits varied rock outcrop categories, with the category of less than 5% being most dominant in the Pante-Macassar Sub-Region. This indicates a large area with very low rock outcrops, suggesting that most of the land is covered by soil or vegetation. This condition may make the area suitable for agricultural activities and settlement due to the more stable and easily cultivable surface. It also suggests that most areas in RAEOA have minimal rock outcrops. This could imply that the land surface is largely covered by vegetation or fine soil, which tends to be more stable and supportive of plant growth and agricultural activities.

The next category is 5–15%, with the highest percentages found in the Nitibe and Pante-Macassar Sub-Regions. This indicates that some areas have a moderate amount of rock outcrops, which may be related to specific geological conditions such as hill slopes or rocky regions. These areas likely have different characteristics in terms of soil drainage and land use. The distribution of moderate rock outcrops in these areas shows a mix of open land and rock structures, which could present technical challenges in land use, but it remains suitable for integrated farming systems or agroforestry.

For the 15–25% rock outcrop category, Passabe shows dominance. This condition suggests that a significant portion of Passabe has prominent geological characteristics, which must be considered in sustainable land-use planning. The presence of these rocks begins to influence land characteristics, and the area may be suitable for conservation or agroforestry activities, especially in slope areas or transition zones. Finally, the >25% category represents the smallest percentage, indicating that only a small portion of RAEOA has very high rock outcrops. Areas with high rock outcrop levels (>25%) typically have limitations for agricultural use. Therefore, a strategic approach based on conservation, along with forest integration, is essential for maintaining ecological balance and supporting sustainable land use. The rock outcrop data in RAEOA is presented in **Figure 4.10**.

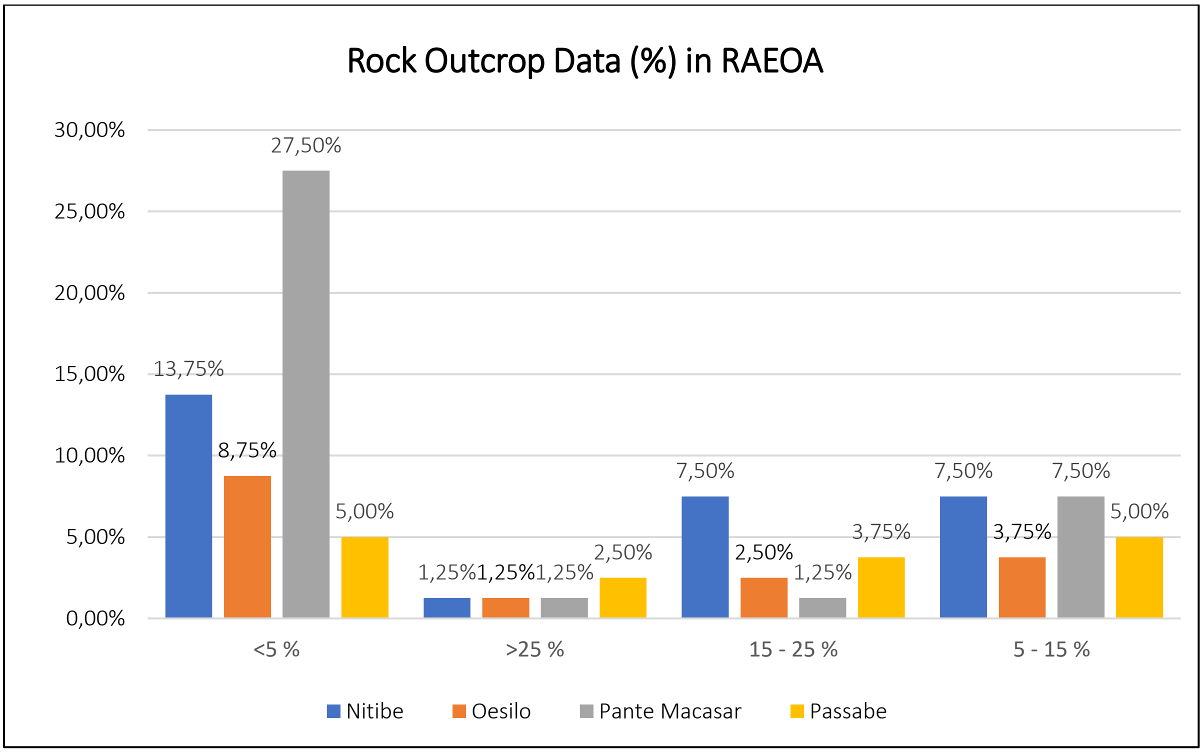


Figure 4.10 Rock Outcrop Data (%) in RAEOA

4.10 FLOOD HAZARD

Flooding is one of the most frequent natural disasters with widespread impacts on communities. In areas with high rainfall, soil texture that cannot optimally absorb water, steep slopes, and inadequate drainage systems can increase the risk of flooding. The flood hazard levels in RAEOA show that each Sub-Region has different levels of vulnerability to flooding threats.

The flood hazard categories used include: very low, low, moderate, high, very high, and no flood. The "no flood" category is most dominant in the Nitibe Sub-Region, indicating that most of the area in Nitibe is relatively safe from flood risks compared to other Sub-Regions. This is also linked to the good drainage conditions in the area. Drainage helps quickly and efficiently channel excess rainfall from the surface into drainage systems, preventing pooling and excessive surface runoff (Antaria, S., & Al Imran, H., 2025; Haribowo, R., 2022; Santoso, A.T., 2018).

In areas with high and very high flood hazard categories, such as Pante-Macassar and Nitibe Sub-Regions, the flood vulnerability is greater. This indicates that these regions require special attention in flood risk mitigation and management efforts. This is because drainage in these areas is dominated by systems that are somewhat functional or somewhat hindered. Drainage systems that are not functioning optimally or are obstructed can be major contributors to flooding. The flood hazard graph for RAEOA is presented in **Figure 4.11**.

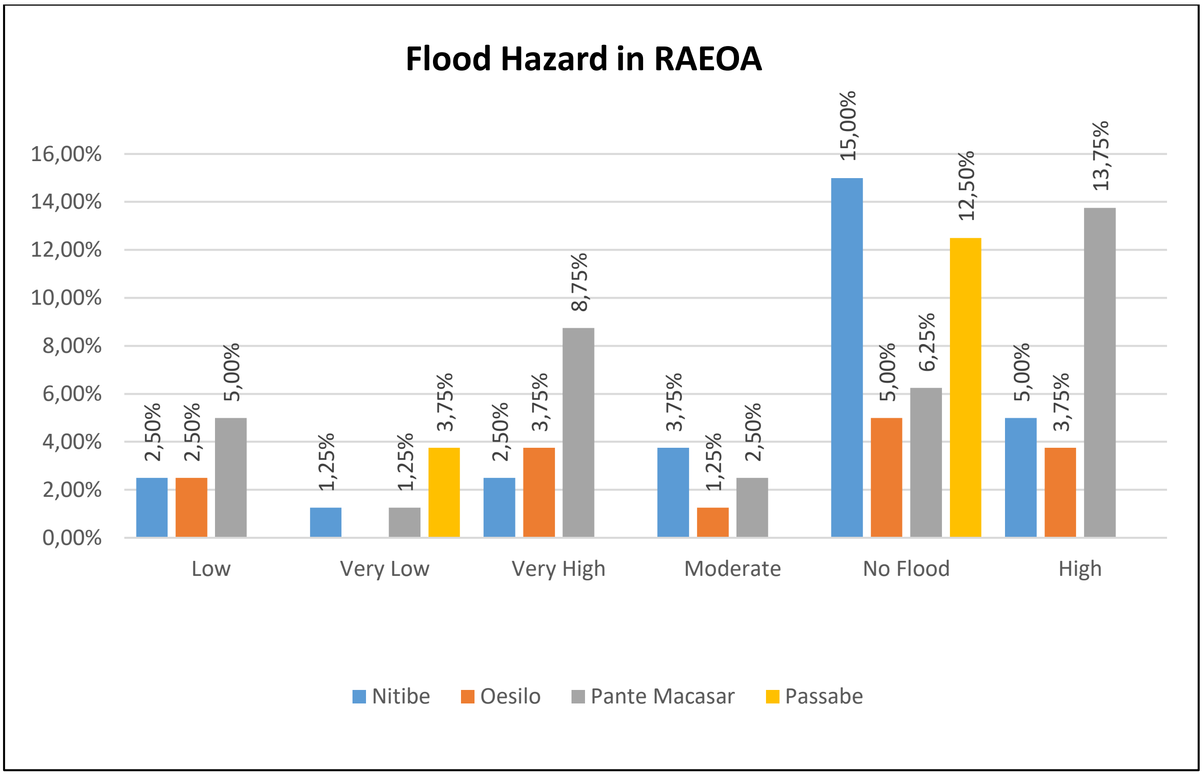
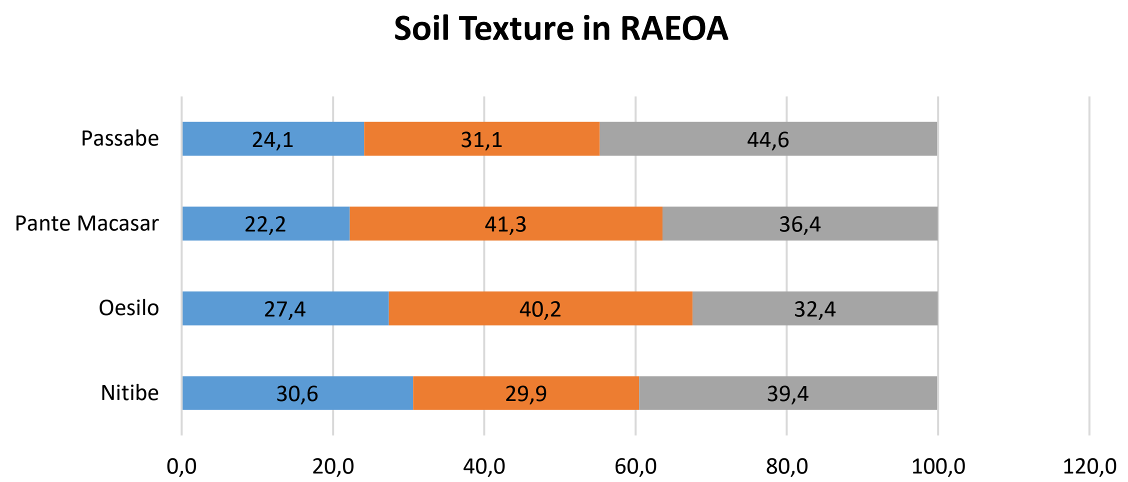


Figure 4.11 Flood Hazard Data in RAEOA

4.11 SOIL TEXTURE

Soil texture is one of the main components in land suitability evaluation because it directly affects infiltration, percolation, aeration, and fertilization efficiency. According to Hardjowigeno (1992), soil texture classification is based on the proportion of sand (2 mm–0.05 mm), silt (0.05 mm–0.002 mm), and clay (<0.002 mm), forming 12 primary texture classes. Setiawan and Arifin (2014) further emphasized that topographic characteristics, such as elevation and the Topographic Wetness Index (TWI), influence soil texture distribution. Areas with high TWI tend to accumulate fine particles like clay, while regions with steep slopes are richer in sand.

RAEOA exhibits a variety of soil textures, reflecting different geomorphological conditions and soil formation processes in each Sub-Region. In the Nitibe and Oesilo Sub-Regions, the soil is generally clayey with a dominant clay fraction compared to sand and silt. This texture tends to have high water retention but slow drainage and limited aeration. Such conditions can increase the risk of waterlogging and require adaptive water management strategies. Conversely, the Pante-Macassar and Passabe Sub-Regions are dominated by loam texture, which has a balanced composition of soil fractions (sand, silt, and clay). Loam soil is typically friable, has good water-holding capacity, and supports optimal root growth. This texture is more versatile for various land uses, including intensive agriculture and agroforestry. The soil texture data for RAEOA is presented in **Figure 4.12**.



	Nitibe	Oesilo	Pante Macasar	Passabe
🟦 Clay (%)	30,6	27,4	22,2	24,1
🟧 Silt(%)	29,9	40,2	41,3	31,1
⬜ Sand (%)	39,4	32,4	36,4	44,6

Figure 4.12 Soil Texture in RAEOA

4.12 pH

Soil pH is an important chemical parameter that indicates the level of acidity or alkalinity of the soil, ranging from 0 to 14. pH value plays a crucial role in determining nutrient availability, microorganism activity, and the suitability of land for plant growth. A study conducted by Santos & Barreto (2024) in Dili, Timor-Leste, identified surface soil pH variation between 5.3 and 6.1, which is categorized as slightly acidic and may limit land productivity, especially during the dry season. Thus, understanding soil pH is fundamental in land suitability evaluation, land-use planning, and implementing adaptive and sustainable land management strategies, particularly in Timor-Leste, which has ecological characteristics of advanced tropical soils.

In RAEOA, soil acidity (pH) varies across Sub-Regions, with values ranging from 6.81 to 7.80. The lowest pH value, 6.81, was recorded in the Passabe Sub-Region, while the highest value, 7.80, was found in Pante-Macassar. Oesilo's soil has a pH of 7.47, and Nitibe’s pH is 7.52. This pH range indicates that most of the soils in RAEOA are in conditions that support the availability of macronutrients such as nitrogen (N), phosphorus (P), and potassium (K). Soils with neutral to slightly alkaline pH generally have a stable cation exchange capacity (CEC) and do not experience extreme nutrient fixation. However, pH values above 7.5 can reduce the solubility of micronutrients such as Fe, Mn, and Zn, which should be considered in fertilization strategies. According to Harahap *et al.* (2021), soils with neutral to slightly alkaline pH have good agronomic potential but still require moisture and organic matter management to maintain nutrient balance. Kusuma and Yanti (2021) emphasized that soil moisture content also affects pH values and microbial activity, impacting overall soil fertility dynamics. Soil pH data for RAEOA is presented in **Figure 5.1 in Chapter 5 of this book.**

4.13 TOTAL NITROGEN

The availability of total nitrogen (N-total) in RAEOA is categorized as low to very low, with values ranging from 0.10% to 0.16%. The Oesilo and Passabe Sub-Regions show nitrogen levels of 0.16%, while Pante-Macassar and Nitibe record values of 0.11% and 0.10%, respectively. This reflects a significant limitation of nitrogen, which can directly impact crop productivity.

As an essential macronutrient, nitrogen plays a critical role in chlorophyll formation, protein synthesis, and vegetative tissue growth. When nitrogen is insufficient, plants tend to exhibit chlorosis, stunted growth, and reduced yields. Yuliani *et al.* (2017) emphasize that nitrogen availability is heavily influenced by soil characteristics and fertilization techniques. Soils with low organic matter content and high rainfall are prone to nutrient leaching, limiting nitrogen content. Nitrogen in the soil is stored in organic forms that are not directly available to plants. Mineralization is required to convert nitrogen into absorbable forms such as nitrate and ammonium. In RAEOA's soils, which are generally neutral to slightly alkaline, ammonium is more stable, but it remains vulnerable to leaching if soil structure is inadequate and water management is suboptimal.

A study by Da Costa (2023) on grasslands indicated that low total nitrogen levels of 0.11% are considered low. This reduced nitrogen content is associated with increased surface runoff due to excessive grazing, which leads to soil compaction and reduced porosity, thus enhancing nutrient leaching during the rainy season. Therefore, adaptive nutrient management strategies tailored to local conditions are necessary, such as precise nitrogen fertilization, improving organic matter, and crop rotation with legumes capable of nitrogen fixation. This approach is expected to increase nitrogen availability, improve soil structure, and support the sustainability of agricultural systems in RAEOA. The N-total content in RAEOA is presented in **Figure 4.12**.

4.14 AVAILABLE PHOSPHORUS

The available phosphorus (P-available) content in RAEOA is classified as very low, ranging from 0.99 ppm to 1.60 ppm. The Passabe Sub-Region recorded the highest value of 1.60 ppm, followed by Oesilo (1.57 ppm), Pante-Macassar (1.15 ppm), and Nitibe with the lowest value of 0.99 ppm. This distribution indicates the limited phosphorus availability for plant uptake across RAEOA.

Phosphorus is an essential macronutrient for root growth, cell division, and plant generative development. However, although total phosphorus in the soil may be sufficient, the available form is often very limited. This is due to the adsorption of phosphate by clay particles, aluminum (Al), iron (Fe), and allophane, especially in Andosol soils (Sari *et al.*, 2017). In acidic soils, the solubility of Al and Fe increases, strengthening phosphate bonds and inhibiting its availability (Tan, 1995). Conversely, in soils with high pH, phosphorus tends to bind with calcium (Ca) and magnesium (Mg), forming less soluble phosphate compounds (Alwi *et al.*, 2023).

In addition to soil chemical factors, land management activities also affect phosphorus dynamics. A study by Da Costa (2023) in Luro, Timor-Leste, showed that available phosphorus levels varied due to free grazing during the dry season. This activity led to soil compaction, reduced organic matter, and soil structure degradation, resulting in decreased land productivity. Matima *et al.* (2010) reported that excessive grazing can increase soil pH and accelerate the loss of macronutrients, including phosphorus, through organic matter reduction and disruption of nutrient cycles. The available phosphorus content in RAEOA is presented in **Figure 4.12.**

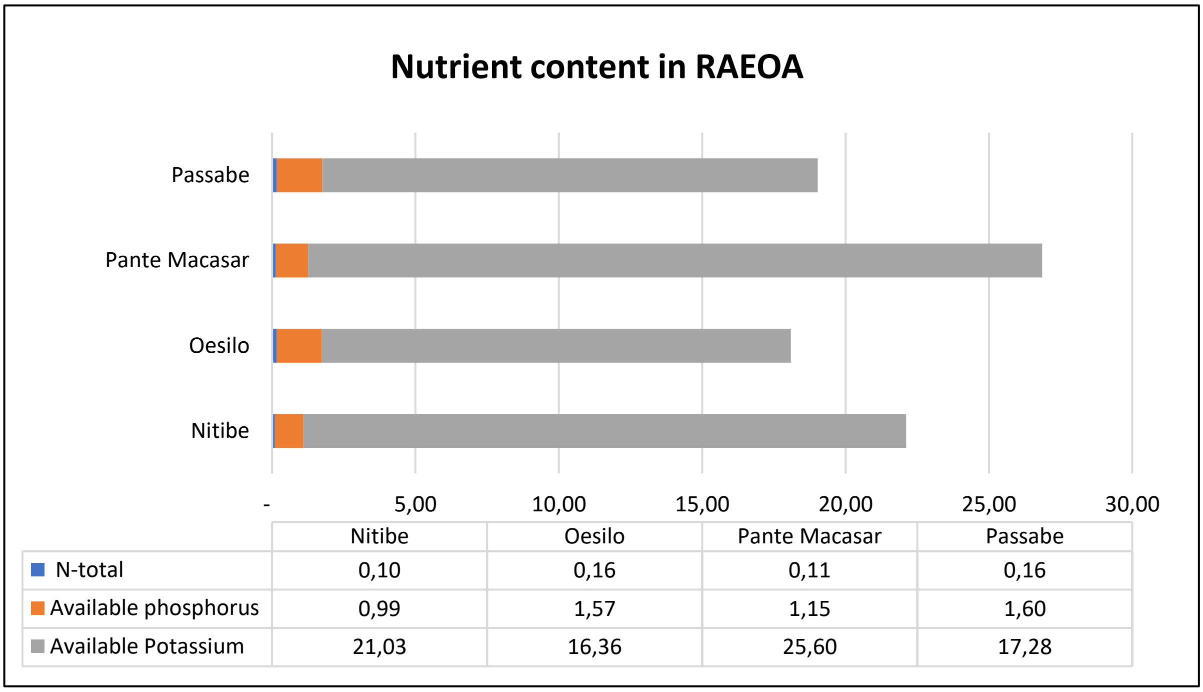
4.15 AVAILABLE POTTASIUM

Potassium (K) is a macronutrient that plays a critical role in plant physiological functions, including osmotic pressure regulation, enzyme activation, protein synthesis, and the distribution of water and nutrients. Potassium deficiency can lead to characteristic symptoms such as necrosis on the edges of older leaves, inhibited root growth, weak stems, and reduced yields. Soils with low available potassium levels typically have low cation exchange capacity (CEC) and are prone to leaching, whereas soils with high CEC and dominance of active clay minerals tend to retain potassium better (Camila *et al.*, 2023).

In Timor-Leste, fluctuations in surface soil potassium levels in the Dili region have a significant impact on local soil fertility and productivity (Santos & Barreto, 2024). This underscores the importance of adaptive management of available potassium, especially in wet tropical areas that are at high risk of nutrient leaching.

In RAEOA, available potassium status is classified as low to moderate. The Pante-Macassar and Nitibe Sub-Region show moderate potassium levels, with values of 25.60 me/100g and 21.03 me/100g, respectively, while Passabe and Oesilo fall into the low category with values of 17.28 me/100g and 16.36 me/100g, respectively. This variation reflects differences in soil capacity to supply potassium, which directly impacts fertilization effectiveness and land productivity.

Batubara *et al.* (2024) emphasized that soil potassium status is heavily influenced by soil physical and chemical characteristics, especially soil texture, CEC, and organic matter content. Clayey soils with adequate organic content tend to have better potassium retention. Additionally, Punuindoong *et al.* (2022) indicated that potassium distribution is also affected by topographic position and soil depth. On flat lands, potassium levels tend to be lower due to leaching and erosion, whereas in, sloped areas, nutrient accumulation can occur locally. The available potassium content in RAEOA is presented in **Figure 4.13.**



	Nitibe	Oesilo	Pante Macasar	Passabe
🟦 N-total	0,10	0,16	0,11	0,16
🟧 Available phosphorus	0,99	1,57	1,15	1,60
⬜ Available Potassium	21,03	16,36	25,60	17,28

Figure 4.13 Nutrients Content Data in RAEOA

4.16 SALINITY / TOXICITY

Soil salinity refers to the concentration of dissolved salts that affects soil structure, permeability, and pH. In intensive agricultural lands, increased salinity is often caused by the accumulation of fertilizers, pesticides, and land management practices (Novi *et al.*, 2016). This condition increases osmotic pressure in the root zone, hindering water and nutrient uptake, and can lead to plant wilting, even when water is available. Saline soils also experience physical degradation, such as the breakdown of aggregates and reduced aeration. The dominance of sodium ions (Na^+) can replace essential nutrient ions such as calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^+), thereby decreasing the availability of these critical nutrients.

In RAEOA, salinity levels are generally safe for cultivation. The Passabe Sub-Region has a very low value of 0.97 dS/m, while Pante-Macassar, Oesilo, and Nitibe record values of 1.35 dS/m, 1.04 dS/m, and 1.00 dS/m, respectively, which are classified as low. According to Rahayu *et al.* (2025), soils with electrical conductivity below 2 dS/m do not pose significant saline stress. Idwar *et al.* (2025) state that regions with high rainfall and good drainage tend to undergo natural leaching, which is effective in lowering salt concentrations in the upper soil layers. The salinity content in RAEOA is presented **in Figure 5.1 in Chapter 5** of this book.

V. SOIL FERTILITY

Soil fertility refers to the soil’s capacity to supply nutrients and water, as well as to provide chemical conditions that support optimal plant growth. The level of soil fertility is evaluated using several key chemical parameters, including cation exchange capacity (CEC), base saturation, soil organic carbon (SOC), Total Phosphorus, and Total Potassium.

5.1 CATION EXCHANGE CAPACITY (CEC)

Cation Exchange Capacity (CEC) is a crucial indicator in determining soil fertility, as it reflects the soil's ability to absorb and retain essential nutrient cations such as potassium (K+), calcium (Ca^{2+}), and magnesium (Mg^{2+}). In tropical regions like the RAEOA, CEC is influenced by the clay mineral composition, organic matter content, and soil pH. Soils with higher clay and organic matter content have a greater negative charge, allowing them to bind more cations and increase the CEC value (Costa *et al.*, 2020). Effective strategies to improve CEC include adding organic materials such as compost, manure, and biochar, as well as employing conservation techniques such as terracing and minimal tillage. Biochar, in particular, has a high exchange capacity and can improve soil structure, making it effective for increasing CEC in tropical soils (Domingues *et al.*, 2020).

Soil analysis in the ***Região Administrativa Especial de Oé-Cusse Ambeno* (RAEOA)** shows high to very high CEC values. The Oesilo Sub-Region has a CEC of 28.05 me/100g, categorized as high, followed by Pante Macasar and Nitibe. The Passabe Sub-Region recorded the highest value at 42.12 me/100g, which falls into the very high category. This indicates that the soils in RAEOA have significant potential to support plant growth through efficient nutrient absorption. The CEC data for RAEOA is presented in **Figure 5.1**.

5.2 BASE SATURATION (BS)

Base saturation (BS) represents the percentage of the cation exchange capacity (CEC) occupied by base cations such as Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}. This value is an important indicator in assessing soil fertility. In tropical regions, CEC tends to be low due to the dominance of kaolinite minerals, but BS remains high when base cations dominate the soil charge (Costa *et al.*, 2020; McLaren & Cameron, 1996). High BS reflects fertile soils with relatively neutral pH and good nutrient availability. In contrast, low BS indicates dominance of acidic ions like H^+ or Al^{3+}, which can inhibit plant growth. Factors influencing BS include organic matter content, clay mineral type, and soil pH.

Analysis of RAEOA soils shows that BS is very high, ranging from 95.89% to 99.60%, with the lowest value in Passabe and the highest in Pante Macasar. This condition supports fertilization efficiency, soil biological activity, and land productivity.

To maintain optimal BS, soil management practices are needed, including the addition of organic matter, liming to stabilize pH, and the use of fertilizers containing base cations. Conservation practices and crop rotation are also important to sustain the chemical balance of the soil. The base saturation data for RAEOA is presented in the subsequent section.

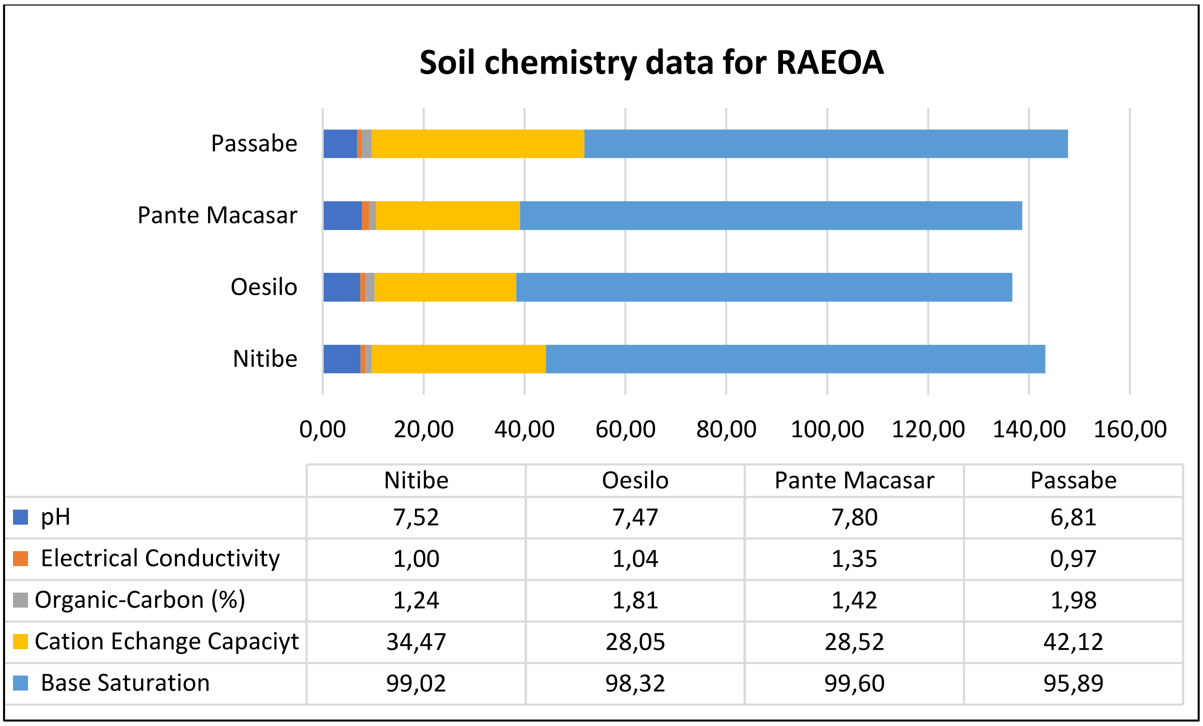
5.3 SOIL ORGANIC CARBON

Soil organic carbon (C-organic) is an important indicator of soil fertility and ecosystem health, as it plays a key role in improving soil structure, increasing cation exchange capacity (CEC), and maintaining moisture levels and microbial activity.

Laboratory analysis shows that soils in RAEOA have low C-organic content, ranging from 1.24% to 1.98%. The Nitibe Sub-Region recorded the lowest value at 1.24%, while the Passabe Sub-Regionhad the highest at 1.98%. This range is still below the ideal threshold for productive tropical soils, indicating a need for interventions to improve the quality of organic matter in the soil.

Factors influencing the low C-organic content in RAEOA include the tropical climate, which accelerates the decomposition of organic material, limited organic inputs from agricultural activities, and the dominance of clay minerals with low CEC, such as kaolinite. To address this, soil management strategies are needed, including the addition of organic materials (compost, manure, biochar), liming to neutralize acidity, and implementing conservation farming systems such as crop rotation and cover cropping.

These measures can gradually increase C-organic content, improve soil physical and chemical properties, and support sustainable agricultural productivity in RAEOA. The organic carbon content data for RAEOA is presented in **Figure 5.1**.



	Nitibe	Oesilo	Pante Macasar	Passabe
🟦 pH	7,52	7,47	7,80	6,81
🟧 Electrical Conductivity	1,00	1,04	1,35	0,97
⬜ Organic-Carbon (%)	1,24	1,81	1,42	1,98
🟨 Cation Echange Capaciyt	34,47	28,05	28,52	42,12
🟦 Base Saturation	99,02	98,32	99,60	95,89

Figure 5.1 Soil Chemistry Data in RAEOA

5.4 TOTAL PHOSPHORUS

Total phosphorus (P-total) is an important soil fertility indicator that supports energy formation, root growth, and organic compound synthesis. Its availability is influenced by soil texture, organic matter, and the content of iron and aluminum oxides, which cause phosphorus to be bound in insoluble forms (Sanchez, 2019).

Laboratory analysis shows that soils in RAEOA have moderate to very high P-total content, ranging from 36.48 mg/100g to 67.29 mg/100g. The Oesilo Sub-Region has the lowest value at 36.48 mg/100g, categorized as moderate. Pante Macasar and Nitibe are in the high category, while Passabe records the highest value of 67.29 mg/100g, which is considered very high. According to Sulastri *et al.* (2019), soils with P-total content above 50 mg/100g can be classified as high to very high. High phosphorus content has the potential to promote plant growth, but its effectiveness still depends on the availability of soluble phosphorus and the soil’s environmental conditions.

The high P-total content, particularly in Passabe, can be linked to organic matter accumulation, low leaching, and the possible input of phosphates from agricultural activities or phosphate rock weathering. In contrast, locations with moderate values like Oesilo may be influenced by lighter soil textures or high weathering levels. Optimization of phosphorus can be achieved through soil pH management via liming, organic matter addition, and selecting appropriate phosphate fertilizers based on soil characteristics (Tiessen *et al.*, 2014). The total phosphorus content in RAEOA is presented in **Figure 5.2.**

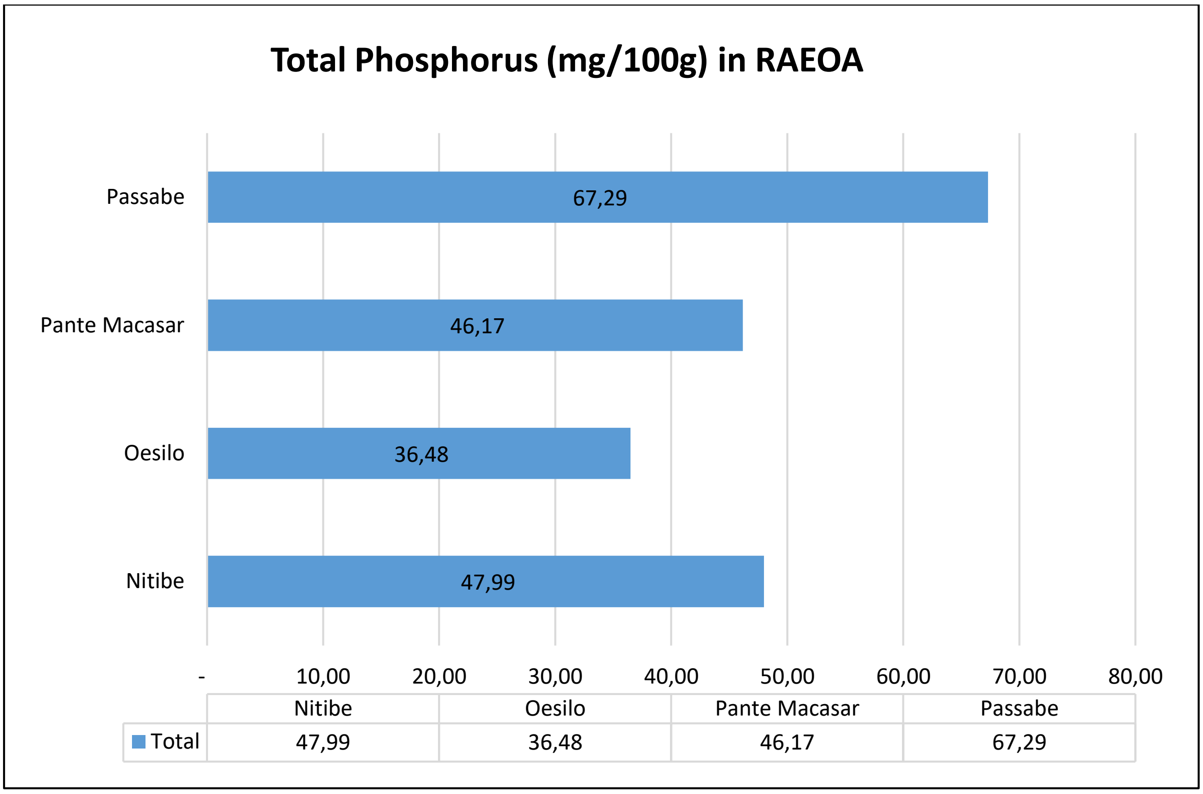


Figure 5.2 Total Phosphorus in RAEOA

5.5 TOTAL POTTASIUM

Total potassium reflects the overall amount of potassium in the soil, including both soluble forms and those bound to clay minerals and organic matter. This content is influenced by the weathering of parent rock, land use type, and biological activity. In Timor-Leste, potassium levels are generally categorized as moderate due to the dry tropical climate and traditional farming practices with minimal potassium fertilizer use (Soares *et al.*, 2019)

Soil analysis in RAEOA indicates very high K-total levels, ranging from 70.37 mg/100g to 138.92 mg/100g. The Oesilo Sub-Region recorded the lowest value of 70.37 mg/100g, followed by Passabe and Nitibe. The Pante Macasar Sub-Regionshowed the highest value at 138.92 mg/100g. According to Sari *et al.* (2020), soils with K-total content above 60 mg/100g are classified as high to very high. The high potassium content in Pante Macasar is suspected to result from the dominance of primary minerals and low leaching, while the lower values in Oesilo may be influenced by intensive weathering and light soil texture.

Optimizing K-total can be achieved through organic fertilization (compost and manure), appropriate use of potassium mineral fertilizers, and soil conservation techniques such as cover cropping and mulching. Adding organic matter also improves the soil's ability to retain potassium through clay colloid binding (Lima *et al.*, 2020). The K-total content in RAEOA is presented in **Figure 5.3.**

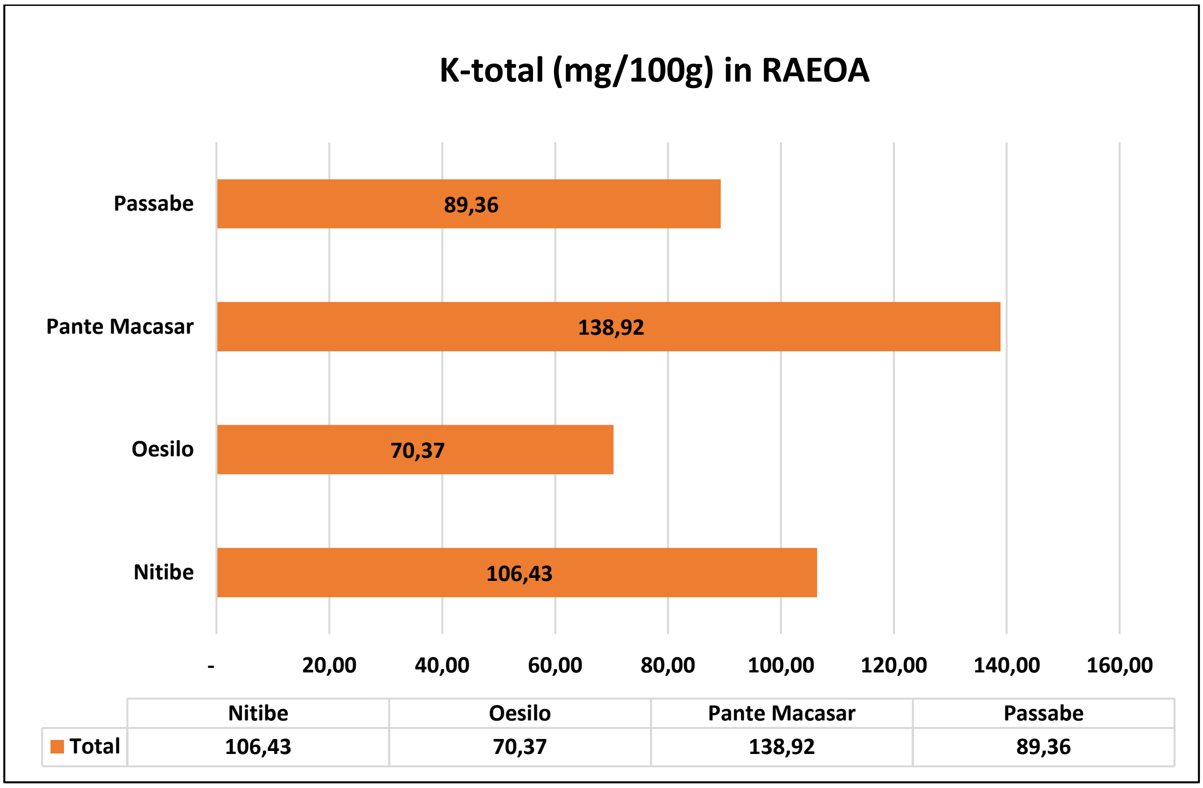


Figure 5. 3 Total Potassium in RAEOA

5.6 TOTAL ZINC

Total Zinc reflects the total amount of zinc in the soil, both available and chemically bound. In RAEOA, soils derived from weathered limestone and clay generally exhibit high weathering rates and low organic matter content, causing most of the zinc to be bound to clay minerals, iron oxides, and aluminum. This condition results in low zinc availability for plants. In highly weathered tropical soils like those in Timor, around 65–80% of zinc is in an insoluble form due to binding with oxide and silicate fractions (Ferreira *et al.*, 2023). A study by Costa *et al.* (2022) in the sloping agricultural areas of Timor-Leste showed that the shifting cultivation system (slash and burn) contributes to soil degradation and a reduction in Zn-total levels, particularly in sloped and rocky landscapes like those found in RAEOA.

Laboratory analysis shows that soils in the ***Região Administrativa Especial de Oé-Cusse Ambeno*** **(RAEOA)** have Zn-total content ranging from 61.68 ppm to 75.39 ppm. The Nitibe Sub-Regionrecorded the lowest value at 61.68 ppm, followed by Passabe and Pante Macasar. Meanwhile, the highest value was again found in Nitibe, at 75.39 ppm, indicating spatial variation within the same administrative area.

Increasing zinc availability can be achieved through the application of organic materials (compost, manure, biochar), the use of Zn fertilizers such as $ZnSO_4$, and mycorrhizal inoculation. Managing soil pH to remain neutral to slightly acidic is also crucial to prevent zinc from precipitating in insoluble forms. The Zn-total content in RAEOA is presented in **Figure 5.4.**

5.7 AVAILABLE ZINC

Zn-available is the fraction of zinc in the soil that is soluble in water or exchangeable, meaning it can be directly absorbed by plant roots. This micronutrient plays a vital role in various plant metabolic processes, such as hormone formation (auxin), protein synthesis, and enzyme activity. Even though the total Zn content in soil may be high, available zinc can still be low because zinc bound to clay minerals or organic matter is difficult to dissolve and cannot be utilized by plants.

Laboratory analysis shows that the available Zn content in the ***Região Administrativa Especial de Oé-Cusse Ambeno*** **(RAEOA)** ranges from 0.45 ppm to 0.82 ppm. The Nitibe Sub-Region recorded the lowest value of 0.45 ppm, while the Oesilo Sub-Region showed the highest value of 0.82 ppm. This range reflects spatial variation influenced by soil characteristics, land use, and weathering levels.

High zinc content can reduce phosphorus availability due to the formation of insoluble Zn-P complexes, especially in soils with high pH, light texture, and excess phosphorus content (Barber, 1995). Conversely, Zn-available levels can increase due to excessive zinc fertilization, heavy metal contamination, or acidic soil conditions that accelerate the dissolution of metals. The available zinc content in RAEOA soils is presented in **Figure 5.4**.

5.8 TOTAL SULFUR

Sulfur is a secondary macronutrient that plays a critical role in amino acid synthesis and supports plant enzyme activity. In the soil, sulfur exists in both organic and inorganic forms, with a dominance in the organic fraction (Brady & Weil, 2008). The total sulfur content (S-total) includes both forms of sulfur.

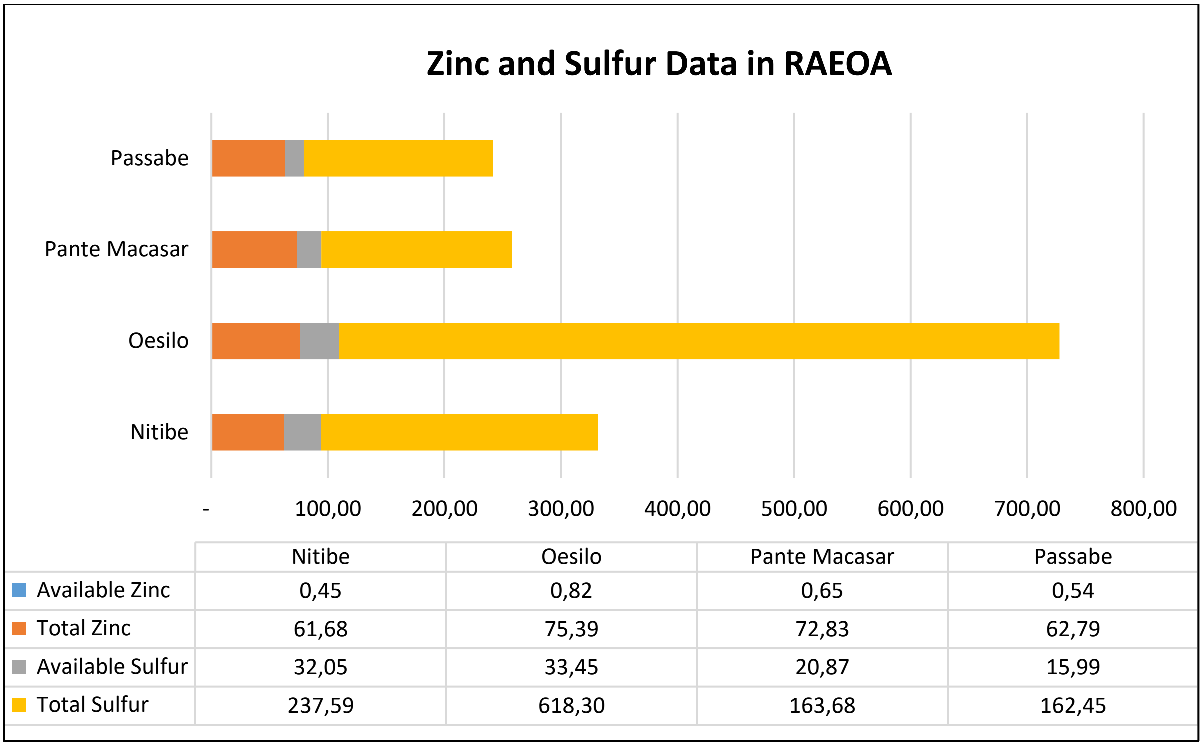
The analysis results show that soils in the Região Administrativa Especial de Oé-Cusse Ambeno (RAEOA) have S-total content ranging from 162.45 ppm to 618.30 ppm. The Passabe Sub-Region recorded the lowest value, while the Oesilo Sub-Regionshowed the highest value. This variation reflects differences in soil conditions, such as organic matter accumulation, weathering levels, and microbial activity.

Low sulfur levels are typically found in soils that are poor in organic matter and have undergone repeated chemical fertilization without the addition of organic materials. In contrast, higher sulfur levels are generally found in soils with high organic matter accumulation, such as peat soils or poorly drained areas. However, excessive sulfur in the form of sulfates can interfere with the absorption of other nutrients and increase soil acidity. The data on S-total content is presented in **Figure 5.4.**

5.9 AVAILABLE SULFUR

Available sulfur (S-available) is the portion of total sulfur that has undergone mineralization from organic matter, making it present in the form of sulfate (SO_4^{2-}), which can be absorbed by plants. This content serves as a direct indicator of soil fertility concerning sulfur nutrients, which play an essential role in protein synthesis and enzyme formation in plants. The mineralization process is influenced by the organic matter content of the soil. The higher the organic matter content, the greater the potential for sulfur to be released in a form available to plants. According to Widijanto *et al.* (2011), organic matter decomposition produces organic sulfur compounds that are then converted into inorganic forms through microbial activity in the soil.

In RAEOA, the concentration of S-available shows significant spatial variation, ranging from 15.09 ppm to 33.45 ppm. The Passabe Sub-Regionrecorded the lowest value, while the Oesilo Sub-Region showed the highest value. These differences reflect variations in soil conditions and land management practices at each location. High S-available levels are often the result of excessive and repeated sulfur fertilization without prior soil analysis. In contrast, low levels are often linked to low organic matter, limited sulfur fertilization, and topographical conditions such as steep slopes, which accelerate erosion and nutrient leaching. These factors collectively affect the availability of sulfur for plants. The S-available content data is presented in **Figure 5.4.**



	Nitibe	Oesilo	Pante Macasar	Passabe
🟦 Available Zinc	0,45	0,82	0,65	0,54
🟧 Total Zinc	61,68	75,39	72,83	62,79
◼ Available Sulfur	32,05	33,45	20,87	15,99
🟨 Total Sulfur	237,59	618,30	163,68	162,45

Figure 5.4 Zinc and Sulfur Data in RAEOA

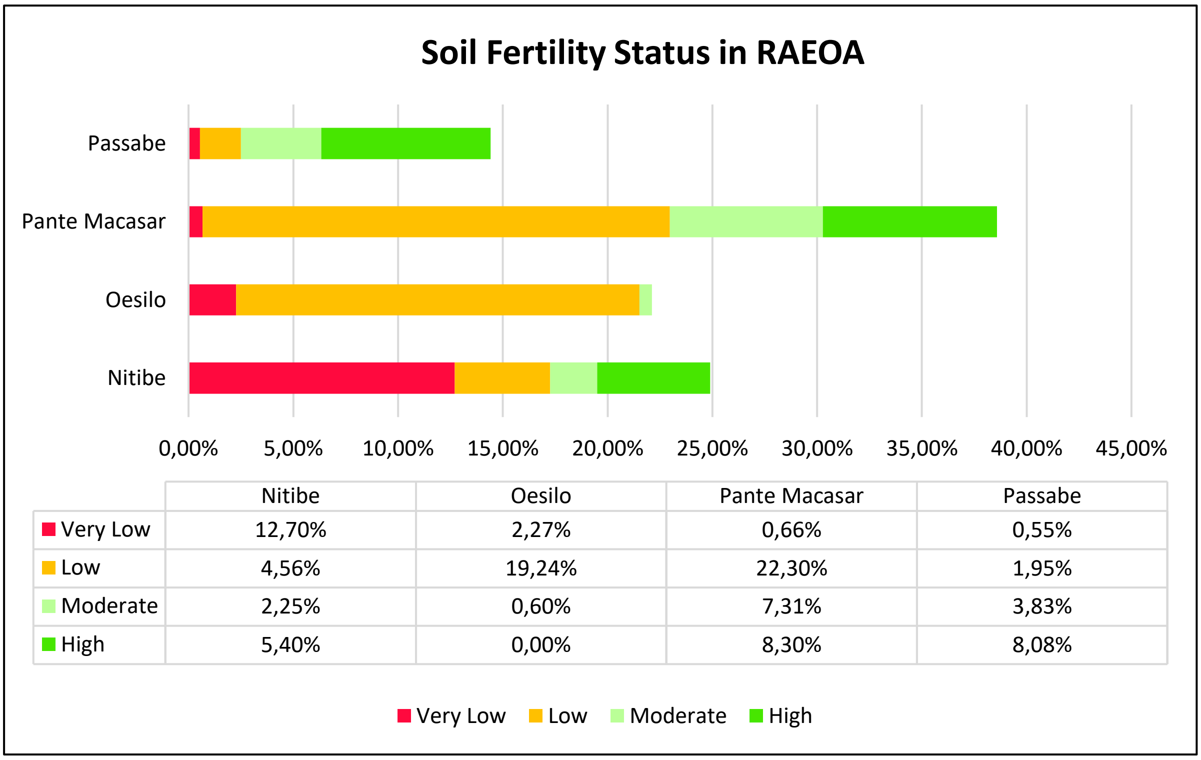
5.10 SOIL FERTILITY STATUS

Laboratory analysis of the soil in the ***Região Administrativa Especial Oecussi-Ambeno*** (RAEOA) region indicates that most of the land has low fertility (**Figure 5.5**), and the soil fertility map is presented in **Figure 5.6.** The area with low fertility covers 391.00 km², or about 48.06% of the total area. On the other hand, land with high fertility accounts for 177.18 km² (21.78%), very low fertility is found in 131.64 km² (16.18%), and moderate fertility covers 113.81 km² (13.99%). This distribution reflects the agronomic challenges that need to be addressed strategically to support agricultural productivity in the region.

Spatially, the distribution of soil fertility across Sub-Region shows different characteristics. The Nitibe Sub-Region is dominated by land with very low fertility, covering 103.34 km² or 12.70% of the total RAEOA area. The Oesilo and Pante Macasar Sub-Region each have the largest proportion in the low fertility category, with areas of 156.58 km² (19.24%) and 181.47 km² (22.30%), respectively. Meanwhile, the Passabe Sub-Region has the highest fertility status, with 65.73 km² or 8.08%.

Soil fertility status assessment is based on several chemical parameters that serve as indicators of the soil's capacity to provide nutrients for plants. These parameters include soil pH, cation exchange capacity (CEC), base saturation (BS), organic carbon content, and the levels of phosphate (P_2O_5) and potassium (K_2O). In addition to chemical factors, steep topography accelerates erosion and nutrient leaching, especially in land that is not managed conservatively. Agricultural practices that are not based on soil analysis also contribute to soil degradation, as fertilization is often done inappropriately and imbalanced. This reinforces the urgency of applying data-driven approaches for more effective land management.

To increase land productivity sustainably, an agroecological zoning-based approach is necessary, considering soil characteristics and local environmental conditions. This strategy includes systematically mapping soil fertility, applying soil conservation techniques, and using fertilizers tailored to the specific needs of the location. This approach is considered effective in supporting adaptive and sustainable agricultural systems in the RAEOA region.



	Nitibe	Oesilo	Pante Macasar	Passabe
🟥 Very Low	12,70%	2,27%	0,66%	0,55%
🟧 Low	4,56%	19,24%	22,30%	1,95%
🟩 Moderate	2,25%	0,60%	7,31%	3,83%
🟩 High	5,40%	0,00%	8,30%	8,08%

Figure 5.5 Soil Fertility Status in RAEOA

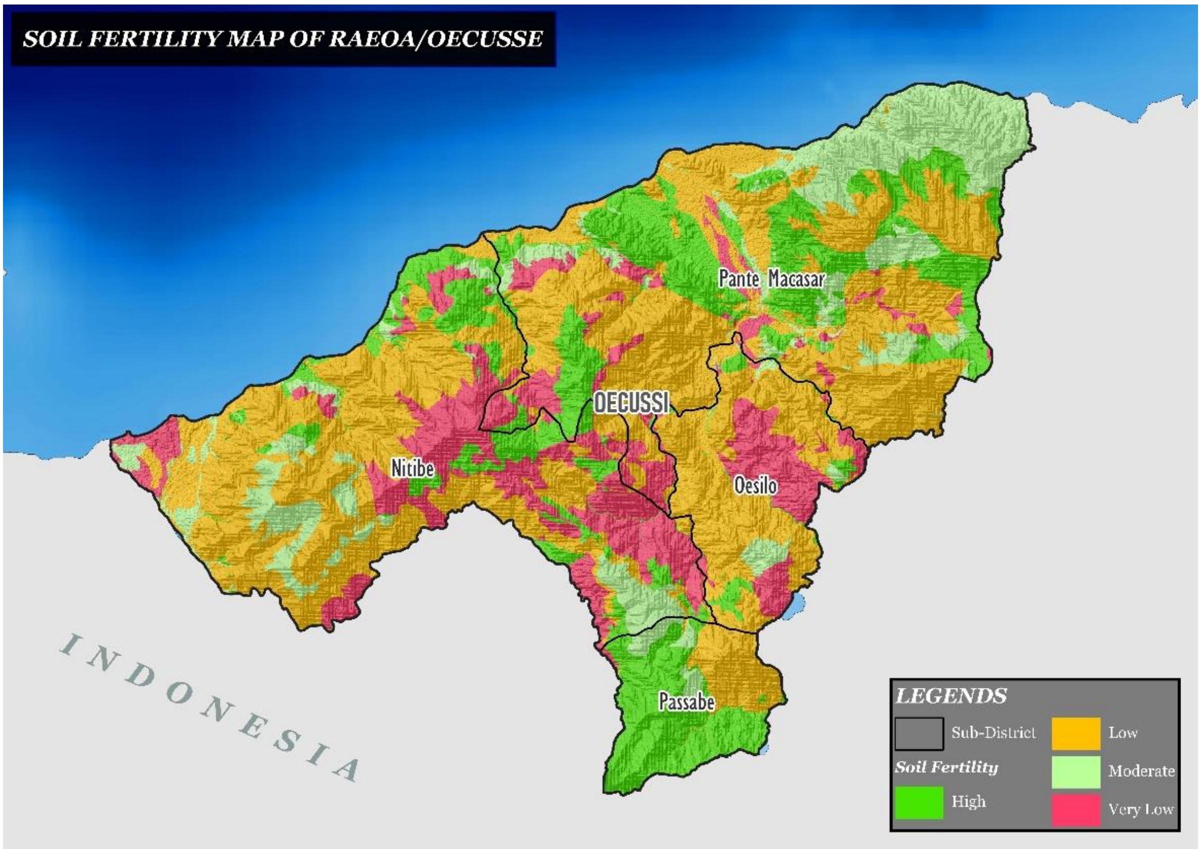


Figure 5.6 Soil Fertility Status Map of RAEOA

VI. EROSION AND CONSERVATION

6.1 SOIL EROSION

Soil erosion analysis plays an important role in land suitability evaluation, particularly for the development of agricultural commodities. Soil erosion not only affects land productivity but also impacts ecosystem sustainability, environmental degradation, and the loss of soil’s ability to retain nutrients and water. In the context of agricultural land management, erosion analysis serves as the foundation for designing appropriate soil conservation strategies to mitigate negative impacts and maintain land-use sustainability.

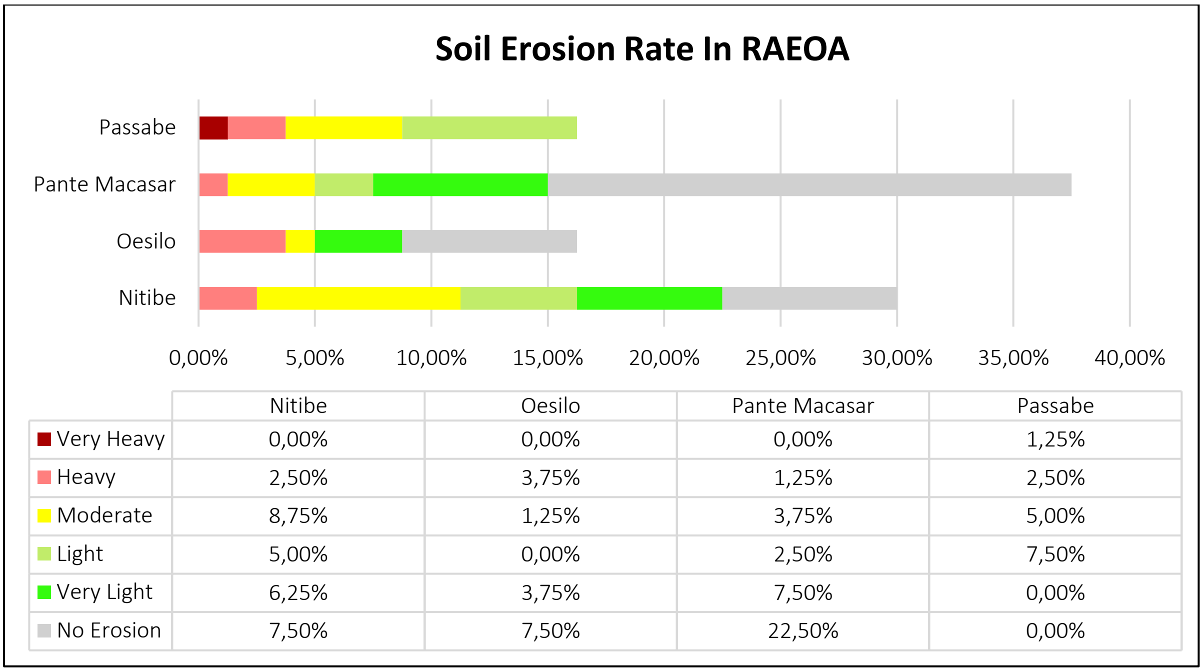
According to the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1978), soil erosion is influenced by several key factors, including rainfall erosivity, soil erodibility, slope length and steepness, vegetation cover, and land management practices. In Timor-Leste, many of these factors exhibit characteristics that contribute to high erosion rates. The topography, dominated by steep slopes, low land conservation levels, unstable soil structure due to geological influences, and minimal vegetation cover, are the main factors accelerating erosion rates. As stated by Morgan (2005), uncontrolled soil erosion can lead to the loss of the topsoil layer, which is the most fertile component of the soil, thus limiting its productivity capacity.

Região Administrativa Especial de Oé-Cusse Ambeno (RAEOA) experiences varying levels of erosion, ranging from very light to very severe. The Pante Macassar Sub-Region has very light erosion, primarily due to the flat terrain. Flat land is typically more stable, but erosion can increase quickly when the slope exceeds 2%-5%. At a 10% slope, erosion can increase up to eight times, and at a 15% slope, it increases further (Anthony, 2001). This is illustrated in Figure 6.1. On the other hand, the Passabe Sub-Region is categorized as having very severe erosion. This area is dominated by Inceptisols, which are highly susceptible to erosion. Inceptisols have various soil structures, such as blocky, granular, and massive, which are prone to rainwater erosion. These soils are also clay-rich, with low water absorption capacity and low permeability (Surono *et al.*, 2013; Suripin, 2001).

In addition to slope, soil type plays a crucial role in determining erosion levels in the area. The Oesilo Sub-Region is predominantly composed of

Inceptisols and Entisols, as discussed in **Chapter 2 of this book**. Both of these soil types are highly prone to erosion. Inceptisols have blocky, granular, and massive structures that are easily eroded by water, coupled with their clay texture, which poorly absorbs water, further increasing the risk of erosion. Meanwhile, Entisols, which are newly developed soils with a dominant sandy texture and low aggregation, are very vulnerable to erosion, as noted by Andrieni *et al.* (2022) and Chapparo *et al.* (2020).

The erosion data for RAEOA is presented in **Figure 6.1,** and the distribution map of soil erosion levels in RAEOA is shown in **Figure 6.2.**



	Nitibe	Oesilo	Pante Macasar	Passabe
🟥 Very Heavy	0,00%	0,00%	0,00%	1,25%
🟥 Heavy	2,50%	3,75%	1,25%	2,50%
🟨 Moderate	8,75%	1,25%	3,75%	5,00%
🟩 Light	5,00%	0,00%	2,50%	7,50%
🟩 Very Light	6,25%	3,75%	7,50%	0,00%
⬜ No Erosion	7,50%	7,50%	22,50%	0,00%

Figure 6.1 Soil Erosion Levels of RAEOA

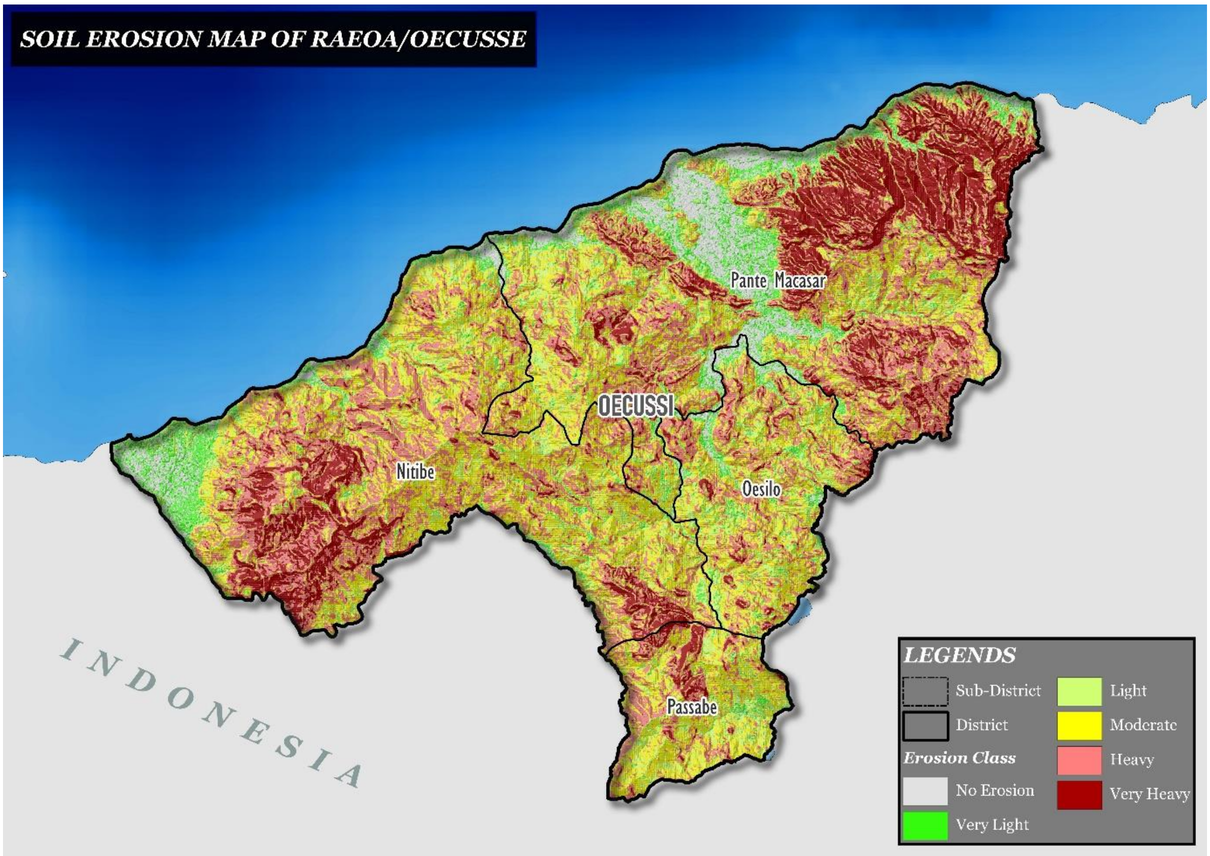


Figure 6.2 Soil Erosion Map of RAEOA

6.2 SOIL AND WATER CONSERVATION

Conservation is the long-term management of natural resources aimed at maintaining land quality and productivity. Conservation plays a crucial role in protecting soil from degradation, rehabilitating degraded soils, and increasing infiltration while maintaining soil fertility.

Conservation in RAEOA is primarily based on slope gradients, which are closely related to erosion potential, ranging from very light to very severe. Land with slopes between 15% and >45% is considered highly vulnerable to erosion and thus requires appropriate conservation management to prevent land degradation. According to the slope classification, RAEOA consists of slope classes of 0–8%, 8–15%, 15–25%, 25–45%, and >45%, which are evenly distributed across all Sub-Region. The areas with slopes greater than 45% are most extensive in the Pante Macassar Sub-Region, covering 7,775 ha, or about 9.56% of the total area of the Sub-Region. Land with such steep slopes has limitations in terms of use and is recommended only for the cultivation of perennial crops or the development of systems that can minimize soil erosion, such as agroforestry systems. The slope class data for RAEOA is presented in **Table 6.1**, and the slope gradient map for RAEOA is presented in **Figure 6.3**.

Table 6.1 The slope class data for RAEOA

Sub-Region	Slope	Class Potential	Area (ha)	Area (%)
Nitibe	>45%	Agroforestry	3.531	4,34
Nitibe	0-8%	Highly Potential	3.194	3,93
Nitibe	15-25%	Moderately Potential	9.529	11,72
Nitibe	25-45%	Agroforestry	10.164	12,50
Nitibe	8-15%	Potential	3.595	4,42
Oesilo	>45%	Agroforestry	520	0,64
Oesilo	0-8%	Highly Potential	1.133	1,39
Oesilo	15-25%	Moderately Potential	3.432	4,22
Oesilo	25-45%	Agroforestry	2.891	3,56
Oesilo	8-15%	Potential	1.712	2,11
Pante Macassar	>45%	Agroforestry	7.775	9,56
Pante Macassar	0-8%	Highly Potential	6.482	7,97
Pante Macassar	15-25%	Moderately Potential	7.641	9,40
Pante Macassar	25-45%	Agroforestry	9.914	12,19
Pante Macassar	8-15%	Potential	3.743	4,60
Passabe	>45%	Agroforestry	473	0,58
Passabe	0-8%	Highly Potential	244	0,30
Passabe	15-25%	Moderately Potential	2.573	3,16
Passabe	25-45%	Agroforestry	1.615	1,99
Passabe	8-15%	Potential	1.143	1,41

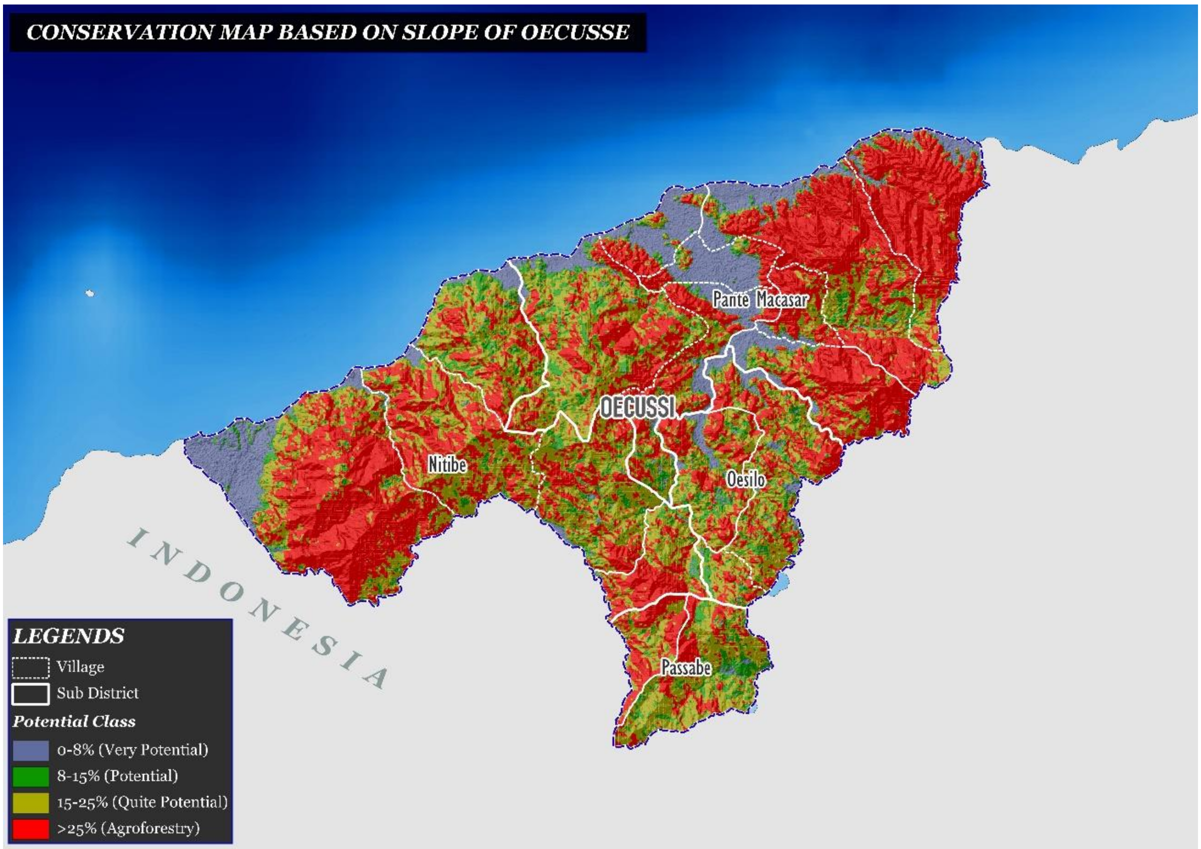


Figure 6.3 Conservation map based on slope gradient of RAEOA

Land in the RAEOA region that is classified as Highly Potential, with a slope gradient of 0–8%, covers an area of 11,053 ha, or about 13.59% of the total area. This zone is highly suitable for the development of various commodities such as food crops, cereals, horticulture, and other cultivated plants.

In contrast, land with a slope gradient of 8–15%, categorized as Potential, covers 10,193 ha (12.54%). However, this category requires the application of soil conservation techniques, such as terracing, to increase land productivity and prevent erosion. Land with a slope gradient of 15–25%, classified as Moderately Potential, spans 23,176 ha (28.51%). Land with slopes greater than 25% covers 36,882 ha, or about 45.37% of the total RAEOA area. This indicates that Highly Potential land is relatively less extensive compared to areas designated for Agroforestry systems. Land with slopes greater than 45% is only suitable for perennial crop cultivation, such as tree species (Beringin, Mahogany, Lenggung, Teak, Gamal, Lamtoro, and others). If these steep or very steep slopes are terraced, planting areas become highly restricted, and the soil becomes more prone to erosion. There is also a high risk of landslides, particularly during the rainy season.

Agroforestry is one of the conservation efforts in the form of a cropping system, which integrates forestry, agriculture, fisheries, and livestock into a unified farming effort to optimize land use. This system allows for efficient and optimal land use (Sanudin & Priambodo, 2013). Based on its components, agroforestry is classified into several systems:

1. Agrosilvicultural System: Integration of trees and specific food crops on the same land.
2. Silvopastoral System: A combination of tree cultivation and livestock forage to support animal husbandry.
3. Agrosilvopastoral: The cultivation of trees, food crops, pasture, and livestock on the same land. This system aims to optimize the land's production function but requires intensive management at the subsystem level.
4. Home Garden System: This system is characterized by the intensive cultivation of perennial and seasonal crops, generally including vegetables, cereals, fruit trees, grasses, and animal husbandry.
5. Other Systems: These include the cultivation of multipurpose trees, beekeeping, and aquaculture, all of which can be utilized for both agricultural and non-agricultural purposes. The agroforestry conservation model is presented in **Figure 6.4.**

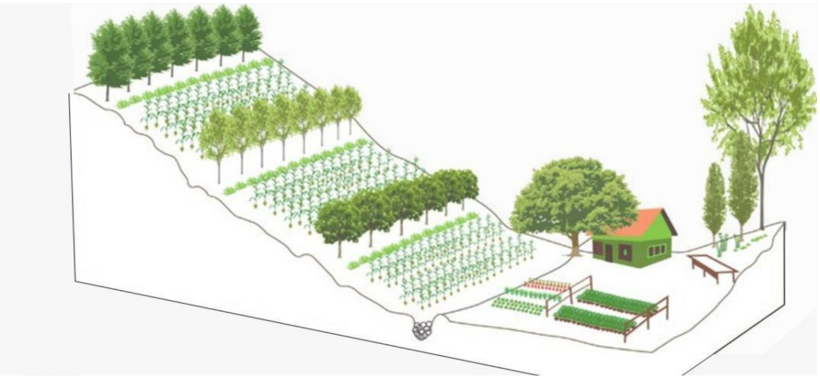


Figure 6.4 Agroforestry Conservation Model
(Source: La *et al.,* 2016)

A. The Importance of the Agroforestry Concept

Agroforestry plays an important role in the production of local commodities (firewood, timber, fruit, and animal feed) as well as global commodities (coffee, tea, cocoa, rubber, and latex). Agroforestry also has a strategic role in helping countries through poverty alleviation, food security, and environmental sustainability. It helps improve farmers' resilience and increases household income by providing diverse harvests at different times throughout the year. The combination of trees, food crops, and livestock helps reduce environmental risks, creates permanent ground cover that combats erosion, minimizes flood damage, and enhances water retention, which benefits crops and pastures.

Agroforestry offers several benefits, including:

1. Improved Food Security and Nutritional Enrichment

Agroforestry provides a diversity of plant species that generate various types of food, contributing to improved food security. The integration of different agroforestry components can enhance agricultural productivity and increase nutritional diversity for consumers.

2. Resilient Livelihoods

The integration of trees, food crops, and livestock can reduce production vulnerability to climate disasters and market shocks. Additionally, agroforestry can help mitigate pest attacks in monoculture systems by creating a better microclimate. Agroforestry also influences climate impacts that hinder agricultural systems, creating more resilient livelihoods.

3. Climate Change Mitigation and Adaptation

The integration of various agricultural plants helps mitigate the effects of climate change on the agricultural sector. The use of trees in agroforestry plays a role in carbon sequestration, regulating the microclimate, reducing the rate of climate change, and influencing plant growth.

4. Environmental Protection

Agroforestry systems help regulate climate and environmental services. Perennial plants help improve air and water quality. Tree litter can be used as organic material to reduce the need for chemical fertilizers. Deep-rooted systems play a role in supporting the nutrient cycle. Agroforestry components also support biodiversity by creating environments suitable for flora and fauna habitats in agricultural landscapes.

5. Poverty Alleviation

Agroforestry can increase income diversification through the cultivation of commercial crops, timber sales, and livestock income. Diversification can improve sustainable agricultural productivity by increasing farmers' income, creating job opportunities, and contributing to poverty alleviation and improved community welfare.

B. Agroforestry and Agro-Ecology in RAEOA

The most successful agroforestry systems in Timor-Leste generally involve mixed cultivation of fruit trees and timber-producing trees alongside spices. The main fruit crops selected include jackfruit, banana, mango, pineapple, and orange. Timber-producing trees commonly planted with fruit crops include mahogany, sandalwood, moringa, and albizia. Agroforestry in this region has adopted a modern approach focused on techniques such as crop rotation, intercropping, and agro-silvopasture.

Paudel *et al.* (2022) illustrated a commonly applied agroforestry model in Timor-Leste, including RAEOA.

1. Alley Cropping in hillside areas along contour lines to reduce landslides and improve long-term water flow. The alley cropping planting system concept is shown in **Figure 6.5.**

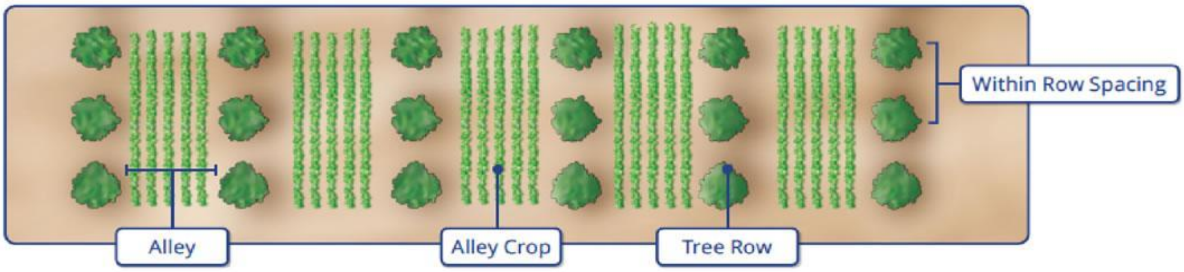


Figure 6. 5 Alley Cropping Planting System Concept
(Source : USDA Alley Cropping)

2. Hedge Planting, which involves creating boundaries/fences using trees or shrubs. This system is mostly implemented in steep hill areas to conserve soil. The concept of hedge planting is shown in **Figure 6.6.**

Figure 6.6 Hedge Planting Concept
(Source: https://www.flickr.com/photos/hedgerowmobile/322445711/)

3. Random Planting of both woody and annual crops with irregular spacing in lowland areas. The concept of random planting is shown in **Figure 6.7.**

Figure 6.7 Random Planting System Concept
(Source: PPID Ministry of Environment and Forestry)

4. Alternating Row Planting, which involves regular planting with seasonal crops between the rows on flat and extensive land. The agroforestry model that can be applied in RAEOA, at elevations of 0–100 m above sea level with annual rainfall ranging from 500 to 1,500 mm, involves the main crop of mahogany (for wood, fruit, and vegetables) and supporting crops such as pineapple, jackfruit, mango, moringa, coconut, banana, soursop, and papaya.

Cogné & Lescuyer (2024) combined agro-ecological and socio-technical data to identify types of Agroforestry Systems (AFS) in the RAEOA, which include home gardens that integrate perennial crops, spices, and small livestock; the integration of crops and fallow land for the development of food crops and trees with specific spacing; the planting of perennial crops (such as papaya, banana, chili, etc.) combined with tree crops (e.g., palm); forest gardens, typically located near water sources; and silvopastoral systems that combine trees, shrubs, and grazing livestock on the same land. The RAEOA has three agro-ecological zones (AEZs) based on elevation and north-south orientation. These zones have biophysical parameters such as elevation, average rainfall, and soil types, which are important for selecting appropriate crops and agroforestry models to be implemented in the RAEOA region (**Table 6.2**).

Table 6.2 Agro-Ecological Zones Data and Main Crop Types

Zone	Altitudes (m)	Rainfall (mm/year)	Main Crops
Zone A	<100	500-1500	Rice, Corn, Cassava, Wood, Coconut
Zone B	100 – 500	500-1500	Corn, Cassava, Rice, Cowpea
Zone C	500 – 1500	1500 – 3000	Red Bean, Coffee, Corn, Rice, Cassava

Agroforestry practices in the RAEOA are traditionally carried out through a system known as Kuda Haur. The following are recommendations for the implementation of agroforestry based on the agro-ecological zones in the RAEOA region (Godinho *et al.*, 2023).

1. Zone A

Appropriate conservation practices include check dam gabion, ridge terraces, biopore holes, riverbank protection, rainwater reservoirs, and drainage systems. Suitable plants include mahogany, sandalwood, teak, and other valuable timber species with high economic value.

2. Zone B

Conservation techniques that can be applied include terraces with channels, bench terraces, rainwater reservoirs, drainage systems, grass planting, and check dams. Suitable plants include mahogany, sandalwood, cinnamon, coffee, cocoa, and vanilla.

3. Zone C

Soil conservation techniques that can be applied include terraces with channels, bench terraces, rainwater reservoirs, drainage systems, grass planting, and check dams. Suitable plants for development include mahogany, sandalwood, blackwood, coffee, vanilla, and clove.

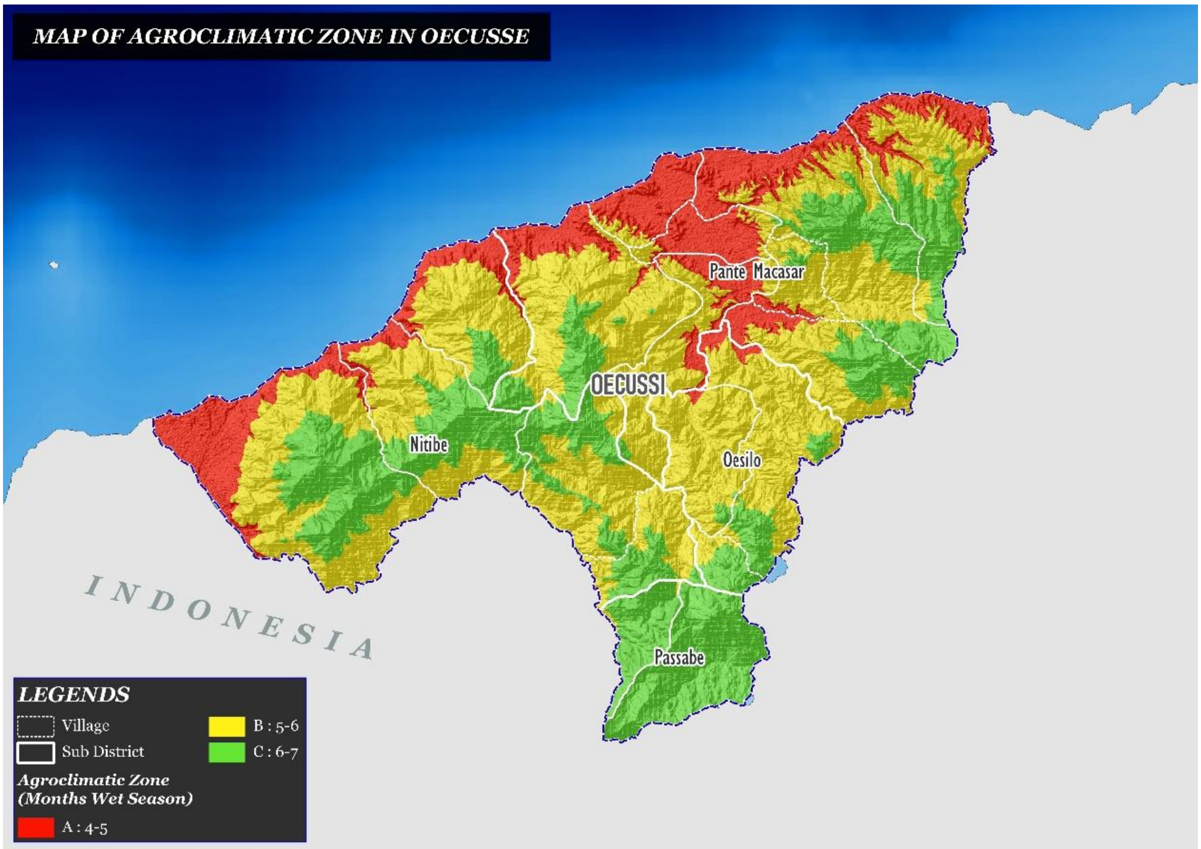


Figure 6.8 Agroclimatic Zone Map of RAEOA

C. Conservation Techniques in RAEOA

Soil conservation techniques are operational and managerial strategies to maintain and enhance the productive capacity of land that is vulnerable to degradation. In practice, conservation efforts include preventing or reducing erosion, preserving, and maintaining the land. Various soil and water conservation techniques have been widely applied in many regions across Asia, such as converting agricultural land back to forest or pasture land, terracing, mulching, and soil management (Huang *et al.*, 2022).

1. Check Dam

A check dam is a small, low dam built in a riverbed or other water channels to reduce the flow velocity, minimize erosion, and promote the deposition of eroded material through a spillway. Dams are useful for preserving agricultural land and strengthening the structure of retaining dams in hilly and disaster-prone areas. Some types of check dams include:

a. **Brushwood**, A brushwood dam is made from wood or branches and is typically used in small river channels. It usually has an effective height of around 1 m above the ground surface, and the minimum foundation depth for the posts is 0.75–1 m. The brushwood conservation model is shown in **Figure 6.9**. Steps in building a brushwood dam*:*

1) Dig a trench about 5 cm wide, and insert wooden posts (150-200 cm) to a depth of about one-third to half the length of the post, with a distance of 30-50 cm between each post.
2) The center should be made lower than the sides to create a gap used to hold the maximum water flow.
3) Branches from trees (mahogany, rosewood, sesbania) and shrubs are woven between the wood to reach the desired height.
4) The ends of the tied materials must extend into the riverbed at least 30 cm.
5) The back of the check dam should be filled with soil.
6) The edges of the brushwood, about 1.5-2.0 times the height of the dam, should be protected from erosion and reinforced with galvanized wire.
7) Side walls should be built to direct water flow toward the dam.
8) Correct the steep gradient of the riverbed head.

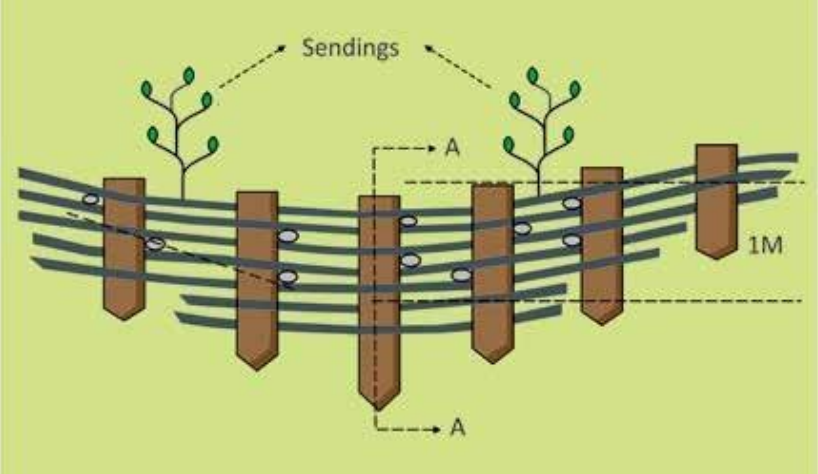


Figure 6.9 Brushwood Check Dam
(Source: Godinho *et al.,* 2023)

b. **Loose Stone**, The loose stone dam is made from loose rocks to block small to medium-sized river channels, while the boulder dam uses large rocks as the barrier, following the same principle as the loose stone dam. Typically, this dam has an effective height of 1–2 m, a minimum foundation depth of half the effective height, and the thickness of the dam at the spillway is between 0.5–1 m. The loose stone model is shown in Figure 6.10. Steps in building a loose stone or boulder dam:

1) Clear the site and mark the construction line using a rope.
2) Cut the riverbed slope with a 1:1 gradient. The foundation of the wing walls should be >0.5 m. The height of the wing walls should match the depth of the spillway.
3) The foundation of the dam should be longer than the spillway.
4) For larger dams, build two wing walls with foundations that match the height to direct the water flow into the spillway or gap and prevent damage to the riverbed edges.
5) Boulder stones are used at the gap and downstream side of the spillway. The center section should be kept lower for the spillway.
6) If there is a large volume of water flow, concrete may need to be used at the gap and the top of the dam or cover everything with wire mesh.
7) An apron made of stones should be built under the dam.

Figure 6. 10 Brushwood Check Dam
Source: https://www.flickr.com/photos/mocobio/27742059100

c. **Gabion**, A gabion dam is constructed using hexagonal or square wire baskets filled with stones. The general specifications for gabions include a maximum effective height of <5 m, a maximum foundation depth of half the effective height, and a dam thickness at the spillway of <1 m. The gabion conservation concept is shown in **Figure 6.11**. Steps in building a gabion dam:

1) The structure must extend at least 0.5 m into the riverbed and must be protected from floodwaters with wing walls.
2) Wing walls with suitable foundations must be built on top to direct the water flow into the spillway or gap and prevent damage to the riverbed edges. The space between the dam and wing walls should be filled with soil.
3) The foundation of the retaining dam should be longer than the spillway.
4) Large stones should be placed along the sides of the gabion box, while smaller stones are used to fill the center. The size of the stones used for construction should be larger than the size of the wire mesh (mesh size of 10 x 10 cm and 15 x 15 cm).
5) If there is debris, a concrete layer may be needed in front of the dam to protect the gabion wire from damage.
6) The spillway dimensions should be calculated based on the maximum flow from the river catchment area.
7) An apron should be built under the dam.
8) The back of the retaining dam needs to be filled with soil to enhance the dam's strength.
9) The gabion boxes should be tied with 12 gauge wire.

Figure 6.11 Gabion Check Dam

Source: https://i.pinimg.com/originals/32/6e/5e/326e5e1d490cc5da1dd6a6ba9bdd477d.jpg

2. Terracing

Terracing is a soil and water conservation method involving the construction of a series of terraces to reduce the length and steepness of slopes. Terracing can directly control water flow and reduce significant soil loss. It alters the continuity of the topography, shortening slopes by cutting runoff and increasing infiltration time. Terracing can also be combined with buffer strips to control soil erosion (Huang *et al.*, 2022). The construction of terraces combined with agroforestry trees can help increase land cover and water infiltration gradually, reducing nutrient loss and improving crop productivity. Terracing is not suitable for shallow soils. The concept of conservation using the terracing system is shown in **Figure 6.12,** and the application of terracing is shown in **Figure 6.14**.

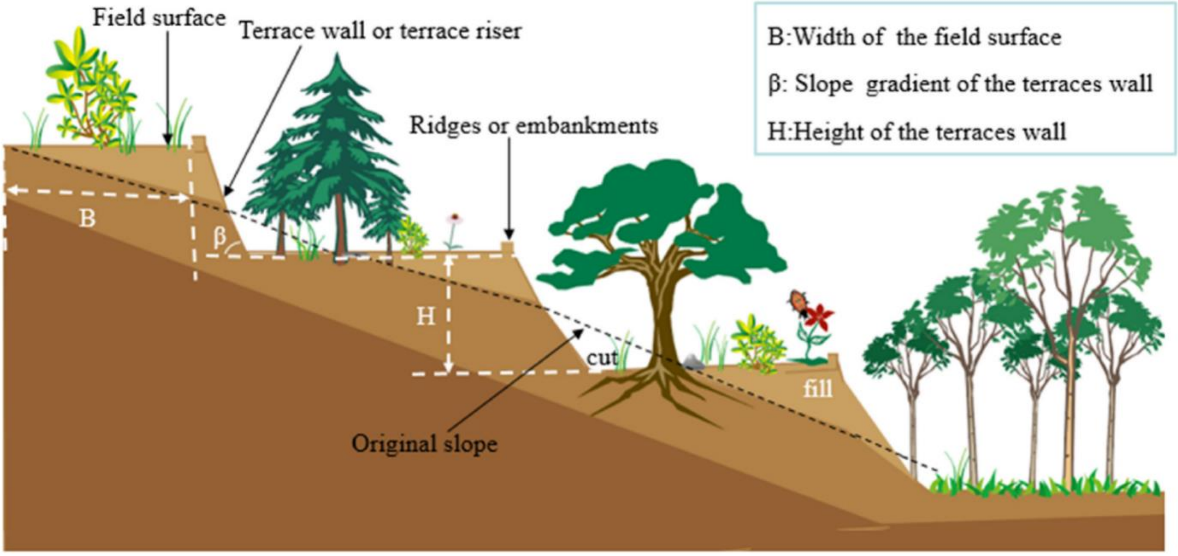
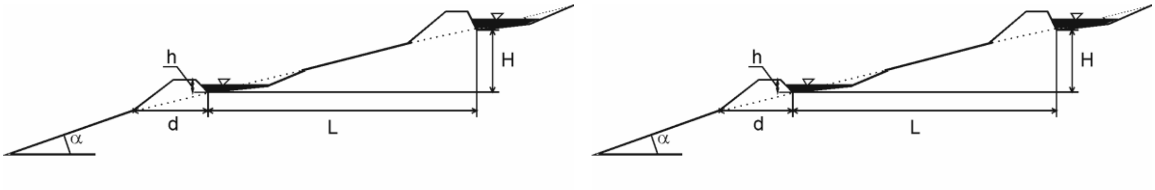


Figure 6.12 Terracing Conservation Concept
Source: (Deng *et al.,* 2021)

Some types of terraces based on their suitability for different slopes include:

a. **Broad Channel Terraces**, These are typically made to capture and direct excess water from fields. This type of terrace is suitable for wet areas and slopes not exceeding 20%.
b. **Ridge Terraces**, These are made to capture and hold excess water by spreading it across the land between hill ridges. These terraces are commonly applied on flat slopes (<3%) because the water spreads more widely without requiring tall ridges. Ridge terraces have water channels at the back of the ridge (embankment) to drain surface water into drainage channels and improve water absorption into the soil. The ridge terrace divides the slope into smaller hydrological units, reducing water flow paths

and influencing water circulation across the slope and within the entire catchment area. According to Prochal (1984) in Baryła & Pierzgalski (2008), ridge terraces can be divided into two types: with and without water outflow. Ridge Terraces without Water Outflow, These have a parallel shape with the contours and are built on water-permeable soil with relatively low rainfall. The flowing water is retained by the embankments and absorbed into the soil. Ridge Terraces with Water Outflow, These terraces have surface or subsurface drainage. For subsurface drainage, water is discharged through wells or underground pumps into ditches, rivers, or reservoirs. These terraces are used in areas with high precipitation and on soils with low water absorption capacity. The concept of ridge terrace division is shown in **Figure 6.13.**



Ridged terraces without water outflow (L, H – horizontal and vertical spacing, respectively)

Ridged terraces with water outflow (1 – well, 2 – pipe, 3 – pond)

Figure 6.13 Concept of Ridge Terraces: Without Outflow (Left); With Outflow (Right)
Source: Baryła & Pierzgalski (2008)

c. **Bench (Step) Terraces**, Used on slopes of 20-50% to transform the land into a series of steps separated by vertical walls covered with stone or vegetation for protection. Step terraces can be made flat, sloping inward (axe slope), or sloping outward, typically built in ecosystems such as rainfed rice fields, dryland fields, and various agroforestry systems.
d. **Individual Terraces**, Terraces made around each individual plant, particularly for perennial crops. This type of terrace is commonly built in plantation areas or orchards.
e. **Orchard Terraces**, A type of terrace for perennial crops, especially plantation and fruit crops. Terraces are made with varying intervals depending on planting distances.

The formula provided is used to calculate VI (which could represent a value related to land slope or terrace stability) in relation to the variables specified.

The formula is:

$$VI = (S \times Wb) / 100 - (S \times U)$$

Where:

- **S** = Slope (%) – This represents the slope percentage of the land or terrace.
- **Wb** = Bench width (m) – This is the width of the bench or terrace in meters.
- **U** = Slope of sub-terraces (m) – This is the slope of the sub-terraces (or secondary terraces), measured in meters.

Figure 6.14 Implementation of Terracing Conservation
Source: https://www.freepik.com/

3. Biopore Infiltration Holes

Biopore holes are cylindrical holes drilled into the soil to enhance water infiltration, reduce flooding, convert organic waste into compost, decrease greenhouse gas emissions (CO_2 and methane), and harness the role of soil and plant roots. Biopore holes can increase water infiltration by up to 40 times, improving soil moisture and maximizing groundwater reserves. Additionally, biopores can enhance soil fertility by converting kitchen waste into compost.

Biopore holes can be made by digging or using a drill to create holes between 30-100 cm deep, with a spacing of approximately 0.5-1 m between each hole. Biopore holes made around trees can have three holes arranged in an equilateral triangle around the tree. The edges of the holes should be reinforced with cement or short PVC pipes to prevent erosion. Only organic waste (kitchen and/or garden waste) should be placed in the holes. The waste should not be too compacted as it will disrupt water infiltration. The compost produced is typically ready within 2-8 weeks. The concept of applying biopore infiltration holes is shown in **Figure 6.15**.

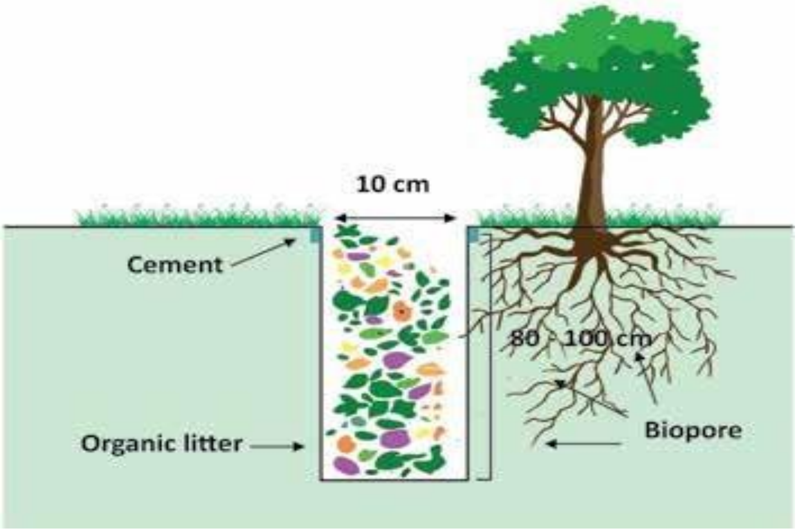


Figure 6.15 Biopore Infiltration Holes
Source: Godinho *et al.,* 2023

4. Riverbank Protection

Riverbank protection is a soil and water conservation technique applied along riverbanks to prevent landslides, reduce soil erosion, improve river water quality, and control sedimentation. This technique can be applied to open areas along riverbanks prone to erosion and landslides, steep riverbanks, denuded riverbanks, and areas with high rainfall. Riverbank management can be carried out by planting grasses, shrubs, and trees with deep roots and dense canopies, or by installing bamboo frameworks. The concept of riverbank protection with vegetation is shown in **Figure 6.16.**

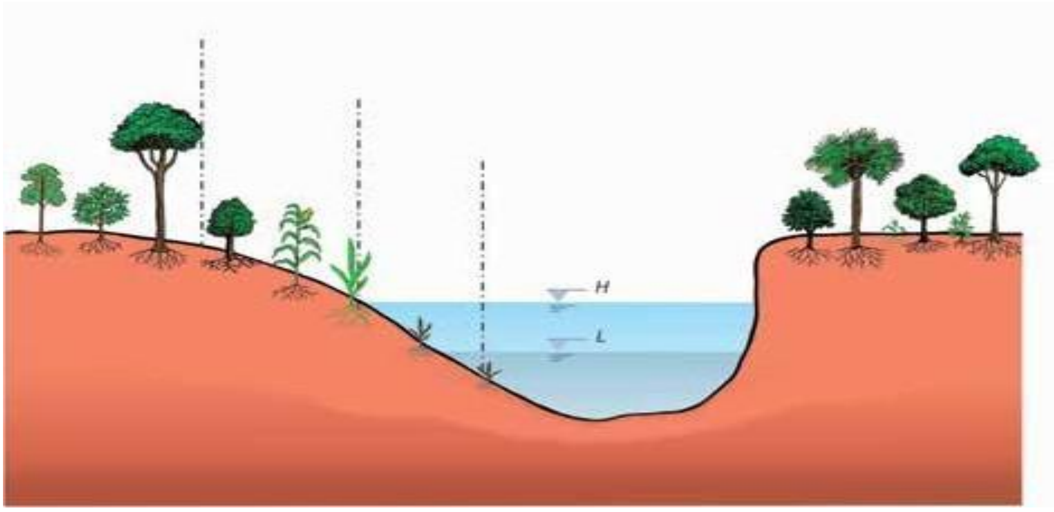


Figure 6.16 Riverbank Protection with Various Layers of Trees, Shrubs, and Grasses (Source: Godinho *et al.,* 2023)

5. Grass Planting

Grass planting is used to suppress soil erosion. The fibrous root system of grass can form a dense mass of interconnected lateral roots, strengthening, holding, trapping, and reinforcing the soil. Grasses with deep, strong, dense, and fibrous root systems can penetrate and bind soil particles, thereby reducing sediment. Grass can also be a functional component of the system, encouraging the formation of terraces even on steep slopes (Do *et al.*, 2023). Grass planting can be done in three ways:

a. **Horizontal/Contour Grass Planting, This** method is used on slopes <65 degrees and erodible land. On slopes <30 degrees, planting distance is 1 x 1 m with 10 x 10 cm spacing; for slopes 30-45 degrees, the planting distance is 50 x 50 cm with 10 x 10 cm spacing; for slopes >45 degrees, the recommended planting distance is 30 x 30 cm with 10 x 10 cm spacing. The concept of horizontal/contour grass planting is shown in **Figure 6.17**.

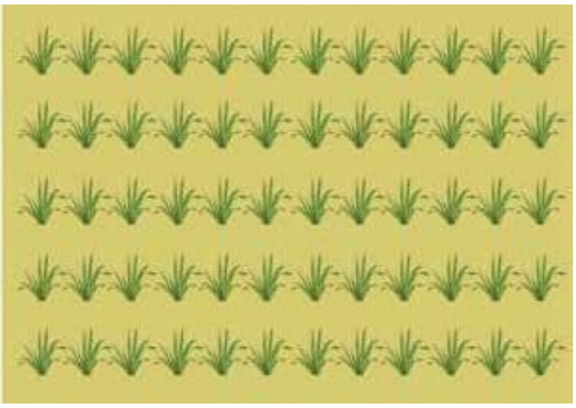


Figure 6.17 Horizontal Grass Planting (Source: Godinho *et al.,* 2023)

b. **Vertical and Downward Grass Planting,** This method can be applied to slopes <65 degrees in moist areas. The recommended planting distance is 10 cm between plants and 50 cm between rows. The concept of vertical and downward grass planting is shown in **Figure 6.18.**

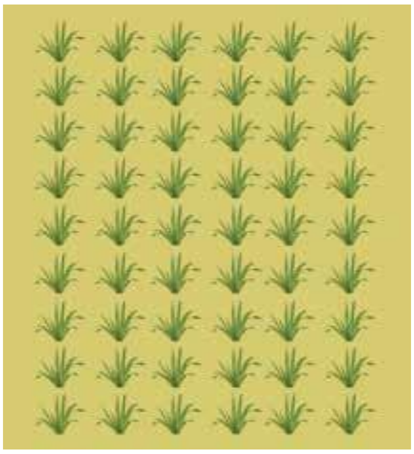


Figure 6.18 Vertical Grass Planting
(Source: Godinho *et al.,* 2023)

c. **Diagonal Grass Planting,** This method is used on slopes <65 degrees with the recommended planting distance of 10 cm between plants and 50 cm between rows. The concept of diagonal grass planting is shown in **Figure 6.19.**

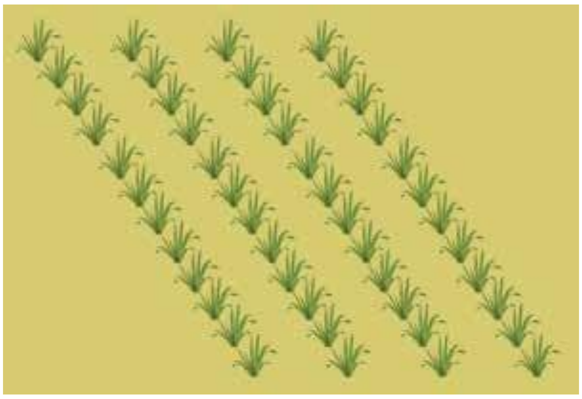


Figure 6.19 Diagonal Grass Planting
(Source: Godinho *et al.,* 2023

6. Rainwater Reservoir

A rainwater reservoir is a water storage pond used to provide irrigation during the dry season, prevent or reduce flooding during the rainy season, improve water infiltration, increase soil productivity, extend the planting period, and enhance farmers' income. This conservation technique can be applied in areas with high rainfall and high surface flow conditions on slopes of 8-30%.

The construction of a rainwater reservoir involves digging, clay lining, and building drainage channels. When digging, the embankment or edges of the reservoir should be higher than the ground surface to prevent soil from entering the reservoir. Drainage channels are constructed to prevent overflow from the reservoir. The distance between the drainage channel and the surface of the reservoir should be between 25-50 cm. Next, the clay lining serves as reinforcement for the embankment or walls of the reservoir, which are usually 25 cm thick. The top cover of the reservoir should be sloped at 70-80 degrees or in steps to prevent landslides. For sandy soils, the dam walls should be lined with plastic, cement, or a mixture of lime and clay (1:1 ratio) to prevent rapid water infiltration. Lastly, the overflow channel should face the area to be irrigated, with a width between 15-25 cm and a depth between 10-15 cm. Furthermore, the rainwater reservoir needs to be maintained by cleaning the drainage channels, reservoir edges, and dam walls, and removing sediment buildup. The concept of creating a rainwater reservoir is shown in **Figure 6.20.**

Figure 6.20 Rainwater Reservoir Construction
Source: Godinho *et al.,* 2023

7. Drainage Channel Construction

Drainage channels are used to direct water to areas where it can be absorbed into the soil or stored. Typically, these channels are also equipped with small waterfalls to prevent erosion and soil loss. The construction of drainage channels begins by digging the soil to a minimum depth of 50 cm from the cultivation space, with a base width of 50 cm. The channel base in bench terraces is made with a slope of 0.1-0.5% outward. Along 1 m of the drainage channel, 20 cm of grass is planted across the channel. Next, a waterfall is constructed using two or three split bamboo poles placed horizontally on the waterfall with a depth of 0.5 m, with the outer part of the bamboo placed on the outside. Maintenance efforts include cleaning the channels of sediment, trimming weeds, and repairing any damaged bamboo structures. The concept of a drainage channel is shown in **Figure 6.21.**

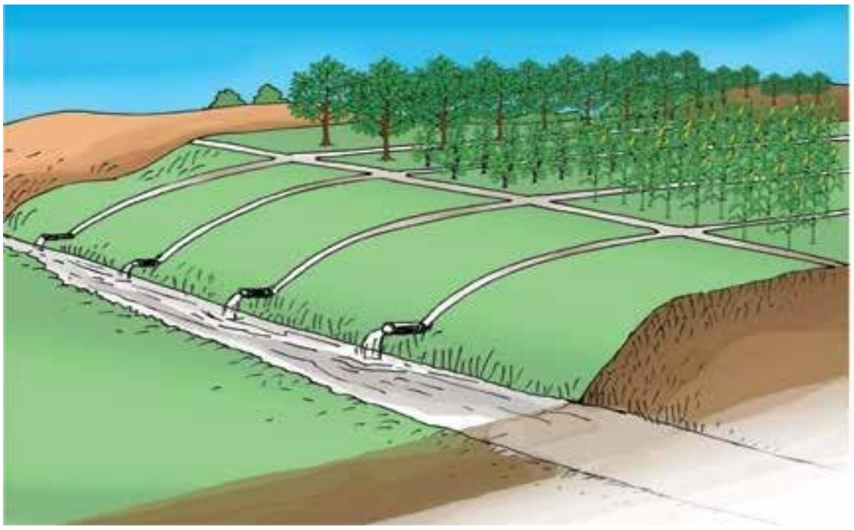


Figure 6.21 Drainage Channel
(Source: Godinho *et al.,* 2023)

8. Wattle Fence / Live Check Dam

A wattle fence is a line of short fences or walls made from vegetative materials and constructed along contours to capture debris moving down slopes, strengthen, and modify slopes. This conservation technique creates a microenvironment for various plant species.

The wattle fence is made by clearing vegetation (wood or branches) to serve as posts. Wooden posts (100 cm) are inserted at intervals of 100 cm along the fence line. Two posts, each 50 cm long, are placed between the main posts and should protrude about 20-30 cm from the ground surface. A trench (at least 15 cm deep) is dug along the contour between the installed posts. The bottom ends of plant cuttings are placed in the trench, and the cuttings are woven between the posts, tightly packing the soil back into the trench. The concept of wattle fence application is shown in **Figure 6.22.**

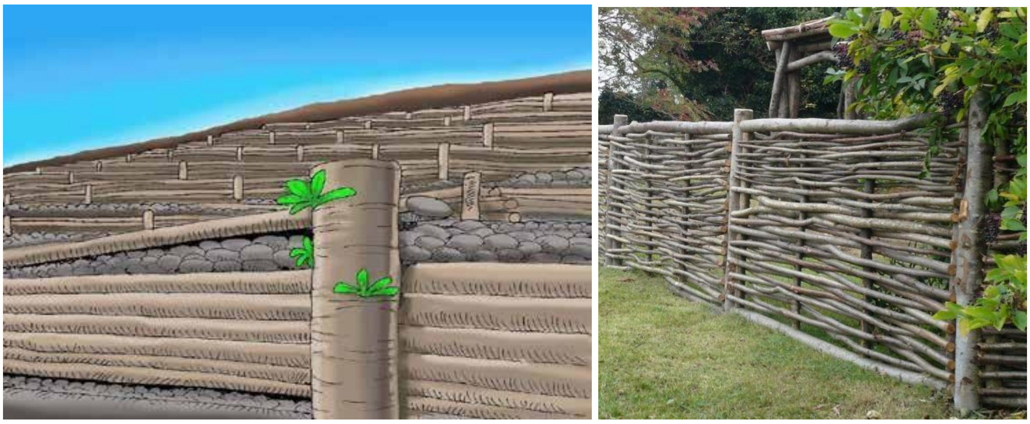


Figure 6.22 Wattle Fence

9. Vegetative Measures

Vegetative actions to achieve better soil and water conservation efficiency include alternating the planting of fruit trees, spices, and food crops. Conservation practices should minimize soil disturbance (minimum tillage), enhance land cover, and promote crop rotation to improve agricultural sustainability (Huang *et al.*, 2022).

a. **Conservation Forest**, Soil and water conservation forests can reduce surface runoff erosion and maintain or restore soil fertility. Tree species and stand structure are the most important factors determining conservation effectiveness. Native tree species and layered vegetation structures (e.g., trees + shrubs + spices) are prioritized for greening patterns.
b. **Hedge Planting**, Using hedge plants is also effective in controlling soil erosion on slopes, retaining runoff, and enhancing soil fertility. Hedge plants that can be used include *Vetiveria zizanoides*, *Leucaena leucocephala*, Guinea grass, Gamal (*Gliricidia sepium*), Calliandra calothyrsus, elephant grass (*Pennisetum purpureum*), and others.
c. **Area Covering**, The intensity of land cover is divided into:
    1) Total Cover, Especially for areas that are highly erodible, mountainous regions, near rivers, and reservoirs.
    2) Half Cover, Land cover is only applied during certain seasons.
    3) Rotational Cover, Applied in areas with light erosion, divided into several sub-areas for rotational coverage.
    4) Cover Combined with Planting, For areas with moderate erosion and very low vegetation cover.

Additionally, increasing vegetation cover can be done using mulch made from leaves, compost, and manure to cover the soil surface. Mulching prevents soil moisture loss due to evaporation, prevents soil erosion, and controls weeds. Materials for mulching include rice and corn straw, legume residues, vetiver grass, and plastic film (Huang *et al.*, 2022).

d. **Crop Rotation**, Crops grown in rotation produce higher yields than those grown continuously. The benefits from crop rotation also depend on seasonal weather conditions and long-term practices. Long-term crop diversification increases agroecosystem productivity compared to monoculture systems and reduces input use. Combinations of legume and brassica plants tend to have a positive impact on the soil due to the mix of tap and fibrous roots, making the soil organisms complex and diverse (Quintarelli *et al.*, 2022).

e. **Water Reservoir,** According to Rustam (2010), a water reservoir is an artificial structure used to store and retain water with a specific small volume, smaller than a dam/reservoir. Reservoirs are usually built by damming small rivers or constructed outside of rivers. The water reservoir stores water during the rainy season and is used by a village during the dry season to meet needs in order of priority: people, livestock, and gardens or fields. The required amount of water will determine the height of the reservoir and its storage capacity. The concept of applying conservation by creating a reservoir is shown in **Figure 6.23.**

Figure 6.23 Application of Water Reservoir

VII. AGRICULTURAL LAND SUITABILITY EVALUATION

Land suitability refers to the extent to which a land area is suitable for a specific use. For example, land may be rated as highly suitable for rice cultivation, moderately suitable for coffee, or marginally suitable for citrus crops. Land suitability can be evaluated based on two conditions: the current condition and the condition after improvements.

7.1 AGRICULTURAL LAND SUITABILITY

Land suitability assessment based on the current condition uses data from field surveys. This assessment reflects the land’s capacity in its existing state, without additional interventions. Current land suitability or suitability in its natural state does not consider any improvements or management actions that could be implemented to address existing constraints or limiting factors in each land unit/map unit. To determine the class of current land suitability, an evaluation of each land quality is first conducted based on the most limiting factor or forest land characteristic. Then, the land suitability class is determined based on the poorest/most limiting land quality.

Potential land suitability refers to land suitability after improvements have been made. For example, land that is currently marginally suitable (S3) due to nutrient deficiencies can become moderately suitable (S2) or even highly suitable (S1) after improvements such as fertilization. The assessment of potential land suitability involves implementing possible improvements to the quality of land characteristics that are limiting factors, so that the land's suitability is expected to increase. With technology, lands that naturally have a low suitability class (current suitability) can be upgraded to a higher suitability class (potential suitability).

In land use planning, the main focus is on potential land suitability because this assessment provides a picture of the land's maximum potential for various uses after improvements are made. Therefore, potential land suitability helps in planning land use effectively and sustainably, and in determining the necessary steps for improvements to achieve optimal results.

7.2 LAND SUITABILITY CLASSIFICATION STRUCTURE

The land suitability classification system, according to the Framework of Land Evaluation (FAO, 1976), is widely used in Indonesia and other developing countries. This framework classifies land suitability using four categories: order, class, sub-class, and unit (Hardjowigeno, 2015). Systematically, land suitability is presented as follows:

Table 7.1 Land Suitability Classification System (FAO, 1976)

Order	:	Indicates whether a land area is suitable or not for a specific use.
Class	:	Indicates the level of suitability of the land.
Sub-class	:	Indicates the type of constraints or types of improvements required within each class
Unit	:	Indicates the differences in the extent of limiting factors affecting the management of the subclass

Orders and classes are generally used in land survey mapping, subclasses in semi-detailed land mapping, and units for detailed land mapping. Orders are also used in land mapping at a coarse scale (exploratory):

Land Suitability Order

The suitability order describes the general suitability of land, meaning whether a land area is suitable or not for a specific land use purpose. At the order level of suitability, land is classified into suitable (S) and not suitable (N).

Suitable Order (S)

Land in this order is land that can be used for a long period for a designated use with a high level of satisfaction after input is provided, with little or no risk of resource damage.

Not Suitable Order (N)

Land in this order has various difficulties or obstacles, either physically (e.g., very steep slopes, rocky terrain) or economically (i.e., input-output imbalance, which prevents the land from being used for the intended purpose).

Land Suitability Class

The suitability class indicates the level of land suitability within the order. At the class level, land that falls into the suitable order (S) is further differentiated into highly suitable (S1), moderately suitable (S2), and marginally suitable (S3). Land that falls into the not suitable order (N) is not further differentiated.

Highly Suitable (S1)

Land in this class has no significant limiting factors or only minor limitations that do not reduce productivity significantly, allowing for sustainable land use

Moderately Suitable Class (S2)

Land in this class has somewhat severe limitations, requiring specific management practices. These limitations reduce productivity or profit and increase the necessary inputs.

Marginally Suitable Class (S3)

Land in this class has severe limitations that require intensive management to maintain. These heavy limitations may decrease productivity and profit, requiring additional inputs to achieve the desired output.

Not Suitable Class (N1)

Land in this class has extremely severe limitations that are difficult to overcome, preventing its sustainable use in the long term.

Permanently Not Suitable Class (N2):

Land in this class has permanent limitations that prevent any possibility of sustainable land use in the long term.

7.3 LAND SUITABILITY EVALUATION RESULTS

Land suitability analysis is a fundamental step in designing sustainable land resource management strategies. This evaluation process is based on an integrated approach that includes the use of geospatial data, field observations, as well as physical and chemical soil analysis in laboratories. This approach allows for the identification of both the potential and limitations of the land's bio-physical characteristics for the development of various agricultural commodities, livestock feed, and grazing.

Geospatial data is used to map topography, land use distribution, and rainfall patterns in each region, while field observations provide direct information about the land's bio-physical condition, such as slope gradient, vegetation cover, and drainage quality. Soil sample analysis in laboratories complements this processREG by providing data on macro-nutrient content (N, P, K), organic matter, cation exchange capacity (CEC), pH, and soil texture.

Subsequently, the data collected is analyzed based on the actual growth requirements of each plant species, as well as the potential suitability after various land improvement efforts, such as fertilization, addition of organic matter, or the implementation of soil conservation techniques. This process results in comprehensive information to determine commodity development priorities, identify limiting factors, and design relevant technical solutions. The placement of several plant species in the same column in **Table 7.2** indicates that these plants share similar growth requirements and limiting factors. This means that they require similar environmental conditions to grow optimally and face relatively the same constraints in cultivation. In contrast, plants placed in different columns have distinct growth requirements and limitations, thus necessitating management approaches tailored to each species' needs.

This scientific approach serves as the basis for the land suitability evaluation in the ***Região Administrativa Especial de Oé-Cusse Ambeno*** **(RAEOA)**. The results of this analysis provide strategic guidance to maximize land productivity while maintaining the sustainability of natural resources in each region.

A. Land Suitability Evaluation of Nitibe Sub-Region

Nitibe Sub-Region shows significant potential for agricultural development, based on land suitability and agro-climatic conditions. A variety of commodities can be cultivated, ranging from wetland food crops such as irrigated rice, to dryland crops such as upland rice, sorghum, and cassava. Horticultural commodities also have development potential, including vegetables (shallots, chili, broccoli), fruits (mango, soursop, pineapple), and ornamental plants (roses, asters, sunflowers). Spices and medicinal plants such as lemongrass and turmeric, as well as industrial commodities (kapok), further expand agricultural diversification. To support the livestock sector, the development of elephant grass as livestock feed can be achieved through soil quality improvement, particularly by adding organic matter.

However, agricultural development in Nitibe Sub-Region faces several technical limitations, including the dry season period, rainfall intensity, slope gradient, erosion levels, drainage, flood potential, and soil depth**. These constraints can still be addressed through optimizing irrigation systems, building drainage channels, adding organic matter, and implementing soil conservation techniques such as terracing with supporting and cover crops.** On the other hand, there are also permanent limitations that cannot be improved, such as temperature, surface rocks, and rock outcrops. Land management approaches such as rock clearing and planting hole preparation remain feasible to enhance efficiency and cultivation productivity.

Overall, Nitibe Sub-Region has a land suitability level that supports sustainable agricultural development. However, some commodities, such as wheat, potatoes, carrots, garlic, peas, and arabica coffee, are not recommended for development due to permanent temperature limitations. Information on other potential commodities that can be developed in this area is available in **Table 7.5.**

B. Land Suitability Evaluation of Oesilo Sub-Region

Oesilo Sub-Region shows considerable potential for agricultural development, based on land suitability and agro-climatic conditions. A variety of commodities can be cultivated, including food crops such as upland rice, mung beans, and corn. Horticultural commodities also have development potential, including vegetables (broccoli, eggplant, tomato), fruits (oranges, watermelon, papaya, rambutan), and flowers (roses, asters, sunflowers). Spices and medicinal plants such as galangal and cardamom, as well as industrial commodities (tobacco and sugarcane), further diversify agriculture. To support the livestock sector, the development of legumes as livestock feed can be achieved through soil quality improvement, particularly by adding organic matter.

Although there is significant development potential, several limiting factors affect land productivity. These factors include rainfall intensity, dry season periods, slope gradient, **erosion levels, drainage, flood potential, soil depth, and nutrient content such as total nitrogen (N-total), available phosphorus, and available potassium.** These constraints can be mitigated through land management interventions, such as optimizing irrigation systems, building drainage channels, balanced fertilization, adding organic matter, and implementing soil conservation techniques like terracing with supporting and cover crops.

However, there are also permanent limitations that cannot be technically improved, such as temperature, surface rocks, and rock outcrops. Land management approaches such as rock clearing and planting hole preparation remain feasible to enhance efficiency and cultivation productivity. Adaptive approaches, such as rock clearing and modifying planting holes, can be applied to improve land utilization effectiveness.

Overall, Oesilo Sub-Region has a land suitability level that supports sustainable agricultural development. However, some commodities, such as **wheat, potatoes, carrots, garlic, peas, and arabica coffee**, are not recommended for development due to permanent temperature limitations. Information on other potential commodities that can be developed in this area is available in **Table 7.5.**

C. Land Suitability Evaluation of Pante Macassar Sub-Region

Pante Macassar Sub-Region shows significant potential for agricultural development, based on land suitability and agro-climatic conditions. A variety of commodities can be cultivated, ranging from wetland food crops such as irrigated rice to dryland food crops such as rainfed rice, upland rice, and mung beans. Horticultural commodities also have development potential, including vegetables (shallots, broccoli, cucumbers), fruits (oranges, snake fruits, rambutan), and flowers. Spices and medicinal plants such as cardamom and turmeric, as well as industrial commodities (tobacco), further expand agricultural diversification. To support the livestock sector, the development of setaria as livestock feed can be achieved through soil quality improvement, particularly by adding organic matter.

However, agricultural development in Pante Macassar Sub-Region faces several technical limitations, including **dry season periods, rainfall intensity, slope gradient, erosion levels, drainage, flood potential, soil depth, and nutrient content such as total nitrogen (N-total), available phosphorus, and available potassium**. These constraints can be addressed through interventions such as optimizing irrigation systems, building drainage channels, adding organic matter, balanced fertilization, and implementing soil conservation techniques like terracing with supporting and cover crops.

In addition, there are also permanent limitations that cannot be improved, such as temperature, surface rocks, and rock outcrops. Adaptive approaches such as rock clearing and modifying planting holes can be applied to improve land utilization effectiveness.

Overall, Pante Macassar Sub-Region has a land suitability level that supports sustainable agricultural development. However, some commodities, such as wheat, potatoes, carrots, garlic, peas, and arabica coffee, are not recommended for development due to permanent temperature limitations.

Information on other potential commodities that can be developed in this area is available in **Table 7.5.**

D. Land Suitability Evaluation of Passabe Sub-Region

Passabe Sub-Region shows significant potential for agricultural development, based on land suitability and agro-climatic conditions. A variety of commodities can be cultivated, including food crops such as upland rice, sorghum, and corn. Horticultural commodities also have development potential, including vegetables (broccoli, chili, tomato), fruits (breadfruit, oranges, snake fruits, pineapple), and ornamental plants (roses, asters, sunflowers). Spices and medicinal plants such as galangal and cardamom, as well as industrial commodities (tobacco and cotton), further diversify agriculture. To support the livestock sector, the development of elephant grass as livestock feed can be achieved through soil quality improvement, particularly by adding organic matter.

Although there is significant development potential, several limiting factors affect land productivity. These factors include rainfall intensity, dry season periods, slope gradient, erosion levels, drainage, flood potential, soil depth, and nutrient content such as total nitrogen (N-total), available phosphorus, and available potassium. These constraints can be mitigated through land management interventions, such as optimizing irrigation systems, crop rotation, building drainage channels, balanced fertilization, adding organic matter, and implementing soil conservation techniques like terracing with supporting and cover crops.

However, there are also permanent limitations that cannot be technically improved, such as temperature, surface rocks, and rock outcrops. Land management approaches such as rock clearing and planting hole preparation remain feasible to enhance efficiency and cultivation productivity. Adaptive approaches, such as rock clearing and modifying planting holes, can be applied to improve land utilization effectiveness.

Overall, Passabe Sub-Region has a land suitability level that supports sustainable agricultural development. However, some commodities, such as **wheat, potatoes, carrots, garlic, peas, and arabica coffee**, are not recommended for development due to permanent temperature limitations. Information on other potential commodities that can be developed in this area is available in **Table 7.5.**

Table 7.2 Land Suitability Evaluation Analysis Matrix in RAEOA

Commodities	Sub-Region	Limiting Factors	Potential Land Suitability / Land Improvement Efforts
FOOD COMMODITIES			
Irrigated Rice	• Nitibe • Pante Macassar	**N:** Flood	**S1**
Rainfed Rice	• Nitibe • Oesilo • Passabe • Pante Macassar	**N:** Flood **S2:** Slope	**S1**
Dryland Food Commodities			
Upland Rice	• Nitibe • Oesilo • Passabe • Pante Macassar	**N:** Slope **S3:** Drainage **S2:** Surface Rock, Rock Outcrops	**S2:** Slope, Surface Rock, Rock Outcrops
Sorghum Mung Bean Cowpea	• Nitibe • Oesilo • Passabe • Pante Macassar	**N:** Flood **S3:** Rainfall, Erosion **S2:** Slope, Surface Rock, Rock Outcrops	**S2:** Surface Rock, Rock Outcrops, Flood
Cassava	• Nitibe • Oesilo • Passabe • Pante Macassar	**N:** Flood **S3:** Erosion **S2:** Effective Depth, Slope, Surface Rock, Rock Outcrops	**S2:** Effective Depth, Surface Rock, Rock Outcrops, Flood
Corn	• Nitibe • Oesilo • Passabe • Pante Macassar	**N:** Flood **S3:** Effective Depth **S2:** Rainfall, Erosion, Slope, Surface Rock, Rock Outcrops	**S2:** Effective Depth, Surface Rock, Rock Outcrops, Flood
Soybean Mung beans	• Nitibe • Oesilo • Passabe • Pante Macassar	**N:** Flood **S3:** Erosion **S2:** Temperature, Rainfall, Slope, Surface Rock, Rock Outcrops	**S2:** Temperature, Surface Rock, Rock Outcrops, Flood
Taro	• Nitibe • Oesilo • Passabe	**N:** Flood **S3:** Temperature, Rainfall	**S3:** Temperature **S2:** Surface Rock, Rock outcrop, Flood

	• Pante Macassar	**S2:** Drainage, Erosion, Slope, Surface Rock, Rock Outcrops	
Wheat	• Nitibe • Oesilo • Passabe • Pante Macassar	**N:** Temperature, Flood **S3:** Erosion **S2:** Rainfall, Drainage, Slope, Surface Rock, Rock Outcrops	**N:** Temperature **S2:** Surface Rock, Rock Outcrops, Flood
Sweet Potatoes	• Nitibe • Oesilo • Passabe • Pante Macassar	**N:** Dry Month, Flood **S3:** Erosion **S2:** Effective Depth, Slope, Surface Rock, Rock Outcrops	**S3:** Dry Month **S2:** Effective Depth, Surface Rock, Rock Outcrops, Flood
VEGETABLE HORTICULTURAL COMMODITIES			
Potato	• Nitibe • Oesilo • Pante Macassar • Passabe	**N:** Temperature **S3:** Rainfall, Drainage, Flood, Erosion **S2:** Slope, Rock Outcrops, Surface Rock, pH, N-Total, Available Phosphorus, Available Pottasium CEC, BS	**N:** Temperature **S2:** Slope, Rock Outcrops, Surface Rock
Carrot	• Nitibe • Oesilo • Pante Macassar • Passabe	**N:** Temperature **S3:** Drainage, Flood, Erosion **S2:** Slope, Rock Outcrops, Surface Rock, pH, N-Total, Available Phosphorus, Available Pottasium CEC, BS	**N:** Temperature **S2:** Slope, Rock Outcrops, Surface Rock
Garlic	• Nitibe • Oesilo • Pante Macassar • Passabe	**N:** Temperature **S3:** Rainfall, Drainage, Flood, Erosion **S2:** Slope, Rock Outcrops, Surface Rock, N-Total, Available Phosphorus, Available Pottasium CEC, BS	**N:** Temperature **S2:** Slope, Rock Outcrops, Surface Rock
Onion	• Nitibe • Oesilo • Pante Macassar • Passabe	**S3:** Drainage, Flood, Erosion **S2:** Temperature, Rainfall, Slope, Surface Rock, N-Total, Available Phosphorus, Available Pottasium CEC, BS	**S2:** Temperature, Slope, Surface Rock
Chili	• Nitibe • Oesilo • Pante Macassar	**N:** Rainfall **S3:** Drainage, Flood, Erosion	**S2:** Rainfall, Slope, Rock Outcrops, Surface Rock

	• Passabe	**S2:** Slope, Rock Outcrops, Surface Rock, N-Total, Available Phosphorus, Available Pottasium CEC, BS	
Bell Pepper	• Nitibe • Oesilo • Pante Macassar • Passabe	**S3:** Rainfall, Drainage, Flood, Erosion **S2:** Temperature, Slope, Rock Outcrops, Surface Rock, N-Total, Available Phosphorus, Available Pottasium CEC, BS	**S2:** Temperature, Slope, Rock Outcrops, Surface Rock
Caisim	• Nitibe • Oesilo • Pante Macassar • Passabe	**S3:** Drainage, Flood, Erosion **S2:** Temperature, Rainfall, Dry Month, Slope, Rock Outcrops, Surface Rock, pH, N-Total, Available Phosphorus, Available Pottasium, CEC, BS	**S2:** Temperature, Dry Month, Slope, Rock Outcrops, Surface Rock
Green Beans Broccoli	• Nitibe • Oesilo • Pante Macassar • Passabe	**S3:** Drainage, Flood, Erosion **S2:** Temperature, Rainfall, Slope, Rock Outcrops, Surface Rock, N-Total, Available Phosphorus, Available Pottasium CEC, BS	**S2:** Temperature, Slope, Rock Outcrops, Surface Rock
Snow Pea	• Nitibe • Oesilo • Pante Macassar • Passabe	**N:** Temperature **S3:** Drainage, Rainfall, Slope, Rock Outcrops, Flood **S2:** Erosion, Surface Rock, N-Total, Available Phosphorus, Available Pottasium CEC, BS	**N:** Temperature **S2:** Slope, Rock Outcrops, Surface Rock
Cucumber	• Nitibe • Oesilo • Pante Macassar • Passabe	**S3:** Rainfall, Drainage, Flood, Erosion **S2:** Slope, Rock Outcrops, Surface Rock, N-Total, Available Phosphorus, Available Pottasium CEC, BS	**S2:** Slope, Rock Outcrops, Surface Rock
Eggplant Bitter Melon Vegetable Tomato	• Nitibe • Oesilo • Pante Macassar • Passabe	**N:** Flood **S3:** Rainfall, Drainage **S2:** Temperature, Slope, Rock Outcrops, Erosion, Surface Rock, N-Total, Available Phosphorus, Available Pottasium CEC, BS	**S2:** Temperature, Slope, Rock Outcrops, Surface Rock

Cabbage Long Bean	• Nitibe • Oesilo • Pante Macassar • Passabe	**S3:** Rainfall, Drainage, Flood **S2:** Temperature, Slope, Rock Outcrops, Erosion, Surface Rock, N-Total, Available Phosphorus, Available Pottasium CEC, BS	**S2:** Temperature, Slope, Rock Outcrops, Surface Rock
FRUIT HORTICULTURAL COMMODITIES			
Orange Mango Guava Breadfruit	• Nitibe • Oesilo • Pante Macassar • Passabe	**S3:** Slope, N-total, Available Phosphorus **S2:** Erosion, Effective Depth, Rock Outcrops, Surface Rock, Available Pottasium	**S2:** Rock Outcrops, Surface Rock, Effective Depth
Watermelon Melon	• Nitibe • Oesilo • Pante Macassar • Passabe	**N:** Slope, Flood **S3:** Rainfall, Erosion, N-total, Available Phosphorus **S2:** Drainage, Rock Outcrops, Surface Rock, Available Pottasium	**S2:** Slope, Flood, Rock Outcrops, Surface Rock
Banana	• Nitibe • Oesilo • Pante Macassar • Passabe	**N:** Dry Month **S3:** Slope, N-total, Available Phosphorus **S2:** Drainage, Rainfall, Erosion, Rock Outcrops, Surface Rock, Available Pottasium, Texture	**S3:** Dry Month **S2:** Texture, Rock Outcrops, Surface Rock
Papaya	• Nitibe • Oesilo • Pante Macassar • Passabe	**S3:** Slope, N-total, Available Phosphorus **S2:** Rainfall, Erosion, Rock Outcrops, Surface Rock, Available Pottasium	**S2:** Rock Outcrops, Surface Rock
Rambutan	• Nitibe • Oesilo • Pante Macassar • Passabe	**S3:** Rainfall, Slope, N-total, Available Phosphorus **S2:** Erosion, Effective Depth, Rock Outcrops, Surface Rock, Available Pottasium	**S2:** Effective Depth, Rock Outcrops, Surface Rock
Avocado	• Nitibe • Oesilo • Pante Macassar • Passabe	**N:** Dry Month **S3:** Slope, N-total, Available Phosphorus **S2:** Erosion, Effective Depth, Rock Outcrops, Surface Rock, Available Pottasium	**S3:** Dry Month **S2:** Rock Outcrops, Surface Rock, Effective Depth

Jackfruit	• Nitibe • Oesilo • Pante Macassar • Passabe	**S3:** Slope, N-total, Available Phosphorus **S2:** Rainfall, Erosion, Effective Depth, Rock Outcrops, Surface Rock, Available Pottasium	**S2:** Rock Outcrops, Surface Rock, Effective Depth
Soursop	• Nitibe • Oesilo • Pante Macassar • Passabe	**S3:** Slope, N-total, Available Phosphorus **S2:** Temperature, Erosion, Effective Depth, Rock Outcrops, Surface Rock, Available Pottasium, pH	**S2:** Temperature, Rock Outcrops, Surface Rock, Effective Depth
Snake fruit	• Nitibe • Oesilo • Pante Macassar • Passabe	**S3:** Slope, N-total, Available Phosphorus **S2:** Erosion, Rock Outcrops, Surface Rock, Available Pottasium, pH	**S2:** Rock Outcrops, Surface Rock
Longan	• Nitibe • Oesilo • Pante Macassar • Passabe	**S3:** Rock Outcrops **S2:** Temperature, Rainfall, Erosion, Slope, Effective Depth, Surface Rock, Available Pottasium	**S2:** Temperature, Rock Outcrops, Surface Rock, Effective Depth
Durian	• Nitibe • Oesilo • Pante Macassar • Passabe	**N:** Flood **S3:** Rainfall, Slope, Rock Outcrops, N-total, Available Phosphorus **S2:** Effective Depth, Surface Rock, Available Pottasium	**S2:** Flood, Rock Outcrops, Surface Rock, Effective Depth
Srikaya	• Nitibe • Oesilo • Pante Macassar • Passabe	**S3:** Slope, N-total, Available Phosphorus **S2:** Temperature, Erosion Effective Depth, Rock Outcrops, Surface Rock, Available Pottasium	**S2:** Temperature, Rock Outcrops, Surface Rock, Effective Depth
Pineapple	• Nitibe • Oesilo • Pante Macassar • Passabe	**S3:** Slope, N-total, Available Phosphorus **S2:** Erosion, Rock Outcrops, Surface Rock, Available Pottasium, pH	**S2:** Rock Outcrops, Surface Rock
Strawberry	• Nitibe • Oesilo • Pante Macassar • Passabe	**N:** Slope **S3:** Erosion, N-total, Available Phosphorus **S2:** Temperature, Rock Outcrops, Surface Rock, Available Pottasium	**S2:** Temperature, Slope, Rock Outcrops, Surface Rock

Grape	• Nitibe • Oesilo • Pante Macassar • Passabe	**S3:** Slope, N-total, Available Phosphorus **S2:** Erosion, Effective Depth, Rock Outcrops, Surface Rock, Available Pottasium	**S2:** Rock Outcrops, Surface Rock, Effective Depth
Passion Fruit	• Nitibe • Oesilo • Pante Macassar • Passabe	**S3:** Temperature, Rainfall, Slope, N-total, Available Phosphorus **S2:** Erosion, Effective Depth, Rock Outcrops, Surface Rock, Available Pottasium	**S3:** Temperature **S2:** Rock Outcrops, Surface Rock, Effective Depth
FLOWER HORTICULTURAL COMMODITIES			
Roses Aster	• Nitibe • Oesilo • Pante Macassar • Passabe	**N:** Slope **S3:** Drainage, Erosion **S2:** Temperature, Rock Outcrops, Surface Rock, C-Organic, N-total, Available Phosphorus	**S2:** Temperature, Slope, Rock Outcrops, Surface Rock
Sun Flowers	• Nitibe • Oesilo • Pante Macassar • Passabe	**N:** Slope **S3:** Drainage, Erosion, Rainfall **S2:** Rock Outcrops, C-Organic, N-total, Available Pottasium	**S2:** Slope, Rock Outcrops, Surface Rock
SPICE AND MEDICINAL COMMODITIES			
Ginger	• Nitibe • Oesilo • Pante Macassar • Passabe	**N:** Rainfall, Dry Month, Slope, Flood **S2:** Drainage, Surface Rock, Rock Outcrops	**S3:** Dry Month **S2:** Rainfall, Slope, Surface Rock, Rock Outcrops, Flood
Vetiver roots	• Nitibe • Oesilo • Pante Macassar • Passabe	**N:** Dry Month, Flood **S3:** Drainage, Rainfall, Slope **S2:** Temperature, Surface Rock, Rock Outcrops	**S3:** Dry Month **S2:** Temperature, Surface Rock, Rock Outcrops, Flood
Lemongrass	• Nitibe • Oesilo • Pante Macassar • Passabe	**N**: Rainfall **S3:** Drainage, Erosion, Slope **S2:** Temperature, Surface Rock, Rock Outcrops	**S2:** Temperature, Rainfall, Surface Rock, Rock Outcrops
Vanilla	• Nitibe • Oesilo • Pante Macassar • Passabe	**N:** Dry Month **S3:** Drainage, Erosion, Slope	**S3:** Dry Month **S2:** Temperature, Effective Depth, Surface Rock, Rock Outcrops

		S2: Temperature, Rainfall, Effective Depth, Surface Rock, Rock Outcrops	
Candlenut	• Nitibe • Oesilo • Pante Macassar • Passabe	**N**: Dry Month **S3:** Drainage, Erosion, Slope, Rock Outcrops **S2:** Surface Rock	**S3:** Dry Month **S2:** Surface Rock, Rock Outcrops
Cinnamon	• Nitibe • Oesilo • Pante Macassar • Passabe	**N**: Dry Month **S3:** Drainage, Slope, Rock Outcrops **S2:** Temperature, Rainfall, Erosion, Surface Rock	**S3:** Dry Month **S2:** Temperature, Surface Rock, Rock Outcrops
Nutmeg Pepper	• Nitibe • Oesilo • Pante Macassar • Passabe	**N**: Rainfall, Dry Month **S3:** Drainage, Slope, Rock Outcrops **S2:** Erosion, Surface Rock	**S3:** Dry Month **S2:** Rainfall, Rock Outcrops, Surface Rock
Jathropa	• Nitibe • Oesilo • Pante Macassar • Passabe	**S3:** Drainage, Slope, Rock Outcrops **S2:** Erosion, Surface Rock	**S2:** Rock Outcrops, Surface Rock
Aromatic Ginger	• Nitibe • Oesilo • Pante Macassar • Passabe	**N**: Rainfall, Slope **S2:** Temperature, Drainage, Effective Depth, Surface Rock, Rock Outcrops	**S2:** Temperature, Rainfall, Effective Depth, Slope, Surface Rock, Rock Outcrops
Turrmeric	• Nitibe • Oesilo • Pante Macassar • Passabe	**N**: Slope, Flood **S3:** Erosion **S2:** Temperature, Drainage, Effective Depth, Surface Rock, Rock Outcrops	**S2:** Temperature, Effective Depth, Slope, Surface Rock, Rock Outcrops, Flood
Galangal	• Nitibe • Oesilo • Pante Macassar • Passabe	**N**: Slope **S3:** Erosion, Effective Depth **S2:** Temperature, Drainage, Surface Rock, Rock Outcrops	**S2:** Slope, Effective Depth, Temperature, Surface Rock, Rock Outcrops
Cardamom	• Nitibe • Oesilo • Pante Macassar • Passabe	**N**: Rainfall, Slope, Flood **S3:** Erosion, Effective Depth **S2:** Drainage, Surface Rock, Rock Outcrops	**S2:** Rainfall, Slope, Flood, Effective Depth, Surface Rock, Rock Outcrops
Sesame	• Nitibe • Oesilo • Pante Macassar • Passabe	**N**: Rainfall, Dry Month, Slope, Flood **S3:** Effective Depth	**S3:** Dry Month **S2:** Rainfall, Dry Month, Slope, Surface Rock, Rock Outcrops, Flood

		S2: Drainage, Surface Rock, Rock Outcrops	
INDUSTRIAL COMMODITIES			
Rubber	• Passabe • Nitibe • Oesilo • Pante Macassar	**N:** Rainfall, Dry Month **S3:** Slope, N-total, Available Phosphorus, Available Pottasium **S2:** Temperature, Drainage, Effective Depth, Rock Outcrops, Surface Rock	**S3:** Dry Month **S2:** Temperature, Effective Depth, Rock Outcrops, Surface Rock
Coconut	• Passabe • Nitibe • Oesilo • Pante Macassar	**N:** Dry Month **S3:** Slope, Rock Outcrops, N-total, Available Phosphorus, Available Pottasium **S2:** Rainfall, Erosion, Effective Depth, Surface Rock	**S3:** Dry Month **S2:** Rock Outcrops, Surface Rock, Effective Depth
Oil Palm	• Passabe • Nitibe • Oesilo • Pante Macassar	**N:** Dry Month **S3:** Rainfall, Slope, N-total, Available Phosphorus, Available Pottasium **S2:** Erosion, Effective Depth, Rock Outcrops, Surface Rock	**S3:** Dry Month **S2:** Rock Outcrops, Surface Rock
Arabica Coffee	• Passabe • Nitibe • Oesilo • Pante Macassar	**N:** Temperature, Dry Month **S3:** Slope, N-total, Available Phosphorus, Available Pottasium **S2:** Erosion, Effective Depth, Rock Outcrops, Surface Rock	**N:** Temperature **S2:** Effective Depth, Rock Outcrops, Surface Rock
Robusta Coffee	• Passabe • Nitibe • Oesilo • Pante Macassar	**N:** Rainfall, Dry Month **S3:** Slope, N-total, Available Phosphorus, Available Pottasium **S2:** Temperature, Drainage, Erosion, Effective Depth, Rock Outcrops, Surface Rock	**S3:** Dry Month **S2:** Temperature, Effective Depth, Rock Outcrops, Surface Rock
Cocoa **Clove**	• Passabe • Nitibe • Oesilo • Pante Macassar	**N:** Dry Month **S3:** Rainfall, Slope, N-total, Available Phosphorus, Available Pottasium	**S3:** Dry Month **S2:** Effective Depth, Rock Outcrops, Surface Rock

		S2: Erosion, Effective Depth, Rock Outcrops, Surface Rock	
Tea	• Passabe • Nitibe • Oesilo • Pante Macassar	**N:** Dry Month **S3:** Temperature, Rainfall, Slope, N-total, Available Phosphorus, Available Pottasium **S2:** Erosion, Effective Depth, Rock Outcrops, Surface Rock	**S3:** Temperature, Dry Month **S2:** Effective Depth, Rock Outcrops, Surface Rock
Tobacco	• Passabe • Nitibe • Oesilo • Pante Macassar	**N:** Rainfall **S3:** Erosion, Slope, N-total, Available Phosphorus, Available Pottasium **S2:** Rock Outcrops, Surface Rock	**S2:** Rock Outcrops, Surface Rock
Sugarcane	• Passabe • Nitibe • Oesilo • Pante Macassar	**N:** Slope **S3:** Erosion, N-total, Available Phosphorus, Available Pottasium **S2:** Rock Outcrops, Surface Rock	**S2:** Rock Outcrops, Surface Rock
Cashew	• Passabe • Nitibe • Oesilo • Pante Macassar	**N:** Dry Month **S3:** Slope, N-total, Available Phosphorus, Available Pottasium **S2:** Drainage, Rainfall, Erosion, Effective Depth, Rock Outcrops, Surface Rock	**S3:** Dry Month **S2:** Effective Depth, Rock Outcrops, Surface Rock
Melinjo	• Passabe • Nitibe • Oesilo • Pante Macassar	**N:** Dry Month **S3:** Rainfall, Slope, N-total, Available Phosphorus, Available Pottasium **S2:** Erosion, Effective Depth, Rock Outcrops, Surface Rock	**S3:** Dry Month **S2:** Effective Depth, Rock Outcrops, Surface Rock
Cotton	• Passabe • Nitibe • Oesilo • Pante Macassar	**S3:** Slope, Rock Outcrops, N-Total, Available Phosphorus, Available Pottasium **S2:** Temperature, Erosion, Surface Rock	**S2:** Rock Outcrops, Surface Rock

Kapok	• Passabe • Nitibe • Oesilo • Pante Macassar	**S3:** Slope, Rock Outcrops, N-total, Available Phosphorus, Available Pottasium **S2:** Temperature, Erosion, Effective Depth, Surface Rock	**S2:** Temperature, Rock Outcrops, Effective Depth, Surface Rock
Quinine	• Passabe • Nitibe • Oesilo • Pante Macassar	**S3:** Temperature, Slope, N-total, Available Phosphorus, Available Pottasium **S2:** Erosion, Effective Depth, Rock Outcrops, Surface Rock	**S3:** Temperature **S2:** Effective Depth, Rock Outcrops, Surface Rock
GRAZING AREAS AND LIVESTICK FEED			
Elephant Grass	• Nitibe • Oesilo • Pante Macassar • Passabe	**S3:** Rainfall, Slope **S2:** Rock Outcrops, Surface Rock, Drainage, Erosion, pH, N-Total, Available Phosphorus, Available Pottasium	**S2:** Rock Outcrops, Surface Rock
Setaria	• Nitibe • Oesilo • Pante Macassar • Passabe	**S2:** Rock Outcrops, Surface RockDrainage, Erosion, Slope, pH, N-Total, Available Phosphorus, Available Pottasium	**S2:** Rock Outcrops, Surface Rock
Legumes	• Nitibe • Oesilo • Pante Macassar • Passabe	**N:** Slope **S3:** Erosion **S2:** Rock Outcrops, Surface Rock, Drainage, Rainfall, pH, N-Total, Available Phosphorus, Available Pottasium	**S2:** Slope, Rock Outcrops, Surface Rock
Grazing	• Nitibe • Oesilo • Pante Macassar • Passabe	**N**: Dry Month **S3:** Rock Outcrops, Slope, pH **S2:** Surface Rock, Rainfall, Erosion, N-Total, Available Phosphorus, Available Pottasium	**S3:** Rock Outcrops, Dry Month **S2:** Surface Rock

Descriptions : Moderately Suitable (S2); Marginally Suitable (S3); Not Suitable (N)

7.4 LAND IMPROVEMENT EFFORTS

Improvement efforts for each limiting factor are crucial for enhancing productivity and sustainability in the agricultural sector. Various constraints, such as shallow effective soil depth, poor drainage, erosion risks, and surface rocks, require appropriate solutions to maximize land potential. On the other hand, some soil chemical parameters, such as Soil Organic Carbon (SOC) and nutrient content (N, P, K), are relatively low in the current state, requiring land improvement efforts to elevate them into potential land for agricultural commodity development.

Recommendations for land improvement efforts for each limiting factor, as the basis for implementing potential land suitability enhancement for agricultural commodities, livestock feed, and grazing, are presented in **Table 7.3.** The level of improvement from actual land quality to potential quality, according to management level, is presented in **Table 7.4**, which is then used as a guideline for transforming actual land suitability into potential suitability.

Table 7.3 Recommendations for Improvement Measures for Each Limiting Factor

No	Soil Quality/Characteritics	Type of Improvement Measures	Management Level
1	**Temperature (tc)** - Average annual temperature	No Improvement possible replacement with suitable crops/varieties	Could not improved
2	**Water Availability (wa)**		
	- Annual rainfall	Irrigation, construction of reservoirs/drip irrigation	Medium, High
	- Rainfall during growth period	Adjustment of planting patterns/planting calendar	
3	**Root Capacity (rc)**		
	- Drainage	Improvement of drainage system, such as construction of drainage channels, ridges/beds	Medium, High
	- Texture	Cannot be improved, can be mitigated by adding organic matter	High
	- Effective Depth	Generally cannot be improved, except in soft and shallow hardpan layers by breaking it during land preparation	Medium, High
	- Coarse Fragment	Depends on the amount and distribution in the profile (if less than 35%, called Obstructing layer, root growth can be improved with organic matter addition and minimum tillage; if more than 90%, called restricting layer, root growth is limited and difficult to improve	High
4	**Nutrient Retention (nr)**		
	- CEC	Addition of organic matter	Medium, High
	- BS	Liming, addition of organic matter	Medium, High
	- pH	Liming if soil pH is low, adding sulfur or ZA fertilizer if pH is high	Medium, High
	- SOC	Addition of organic matter/fertilizer, and returning plant residues to the soil	Medium, High
5	**Nutrient Availability (na)**		
	- Total Nitrogen	Fertilization with N (urea and ZA)	Low, Medium, High
	- Available Phosphorus (Avalaible-P)	Fertilization with P (SP36 and TSP)	Low, Medium, High
	- Available Pottasium (Avalaible-K)	Fertilization with K (KCl) Compound fertilizers (NPK)	Low, Medium, High
6	**Erosion Hazard (eh)**		
	- Slope (%) - Erosion hazard	Erosion control, terracing, contour planting, cover crop planting, mulching, agroforestry implementation.	Medium, High
7	**Flood Hazard (fh)**		
	- High - Duration	Construction of Flood barriers, drainage channels to speed up water	High

		drainage, construction of infiltration well	
8	**Land Preparation (lp)** - Surface Rock (%) - Rock Outcrops (%)	If few (remove rocks), if many/very many, apply TOT (No-Till), create planting holes, add organic matter	Medium, High
9	**Technical Cultural Improvements**	Establishing orchards, pruning, maintenance/care	Medium, High

Descriptions:

- *Low management level: Management can be carried out by farmers with relatively low costs.*
- *Medium management level: Management can be carried out by medium-level farmers, requiring medium capital and intermediate agricultural techniques.*
- *High management level: Management can only be carried out with relatively large capital, typically carried out by the government or large or medium-sized companies.*

Table 7.4 Level of Improvement for Actual Land Quality to Potential Based on Management Level

No	Soil Quality and Characteristics	Management Level		Type of Improvement
		Medium	High	
1	**Radiation Regime**	-	-	-
2	**Temperature Regime**	-	-	-
3	**Air Humidity Regime**	-	-	-
4	**Water Availability**			
	- Dry months	+	++	Crop combination
	- Rainfall	+	++	irrigation
5	**Root Capacity**			
	- Drainage	+	++	Drainage channels*)
	- Soil Texture	-	+	Addition of organic matter
	- Effective Depth	-	+	Creation of planting holes and addition of organic matter
	- Peat, Maturity	-	-	-
	- Peat Thickness	-	-	-
6	**Nutrient Retention**			
	- Cation Exchange Capacity	-	+	Addition of organic matter
	- Base Saturation	-	+	
	- pH	+	+	
	- Soil Organic Carbon	+	++	
7	**Nutrient Availability**			
	- Total Nitrogen	+	++	Urea Fertilizer
	- Available-P	+	++	SP36 and TSP Fertilizer
	- Available-K	+	++	KCL Fertilizer
8	**Flood**			
	- Period	+	++	-
	- Frequency	+	++	-
9	**Salinity**			Irrigation and addition of organic matter
	- Salinity	+	++	
10	**Toxicity**			
	- Aluminium Saturation	+	++	Lime
	- Pyrite depth	-	+	Managing groundwater level
11	**Ease of Cultivation**	-	+	Mechanization
12	**Terrain (land) potensi mechanization potential**	-	+	Terracing
13	**Erosion**	+	++	Soil Conservation efforts

Descriptions:

-	No Improvement possible
+	Improvement is possible and will result in a one-level increase (S3 to S2)
++	A two-level increase (S3 to S1) is possible
***)**	Poor drainage can be improved to better drainage by constructing drainage channels, but rapid/very rapid drainage is difficult to change to moderate/good

7.5 LAND USE GUIDELINES

The land use guidelines in this study are based on the results of the potential land suitability evaluation, considering various improvement interventions that can be implemented. This analysis follows a matching approach between the actual land characteristics and the growth requirements of crops, as outlined in **Tables 7.3** and **Table 7.4.** This process results in land use recommendations that not only reflect the existing biophysical conditions but also consider the potential for increasing suitability through land management and improvement actions. The land use guidelines for various agricultural commodities and grazing/forage feed are presented in **Table 7.5.**

The selection of recommended plant commodities is carried out carefully, based on technical criteria outlined in the land suitability evaluation. This assessment involves various key limiting factors, including water availability, root capacity, nutrient retention and availability, erosion andFlood risks, and ease of land preparation. Each of these factors is analyzed in terms of its potential for improvement, through mechanical, chemical, or biological approaches.

It should be emphasized that although the evaluation results indicate that certain commodities fall within the highly suitable (S1), this does not mean that the crops will automatically grow and develop optimally solely based on the physical land conditions. These recommendations assume that all land management actions are optimally performed, including balanced fertilization according to the specific needs of the crops, appropriate agronomic management, proper irrigation management, climate-appropriate planting patterns, and the soil and water conservation techniques.

Thus, the land suitability classification presented in this document should be understood as the maximum potential that can be achieved if all technical recommendations and land management practices are consistently implemented. The implementation of land use guidelines requires synergy between farmers, agricultural extension agents, and institutional support from the government in the form of policies, technical assistance, and access to production resources.

These guidelines are expected to serve as a strategic reference for planning the sustainable use of land resources, while maintaining productivity, efficiency, and environmental sustainability.

Table 7.5 Land Use Recommendations (Suggestions) for Agricultural Commodity Development in RAEOA

No	SUB-REGION	FOOD CROPS	DRYLAND AGRICULTURE (PLANTATIONS & HORTICULTURE)	FORESTRY	GRAZING AREA AND LIVESTOCK
1	Nitibe	**Wetland Food Crops** **S1:** Irrigated Rice **Dryland Food Crops** **S1:** Rainfed Rice **S2:** Upland Rice, Sorghum, Peanut, Groundnuts, Cassava, Corn, Soybean, Green Bean **S3:** Taro, Sweet Potatoes	**INDUSTRY** **S2:** Tobacco, Sugarcane, Cotton, Kapok **S3:** Rubber, Coconut, oil palm, Robusta Coffee, Cocoa, Clove, Tea, Cashew, Melinjo, Quinine **FRUITS** **S2:** Papaya, Orange, Rambutan, Mango, Guava, Durian, Watermelon, Melon, Jackfruit, Soursop, Srikaya, Breadfruit, Snake fruits, Pineapple, Longan, Strawberry, Grape **S3:** Banana, Avocado, Passion Fruit **VEGETABLES** **S2:** Onion, Bean, Green bean Broccoli, Chili, Pepper, Mustard Green, Cucumber, Eggplant, Bitter Melon, Vegetable Tomato, Cabbage, Long Bean **FLOWERS** **S2: Sun Flowers, Aster, roses** **SPICES & MEDICINES** **S2:** Vetiver root, Lemongrass, Jathropa, Kencur, Kaempferia galanga, Galangal, Cardamon **S3:** Ginger, Vanilla, Candlenut, Cinnamon, Nutmeg, Black Pepper, Cinnamon, Black Pepper, Sesame	**S2:** Agathis, Melaleuca **S3:** Teak, Mahogany, Albizia, Acacia, Eucalyptus, Sandalwood	**S2:** Elephant Grass, Setaria, Legumes **S3:** Grazing

2	Oesilo	Dryland Food Crops **S1:** Rainfed Rice **S2:** Upland Rice, Sorghum, Peanut, Groundnuts, Cassava, Corn, Soybean, Mung beans **S3:** Taro, Sweet Potatoes	INDUSTRY **S2:** Tobacco, Sugarcane, Cotton, Kapok **S3:** Rubber, Coconut, Coconut Mustard Greent, Robusta Coffee, Cocoa, Clove, Tea, Cashew, Melinjo,Quinie FRUITS **S2:** Papaya, Orange, Rambutan, Mango, Guava, Durian, Watermelon, Melon, Jackfruit, Soursop, Srikaya, Breadfruit, Snake fruits, Pineapple, Longan, Strawberry, Grape **S3:** Banana, Avocado, Passion Fruit VEGETABLES **S2:** Onion, Greens Beans, Broccoli, Chili, Bell Pepper, Mustard Green, Cucumber, Eggplant, Bitter Melon, Vegetable Tomato, Cabbage, Long Bean FLOWERS **S2:** Roses, Aster, and Sun Flowers SPICES & MEDICINES **S2:** Vetiver root, Lemongrass, Jathropa, Aromatic Ginger, turmeric, Galangal, Cardamom **S3:** Ginger, Vanilla, Candlenut, Cinnamon, Nutmeg, Black Pepper, Cinnamon, Black Pepper, Sesame	**S2:** Agathis, Melaleuca **S3:** Teak, Mahogany, Albizia, Leucaena, Acacia, Eucalyptus, Sandalwood	**S2:** Elephant Grass, Setaria, Legumes **S3:** Grazing

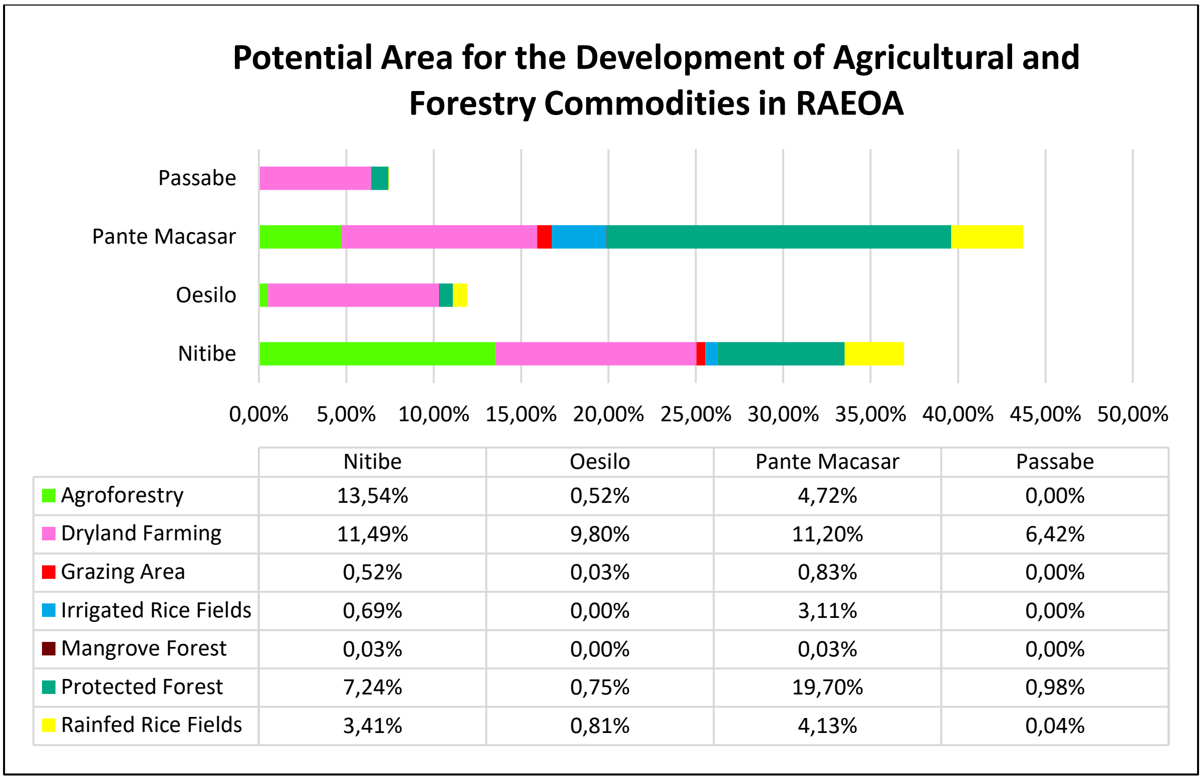
3	Pante Macassar	Wetland Food Crops **S1:** Irrigated Rice Dryland Food Crops **S1:** Rainfed Rice **S2:** Upland Rice, Sorghum, Peanut, Groundnuts, Cassava, Corn, Soybean, Mung beans **S3:** Taro, Sweet Potatoes	INDUSTRY **S2:** Tobacco, Sugarcane, Cotton, Kapok **S3:** Rubber, Coconut, Coconut Mustard Greent, Robusta Coffee, Cocoa, Clove, Tea, Cashew, Melinjo, Quinine FRUITS **S2:** Papaya, Orange, Rambutan, Mango, Guava, Durian, Watermelon, Melon, Jackfruit, Soursop, Custard Apple, Breadfruit, Snake fruits, Pineapple, Longan, Strawberry, Grape **S3:** Banana, Avocado, Passion Fruit VEGETABLES **S2:** Onion, String Bean, Broccoli, Chili, Bell Pepper, Mustard Green, Cucumber, Eggplant, Bitter Melon, Vegetable Tomato, Cabbage, Long Bean FLOWERS **S2**: Roses, Aster, Sun Flowers SPICES & MEDICINES **S2:** Vetiver root, Lemongrass, Jathropa, Aromatic Ginger, Kaempferia galanga, Galangal, Cardamon **S3:** Ginger, Vanilla, Candlenut, Cinnamon, Nutmeg, Pepper, Sesame	**S2:** Agathis, Melaleuca **S3: Teak**, Mahogany, Albizia, Leucaena, Acacia, Eucalyptus, SandalWood	**S2:** Elephant Grass, Setaria, Legumes **S3:** Grazing

4	Passabe	Dryland Food Crops **S1:** Rainfed Rice **S2:** Upland Rice, Sorghum, Peanuts, Groundnuts, Cassava, Corn, Soybean, Mung Beans **S3:** Taro, Sweet Potatoes	INDUSTRY **S2:** Tobacco, Sugarcane, Cotton, Kapok **S3:** Rubber, Coconut, Coconut Mustard Greent, Robusta Coffee, Cocoa, Clove, Tea, Cashew, Melinjo, Quinine FRUITS **S2:** Papaya, Orange, Rambutan, Mango, Guava, Durian, Watermelon, Melon, Jackfruit, Soursop, Srikaya, Breadfruit, Snake fruits, Pineapple, Longan, Strawberry, Grape **S3:** Banana, Avocado, Passion Fruit VEGETABLES **S2:** Onion, Green Beans, Broccoli, Chili, Bell Pepper, Mustard Green, Cucumber, Eggplant, Bitter Melon, Vegetable Tomato, Cabbage, Long Bean FLOWERS **S2:** Rose, Aster, Sun Flowers SPICES & MEDICINES **S2:** Vetiver roots, Lemongrass, Jathropa, Aromatic Ginger, Turmeric, Galangal, Cardamon **S3:** Ginger, Vanilla, Candlenut, Cinnamon, Nutmeg, Pepper, Sesame	**S2:** Agathis, Melaleucane **S3:** Teak, Mahogany, Albizia, Leucaena, Acacia, Eucalyptus, Sandalwood	**S2:** Elephant Grass, Setaria, Legumes **S3:** Grazing

7.6 AGRICULTURAL POTENTIAL DEVELOPMENT ZONING

The research findings indicate that the RAEOA has significant land resource potential to support the development of the agriculture, forestry, and livestock sectors. To maximize this potential, a comprehensive scientific approach was used in the land suitability evaluation, which included field observations, laboratory testing of soil samples, and matching plant growth requirements with the region's agro-climatic map. The results of this evaluation produced a systematic, science-based zoning approach to identify the development potential of various strategic commodities. This zoning reflects the diverse potential for land use to support agriculture, forestry, and livestock sectors sustainably, contributing to food security, environmental protection, and improved community welfare.

The RAEOA has development potential divided into several main categories, including forests covering 386.62 km^2 (47.52%), which include agroforestry, protected forests, and mangroves; dryland agriculture 316.64 km^2 (38.92%); rainfed rice fields 68.24 km^2 (8.39%); irrigated rice fields 30.92 km^2 (3.80%); and grazing areas 11.20 km^2 (1.38%). With structured and sustainable management efforts, the vast potential of this region can be optimized through collaboration between the government, policymakers, and local communities, ensuring the benefits are shared by all parties. The area that can be developed for commodities is presented in **Figure 7.1, and Figure 7.2** illustrates the spatial distribution of the percentage of development areas per Sub-Region in the RAEOA.



	Nitibe	Oesilo	Pante Macasar	Passabe
🟩 Agroforestry	13,54%	0,52%	4,72%	0,00%
🟪 Dryland Farming	11,49%	9,80%	11,20%	6,42%
🟥 Grazing Area	0,52%	0,03%	0,83%	0,00%
🟦 Irrigated Rice Fields	0,69%	0,00%	3,11%	0,00%
🟫 Mangrove Forest	0,03%	0,00%	0,03%	0,00%
🟩 Protected Forest	7,24%	0,75%	19,70%	0,98%
🟨 Rainfed Rice Fields	3,41%	0,81%	4,13%	0,04%

Figure 7.1 Area of Agricultural and Forestry Commodity Development in RAEOA

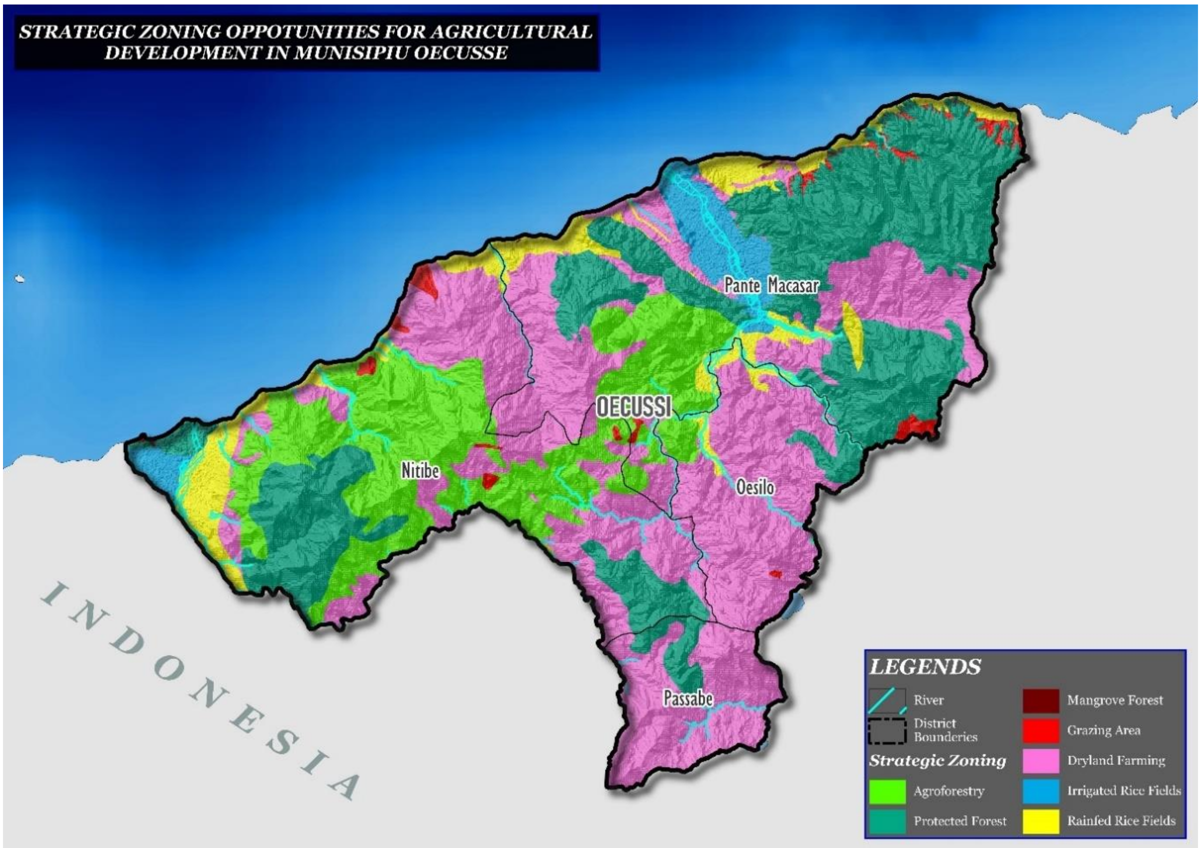


Figure 7.2 Spatial Distribution of Agricultural and Forestry Commodity Development in RAEOA

A. Dryland Agriculture

Dryland agriculture in the RAEOA covers approximately 316.64 km², or 38.92% of the total area. This land is distributed across all Sub-Regions, with the largest distribution in Nitibe (11.49%), followed by Pante Macassar (11.20%), Oesilo (9.80%), and Passabe (6.42%). Topographically, the land spans slopes ranging from 0% to more than 45%, with elevations varying between 10–50 meters and 100–900 meters above sea level. The dominant soils are Inceptisols, Alfisols, and Vertisols, each with physical and chemical properties that support the growth of both annual and perennial crops, although proper management aligned with the land's capacity is required.

This area is located within a monomodal rainfall zone, characterized by a single peak rainy season each year and a dry period lasting between five to eight months. According to agro-climatic classification, the RAEOA falls within zones A, B, and C. These conditions demand the application of adaptive water management strategies, such as the construction of rainwater harvesting systems, soil moisture conservation, and the use of drought-tolerant crop varieties.

The commodities cultivated in the region are highly diverse, reflecting significant potential for diversification. Food crops include upland rice, corn, cassava, sorghum, peanuts, and mung beans. Vegetables grown in the area include shallots, chili, tomatoes, eggplants, long beans, and green Beans. Tropical fruits cultivated include banana, Pineapple, rambutan, guava, papaya, mango, and jackfruit. Additionally, the horticulture sector includes flowers and industrial crops such as tobacco, as well as various spices. This diversification of commodities not only strengthens local food security but also creates economic opportunities through the development of sustainable agricultural value chains.

B. Rainfed Rice Fields

Rainfed rice fields in the RAEOA cover approximately 8.39% of the total area, distributed across flat to gently sloping land with slopes ranging from 0 to 5% and elevations between 10–100 meters above sea level. These topographical conditions are suitable for rice cultivation with low erosion risk. The dominant soil types include Inceptisols, Vertisols, and Alfisols. Inceptisols have stable structures and moderate fertility, Vertisols can retain large amounts of water but are prone to cracking when dry, while Alfisols are known for their productivity and suitability for food crops. The combination of these three soil types generally supports rice growth, particularly on lands with good drainage and minimal degradation.

In terms of agro-climate, this region falls within zones A, B, and C, with a monomodal rainfall pattern, characterized by one peak rainy season each year. This pattern allows for structured planting scheduling, although the limited water supply during the dry season remains a major challenge for rainfed farming systems. Therefore, water use efficiency and the selection of adaptive varieties are crucial aspects in land management.

The distribution of rainfed rice fields is spread across all Sub-Regions, with the largest proportion in Pante Macassar (4.13%), followed by Nitibe (3.14%), Oesilo (0.81%), and Passabe (0.04%). This distribution reflects variations in biophysical suitability, water source availability, and the intensity of land use by local communities. The development strategy for rainfed rice fields in this region should consider spatially-based approaches, water conservation, and enhancing farmers' technical capacities to support sustainable food security.

C. Irrigated Rice Fields

Irrigated rice fields in the RAEOA cover approximately 3.80% of the total area, located in areas with slopes ranging from 0% to 15%. Topographically, these areas are considered flat to gently sloping, which supports rice cultivation with low erosion risk. The dominant soil types include Inceptisols, Vertisols, and Alfisols. Inceptisols have stable structures and moderate fertility, Vertisols can store large amounts of water but are prone to cracking when dry, while Alfisols are known for their productivity and suitability for intensive agriculture.

However, from an agro-climatic perspective, this region faces significant limitations. The monomodal climate zones A, B, and C, which dominate the RAEOA, are characterized by one peak rainy season and a long dry period. This rainfall pattern creates a high dependence on artificial water supply, as natural water availability is insufficient to support the irrigation system sustainably throughout the year. The presence of the Tono Irrigation system supports the development of irrigated rice fields. This irrigation system has a large capacity and broad distribution coverage, providing a stable water supply to support rice cultivation in the lowland areas. The Tono Irrigation system is part of the national priority irrigation network, designed to ensure basic water supply for farmers and strengthen food security in Timor-Leste. With this technical support, the development of irrigated rice fields in the RAEOA continues to have promising prospects.

D. Grazing Areas

The grazing zone in the RAEOA covers 1.38% of the total area, distributed across land with slopes ranging from 0% to 35%. Morphologically, these conditions support grazing activities, though uncontrolled livestock trampling has the potential to cause soil compaction, increased surface runoff, and accelerated erosion, especially on fragile geological substrates.

To mitigate the risk of land degradation, land management is focused on a rotational grazing system, tailored to the carrying capacity of the vegetation and soil. This approach aims to maintain a balance between utilization intensity and the regenerative capacity of the grassland ecosystem. To ensure sustainable forage availability, the area is equipped with a forage bank in the form of elephant grass (*Pennisetum purpureum*), which is planted along the contours of the slope. This vegetation serves a dual purpose as a source of green biomass and as slope reinforcement for soil conservation.

The integration of livestock and crops in this zone offers dual benefits, including improved food security through the provision of animal protein and the use of manure to support agricultural productivity. This approach also enhances the efficiency of integrated farming systems and supports local nutrient cycles.

VIII. FORESTRY POTENTIAL

8.1 LAND SUITABILITY ASSESSMENT RESULTS

Land suitability analysis is a fundamental step in designing strategies for the sustainable management of land resources. This evaluation process is based on an integrated approach that includes the utilization of geospatial data, field observations, and physical and chemical soil analysis in the laboratory. This approach enables the identification of the land’s biophysical potential and limitations for the development of forestry commodities.

Geospatial data are used to map topography, land use distribution, and rainfall patterns in each district, while field observations provide direct information about the land's biophysical conditions, such as slope gradient, vegetation cover, and drainage quality. Laboratory soil sample analysis complements this process by providing data on macro-nutrient content (N, P, K), organic matter, cation exchange capacity (CEC), pH, and soil texture.

Subsequently, the obtained data are analyzed based on the growth requirements of each plant species in its actual conditions, as well as its potential suitability after various land improvement efforts, such as fertilization, organic matter addition, or soil conservation techniques. This process results in comprehensive information for determining commodity development priorities, identifying limiting factors, and designing relevant technical solutions. The placement of several plant species in the same column in **Table 8.1** indicates that these plants share similar growth requirements and limiting factors. This means that they require similar environmental conditions to grow optimally and face relatively similar constraints during cultivation. Conversely, plants placed in different columns have distinct growth requirements and limitations, necessitating a management approach tailored to their specific needs.

This scientific approach forms the basis for the land suitability evaluation in the ***Região Administrativa Especial Oé-Cusse Ambeno*** **(RAEOA)**. The results of this analysis provide strategic guidance for maximizing land productivity while maintaining the sustainability of natural resources in each area.

A. Land Suitability Evaluation of Nitibe Sub-Region

Nitibe Sub-Region shows considerable potential for the development of forestry crops, as assessed by land suitability and agro-climatic conditions. Based on the evaluation results, several plants can be developed, such as sandalwood, mahogany, and gelam, which have high economic value, as well as teak, Albizia, and agathis, which support the sustainable management of natural resources. The main constraints in forestry development in Nitibe Sub-Region include dry months, effective soil depth, surface rocks, and rock outcrops.

These factors can technically be addressed through planting during the rainy season, the addition of organic matter, and the implementation of soil conservation techniques, such as cover crops. However, surface rocks and rock outcrops are permanent limiting factors that cannot be remedied. Despite this, land management is still feasible through methods such as clearing surface rocks and creating planting holes between rock outcrops, which can support the efficiency and productivity of crop cultivation. In addition to the plants mentioned, other species that can be developed in Nitibe Sub-Region are presented in **Table 8.1.**

B. Land Suitability Evaluation of Oesilo Sub-Region

Oesilo Sub-Region has significant potential for the development of forestry crops, based on land suitability and agro-climatic conditions. According to the evaluation results, several plants can be developed, such as sandalwood and Melaleuca, which have high economic value, as well as teak, Albizia, and agathis, which support the sustainable management of natural resources. Meanwhile, pine and altingia are not recommended due to highly unsuitable Temperature conditions. The main constraints in forestry development in Oesilo Sub-Region include dry months, effective soil depth, surface rocks, and rock outcrops.

These factors can technically be addressed through planting during the rainy season, the addition of organic matter, and the implementation of soil conservation techniques, such as cover crops. However, surface rocks and rock outcrops are permanent limiting factors that cannot be remedied. Despite this, land management remains feasible through methods such as clearing surface rocks and creating planting holes between rock outcrops, which can support the efficiency and productivity of crop cultivation. This region has a relatively good land suitability potential to support sustainable agriculture.

C. Land Suitability Evaluation of Pante Macassar Sub-Region

Pante Macassar Sub-Region demonstrates potential for the development of forestry crops with high economic value, including teak, sengon, sandalwood, and gelam, which play a crucial role in supporting the sustainable management of natural resources. Conversely, pine and altingia are not recommended due to Temperaturee conditions that do not align with their growth requirements. The main limiting factors in forestry development in this region include the length of dry months, limited effective soil depth, and the presence of surface rocks and rock outcrops. Several of these constraints can still be addressed through technical approaches, such as planting during the rainy season, adding organic matter, and implementing soil conservation techniques with cover crops. However, surface rocks and rock outcrops are permanent limiting factors that cannot be corrected. Despite this, land management is still feasible through methods such as clearing surface rocks and creating planting holes between rock outcrops, which can enhance land utilization efficiency and increase crop productivity. Overall, this region has a relatively good land suitability level to support sustainable agriculture development.

D. Land Suitability Evaluation of Passabe Sub-Region

Passabe Sub-Region has considerable potential for the development of forestry crops, based on land suitability and agro-climatic conditions. According to the evaluation results, several plants can be developed, such as sandalwood, which was historically abundant in this area, and gelam, both of which have high economic value. Additionally, teak, Albizia, and agathis support the sustainable management of natural resources. Meanwhile, pine and altingia are not recommended due to highly unsuitable Temperaturee conditions. The main constraints in forestry development in Passabe Sub-Region include dry months, effective soil depth, surface rocks, and rock outcrops.

These factors can technically be addressed through planting during the rainy season, the addition of organic matter, and the implementation of soil conservation techniques, such as cover crops. However, surface rocks and rock outcrops are permanent limiting factors that cannot be remedied. Despite this, land management remains feasible through methods such as clearing surface rocks and creating planting holes between rock outcrops, which can enhance the efficiency and productivity of crop cultivation. This region has relatively good land suitability potential to support sustainable agriculture.

Tabel 8.1 Land Suitability Evaluation Matrix for Forestry in RAEOA

Commodity	Sub-Region	Limiting Factor	Potential Land Suitability / Improvement Efforts
Teak	• Passabe • Nitibe • Oesilo • Pante Macassar	**N** : Dry Months **S3** : Rainfall, Effective Depth, Slope, Rock Outcrops, N-Total, Available P, Available K **S2**: Drainage, Erosion, Surface Rocks, pH	**S3** : Dry Months **S2** : Effective Depth, Rock Outcrops, Surface Rocks
Mahogany	• Passabe • Nitibe • Oesilo • Pante Macassar	**N** : Rainfall, Dry Months **S3** : Effective Depth, Slope, Rock Outcrops, N-Total, Available P, Available K **S2** : Drainage, Erosion, Surface Rocks, pH	**S3** : Dry Months **S2** : Rainfall, Effective Depth, Rock Outcrops, Surface Rocks
Agathis	• Passabe • Nitibe • Oesilo • Pante Macassar	**N** : Dry Months **S3** : Rainfall, Effective Depth, Slope, Rock Outcrops, N-Total, Available P, Available K **S2** : Temperature, Erosion, Surface Rocks	**S3** : Dry Months **S2** : Temperature, Effective Depth, Rock Outcrops, Surface Rocks
Altingia	• Passabe • Nitibe • Oesilo • Pante Macassar	**N** : Temperature, Rainfall, Dry Months **S3** : Effective Depth, Slope, Rock Outcrops, N-Total, Available P, Available K **S2** : Erosion, Surface Rocks, pH	**N** : Temperature **S3** : Dry Months **S2** : Rainfall, Effective Depth, Rock Outcrops, Surface Rocks
Sengon	• Passabe • Nitibe • Oesilo • Pante Macassar	**N** : Rainfall, Dry Months, **S3** : Effective Depth, Slope, Rock Outcrops, N-Total, Available P, Available K	**S3** : Dry Months **S2** : Rainfall, Effective Depth, Rock Outcrops, Surface Rocks

		S2 : Erosion, Surface Rocks, pH	
Leucaena	• Passabe • Nitibe • Oesilo • Pante Macassar	**N** : Dry Months, **S3** : Slope, Rock Outcrops, N-Total, Available P, Available K **S2** : Rainfall, Erosion, Effective Depth, Surface Rocks	**S3** : Dry Months **S2** : Rock Outcrops, Effective Depth, Surface Rocks
Acacia	• Passabe • Nitibe • Oesilo • Pante Macassar	**N** : Dry Months **S3** : Slope, Rock Outcrops, N-Total, Available P, Available K **S2** : Erosion, Effective Depth, Surface Rocks	**S3** : Dry Months **S2** : Rock Outcrops, Effective Depth, Surface Rocks
Eucalyptus	• Passabe • Nitibe • Oesilo • Pante Macassar	**N** : Dry Months **S3** : Slope, Rock Outcrops, N-Total, Available P, Available K **S2** : Erosion, Effective Depth, Surface Rocks, pH	**S3** : Dry Months **S2** : Rock Outcrops, Effective Depth, Surface Rocks
Melaleucane	• Passabe • Nitibe • Oesilo • Pante Macassar	**S3** : Drainage, Rock Outcrops, N-Total, Available P, Available K **S2** : Effective Depth, Surface Rocks, pH	**S2** : Rock Outcrops, Effective Depth, Surface Rocks
Pine	• Passabe • Nitibe • Oesilo • Pante Macassar	**N** : Temperature, Rainfall, Dry Months **S3** : Slope, Rock Outcrops, N-Total, Available P, Available K **S2** : Drainage, Erosion, Effective Depth, Surface Rocks, pH	**N** : Temperature **S3** : Dry Months **S2** : Rainfall, Rock Outcrops, Effective Depth, Surface Rocks
Sandalwood	• Passabe • Nitibe • Oesilo • Pante Macassar	**S3** : Drainage, N-Total, Available P, Available K **S2** : Effective Depth, Surface Rocks, Rock Outcrops, pH	**S2** : Rock Outcrops, Effective Depth, Surface Rocks

Description : Moderately Suitable (S2); Marginally Suitable (S3); Not Suitable (N)

8.2 LAND IMPROVEMENT EFFORTS

Efforts to address each limiting factor are strategic steps in enhancing productivity while ensuring the sustainability of the forestry and agricultural sectors. Biophysical limiting factors such as shallow effective soil depth, poor drainage, rock outcrops, unsuitable soil texture, and the presence of surface rocks often serve as the main barriers to land utilization. Without proper interventions, these conditions can reduce the land's capacity to support vegetation growth, including both forestry plants and agricultural commodities.

On the other hand, chemical soil parameters such as low organic carbon content and deficiencies in essential macro-nutrients (N, P, K) further deteriorate soil fertility. This poor chemical soil quality not only limits plant productivity but also affects the efficiency of forestry inputs, increasing production costs and disrupting the sustainability of cultivation systems. Recommended improvement efforts for each limiting factor serve as the basis for enhancing land suitability.

8.3 FORESTRY PLANT DEVELOPMENT ZONING

The research results in dicate that RAEOA has significant land resource potential to support the development of the forestry sector.

RAEOA's forestry development potential is divided into several key categories, covering an area of 386.62 km² (47.52%), which includes agroforestry, protected forests, and mangroves. With structured and sustainable management efforts, the vast potential of this area can be optimized through synergy between the government, policymakers, and local communities, so that the benefits can be shared by all parties. The area available for commodity development is presented in **Figure 7.1** (**Chapter VII**), which illustrates the spatial distribution and percentage of the area allocated for development in each sub-region within RAEOA.

A. Agroforestry

The agroforestry system is spread across several sub-regions, with the largest proportion in Nitibe (13.54%), followed by Pante Macassar (4.72%) and Oesilo (0.52%). These distribution differences reflect variations in biophysical suitability, access to resources, and land use intensity. The cultivated commodities include food crops, fruits, and forestry plants such as maize, cassava, papaya, Pigeon pea, upland rice, coconut, pine, areca nut, pineapple, teak, acacia, leucaena, tobacco, mahogany, sandalwood, mango, and banana. The planting system, which combines 70% forestry vegetation and 30% agricultural crops, has proven effective in reducing slope length and cover factor values, maintaining soil moisture, and stabilizing base flow that supports irrigation in the downstream areas. The integration of these various plant species not only strengthens the economic resilience of local communities but also contributes to soil conservation, increased vegetation cover, and ecosystem stabilization.

The development of coffee cultivation in RAEOA (**Figure 8.1**) has become a priority due to its high economic value. In this agroforestry zone, coffee plants are often found alongside forestry plants that provide shade. The recommended coffee species is robusta due to its suitability with the agro-climatic conditions, particularly at the altitude and Temperaturee that supports optimal growth, such as in Passabe, Nitibe, and Oesilo Sub-Regions, which typically have an elevation of 700 meters above sea level. Robusta coffee grows optimally at elevations of 200–800 meters above sea level, with an average Temperaturee of 24–30°C. The recommended sub-regions have marginal suitability, with the main limiting factor being the dry months. Therefore, the management approach should include planting during the rainy season.

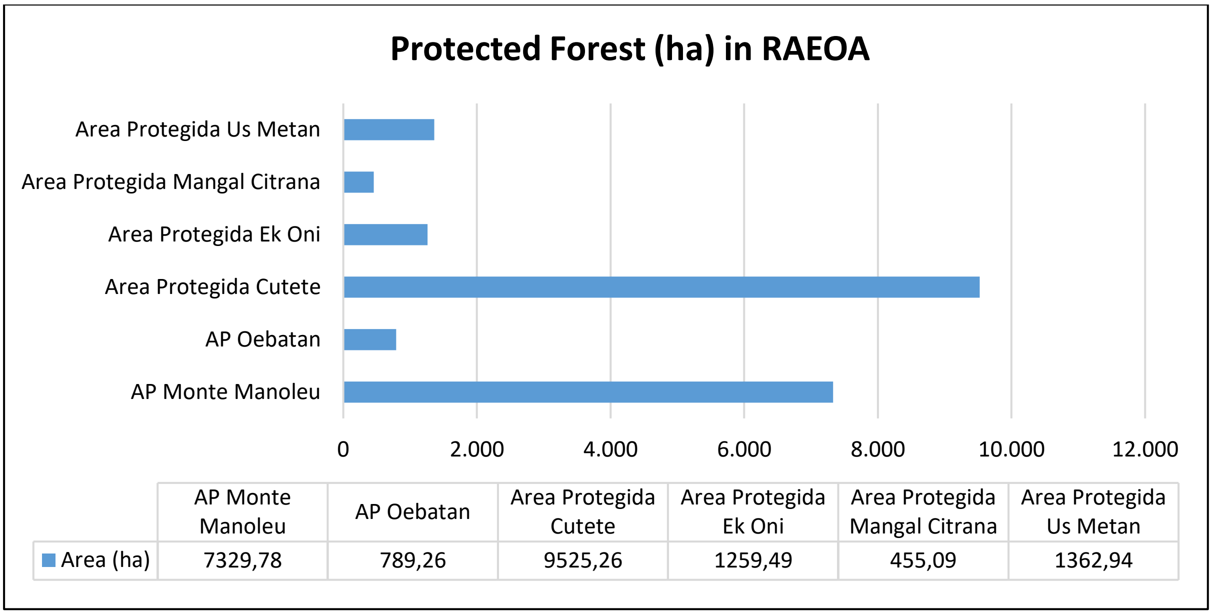
Thus, the development of coffee as a commodity in this area is better focused on the more adaptive robusta variety to local conditions. However, if arabica coffee is still to be cultivated, additional technical interventions are needed, such as selecting microclimates with cooler Temperaturees, using tolerant varieties, and implementing proper shade systems and soil conservation techniques. This approach aims to minimize the risk of cultivation failure and optimize the land's potential sustainably.

Figure 8.1 Robusta Coffee Cultivation in Passabe Sub-Region

B. Protected Forest and Conservation

The protected forest area in RAEOA covers an area of 233.32 ha, or 28.68% of the total land area. Generally, protected forests are located in mountainous regions and upstream areas with slopes greater than 30% and high elevation. This zone is designated as a no-conversion area due to its function in preventing Erosionon, regulating infiltration, and controlling sediment, which are vital for the sustainability of the irrigation system in the lowlands. The largest distribution of protected forests is found in Pante Macassar Sub-Region, covering 19.70% of the area, followed by Nitibe (7.24%), Passabe (0.98%), and Oesilo (0.75%).

There are several Protected Areas (PAS) in the RAEOA, with varying sizes. These areas play a crucial role in maintaining ecosystem balance, conserving biodiversity, and supporting the ecological and social functions of the surrounding communities. The PAS include AP Cutete with an area of 9,525.26 ha (%), AP Monte Manoleu with 7,329.78 ha (%), AP Us Metan with 1,362.94 ha (%), AP Ek Oni with 1,259.49 ha (%), AP Oebatan with 789.26 ha (%), and AP Mangal Citrana with 455.09 ha (%). These are detailed in **Figure 8.2.**



	AP Monte Manoleu	AP Oebatan	Area Protegida Cutete	Area Protegida Ek Oni	Area Protegida Mangal Citrana	Area Protegida Us Metan
■ Area (ha)	7329,78	789,26	9525,26	1259,49	455,09	1362,94

Figure 8.2 Protected Forest Areas in RAEOA

C. Mangrove Forest

In the coastal areas, the mangrove ecosystem occupies estuarine zones with low elevation and high salinity levels. Mangroves function as blue carbon absorbers, wave breakers, tidal flood controllers, and important habitats for fisheries resources. All interventions in the coastal areas designate mangroves as permanent conservation zones that cannot be converted, in order to maintain ecological stability and coastal resilience sustainably. In RAEOA, the mangrove forest zone covers only 23.51 ha or 0.03% (Pante Macassar) and 22.50 ha or 0.03% (Nitibe).

8.4 POTENTIAL FOR SANDALWOOD (*Santalum album* L.) DEVELOPMENT

Sandalwood (*Santalum album L.*) is a tropical tree species with high ecological and economic value. Sandalwood is widely known for producing a distinctive aroma derived from the essential oils in the heartwood. For a long time, sandalwood has been used in various fields, including as raw material for the perfume and cosmetic industries, traditional medicine, and it also plays an important role in cultural and religious activities. The slow growth characteristics of sandalwood make it a strategically valuable commodity that requires sustainable management.

From an economic perspective, sandalwood has significant prospects as a long-term source of income. The price of sandalwood wood and oil in the international market is relatively high, which can contribute to improving the welfare of communities and local income. Furthermore, the development of sandalwood has the potential to promote rural economic diversification, expand job opportunities, and increase regional competitiveness through the use of local resources. In addition to its economic benefits, sandalwood also plays a role in environmental conservation, such as through soil conservation, Erosion on prevention, and improvement of land cover quality.

In the RAEOA region, several Sub-Regions have long developed sandalwood cultivation, including Sub-Regions Pante Macassar, Passabe, Oesilo, and Nitibe. These areas have suitable bio-physical conditions for sandalwood growth, in terms of climate, soil type, and topography. The presence of sandalwood in these Sub-Regions provides an important foundation for further development. With planned management, community participation, and support from local government policies, RAEOA has the potential to become one of the centers of sustainable and competitive sandalwood development at the national and regional levels.

Based on land suitability evaluation for sandalwood development in RAEOA, the suitability criteria range from S2 (moderately suitable) to S3 (marginally suitable), with limiting factors including dry months, rock outcrops, surface rocks, and slope. Improvements that can be made include clearing surface rocks and utilizing them as stone terraces or soil retaining walls, planting sandalwood in sufficiently deep soil gaps, using organic mulch, and planting host plants tolerant of rocky conditions to support sandalwood growth.

On sloped land, the application of soil and water conservation techniques such as terracing, bundling, or contour bundling is crucial to reduce Erosion on, along with planting ground cover vegetation and planting along the contour. Additionally, strategies such as selecting planting sites with adequate soil depth, managing water through ponds or infiltration wells, and implementing agroforestry systems with food crops or shade trees will help increase land productivity while improving environmental conditions for sandalwood growth (Figure 8.3).

Figure 8.3 Sandalwood (*Santalum album L.*) in Nitibe Sub-Region

IX. LIVESTOCK POTENTIAL

9.1 INTRODUCTION

Timor-Leste is a country predominantly characterized by mountainous and highland areas. Administratively, Timor-Leste is divided into 14 districts: Ainaro, Aileu, Autoridade Administrativa Atauro, Bobonaro, Baucau, Covalima, Dili, Ermera, Lautém, Liquiçá, Manufahi, Manatuto, ***Região Administrativa Especial Oe-Cusse Ambeno*** **(RAEOA)**, and Viqueque. The country experiences two seasons: a dry season from June to November, and a rainy season from December to May. The topography, dominated by hills, combined with its proximity to the Australian continent, exposes Timor-Leste to the east monsoon winds, which are dry in nature. As a result, many areas are prone to droughts. Additionally, the low annual rainfall significantly affects vegetation growth across the country.

The hilly topography and low rainfall not only impact vegetation growth and agricultural activities but also limit the availability of forage for the livestock sector. The development of the livestock sector is highly dependent on land resource potential, appropriate land use, and effective management methods. These factors are critical in providing sufficient forage for livestock, which generally consists of grasses and legumes.

Forage for livestock can come from natural sources or cultivation, including from grazing lands (Priyanto, 2016). The optimal use of land for livestock farming is highly influenced by anthropogenic factors and the bio-physical condition of the land. Therefore, applying various technological innovations and institutional approaches is necessary to ensure that land resources are utilized effectively and sustainably (Suryana and Rahman, 2006).

Overall, the livestock sector in Timor-Leste faces several challenges. One of the main reasons is the traditional and extensive management system, which has led to suboptimal production outcomes. The low levels of awareness, knowledge, and technology among livestock farmers also hinder progress, especially in meeting the demands for quality forage in terms of both type and quantity. Livestock is typically kept as household savings, to be sold in emergencies. Additionally, some communities still rely on livestock for labor in land cultivation, using traditional management methods.

The success of livestock farming is influenced by three main factors: breeding, feed, and management (Aman *et al.*, 2019). These three factors form an interconnected system; if one is neglected or receives insufficient attention, even excellent management of the other factors will not result in optimal output. Livestock productivity, especially for ruminants, heavily depends on effective feed management, including the quantity, quality, and continuous availability of feed (Rokhayati and Evadewi, 2023). According to Winarni and Sukaesih (2015), feed plays a crucial role in supporting livestock development as it directly impacts production, productivity, and animal health. The quality of livestock forage itself is influenced by forage varieties, genotypes, harvest maturity, season, and management practices (Adesogan *et al.*, 2015).

One initial step for developing the livestock sector in Timor-Leste is optimizing land use for sustainable forage production. To achieve this, it is essential that the characteristics of the land match the type of forage to be cultivated. Therefore, land suitability evaluation is a key approach in assessing the potential and carrying capacity of land resources (Harahap *et al.*, 2019). This evaluation not only assesses land potential but also determines its suitability for various uses based on the level of management applied (Nugroho *et al.*, 2014). Land suitability evaluation requires environmental data and soil quality for the area. This assessment is carried out by identifying various land characteristics, such as topography, climate, soil conditions, and other physical environmental factors (Iswan *et al.*, 2019). Through this evaluation process, information regarding bio-physical resources, including climate and soil, is gathered, which helps determine land suitability classes and identify limiting factors that need to be addressed (Jawang *et al.*, 2018).

9.2 RESEARCH METHODS

The research was conducted using survey methods and descriptive analysis techniques on the research areas selected purposively, namely the KTS (*Karau Timor Susubeen*) Center and the recommended livestock lands. The data collected include both quantitative and qualitative data sourced from primary and secondary data. Primary data consists of interview data regarding livestock production and socio-economic aspects, as well as biophysical land observations and soil characteristics for forage land suitability. Biophysical and soil properties were further analyzed according to laboratory standards. Secondary data used include the Timor-Leste 2019 agricultural census data.

The interview data obtained were analyzed using a simple tabulation method based on Miles and Huberman's analysis model, which involves data reduction, data presentation, drawing conclusions, and verification. Biophysical land data and soil characteristics were analyzed and presented using a Geographic Information System (GIS) approach with GIS software, which involves various methods depending on the type of data and the objectives to be achieved (Rusdi *et al.*, 2015).

A. Research Procedures

1. Observation of Livestock Production and Socio-Economic Aspects

Observations were conducted through interviews with the following parameters, Type of livestock, Livestock population, Land area, Animal husbandry/pen systems, Feed and nutrition management systems, Water sources, Breeding systems, Livestock health management systems, Livestock products, Marketing, Infrastructure, Characteristics of livestock farmers and Customs/traditions

2. Forage Land Suitability

The research procedures have been detailed in **Chapter III (Methodology).**

9.3 GENERAL OVERVIEW

A. General Existing Conditions

The livestock sector plays a crucial role in supporting the livelihoods of many households in RAEOA region. The distribution of households engaged in livestock farming shows significant variation across each Sub-Region. Pante Macassar Sub-Region has the highest number of households involved in livestock farming, with a total of 300 households (67.57%). On the other hand, Nitibe Sub-Region has the fewest households involved in livestock farming, with only 12 households (2.70%).

Nevertheless, their contributions remain significant in meeting local needs and preserving the livestock traditions that have become an integral part of the community's way of life. With these differences, each Sub-Region plays its part in sustaining the livestock sector in RAEOA. The number of farming households engaged in livestock, as shown in **Figure 9.1,** highlights these variations.

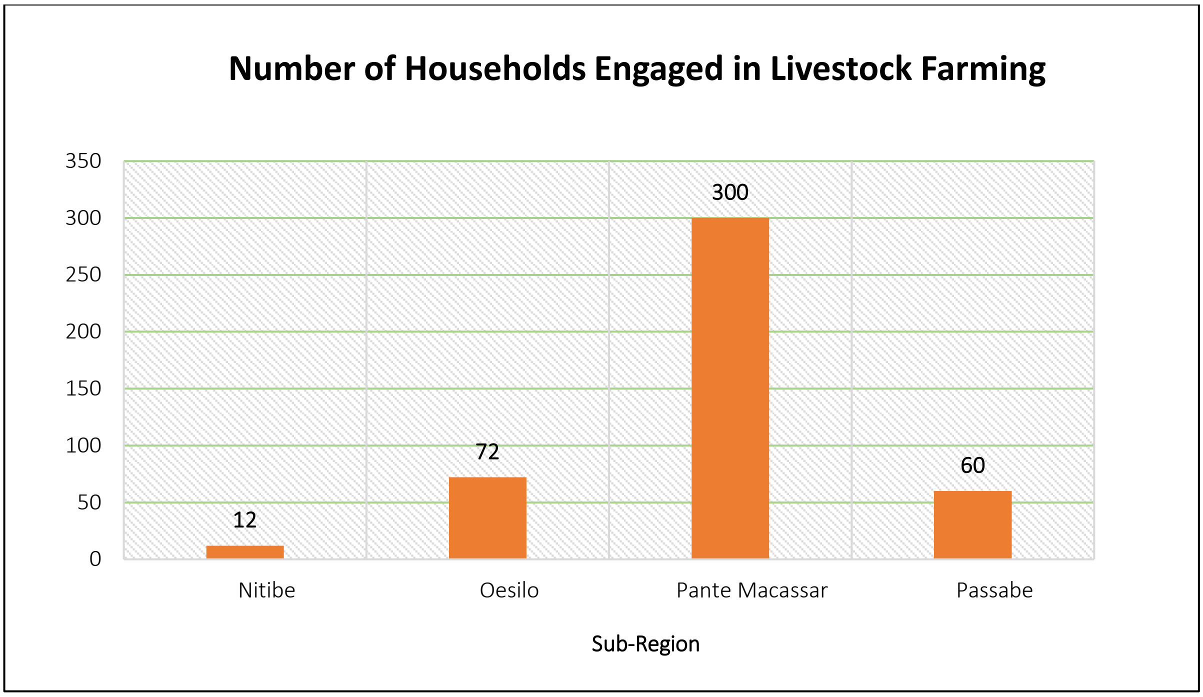


Figure 9.1 Number of Households Engaged in Livestock
(Source: Timor-Leste Agriculture Census, 2019).

Among large livestock, cattle are the predominant species kept in RAEOA. Pante Macassar Sub-Region has the highest number of cattle-keeping households, totaling 2,554 households (37.89 %) with a cattle population of 9,941 head. In contrast, the Passabe Sub-Region has the fewest cattle-keeping households, with 1,278 households (18.96 %) and 4,002 head (**Figures 9.2 and 9.3**). The largest number of horse-keeping households is found in the Nitibe Sub-Region, with 97 households (53.59 %) and a population of 223 head. Conversely, the lowest number of horse-keeping households is in the Sub-Region of RAEOA, with 12 households (6.63 %) and a population of 27 head (**Figures 9.2 and 9.3**). For water buffalo, Pante Macassar Sub-Region shows dominance, with 1,197 households (55.88 %) keeping a total of 5,545 head. The lowest number of buffalo-keeping households is in the Passabe Sub-Region, with 13 households (0.61 %) and 79 head (**Figures 9.2 and 9.3**). Meanwhile, households keeping dairy cattle were not found in any Sub-Region.

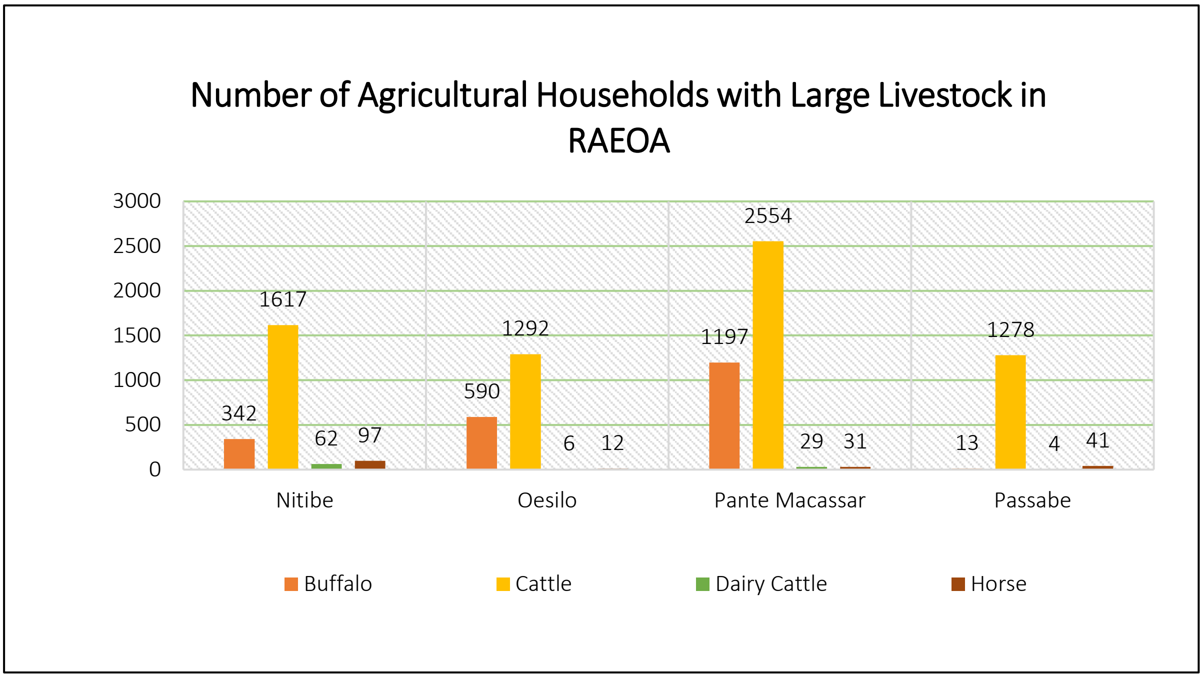


Figure 9.2 Number of Households With Large Livestock
(Source: Timor-Leste Agriculture Census, 2019)

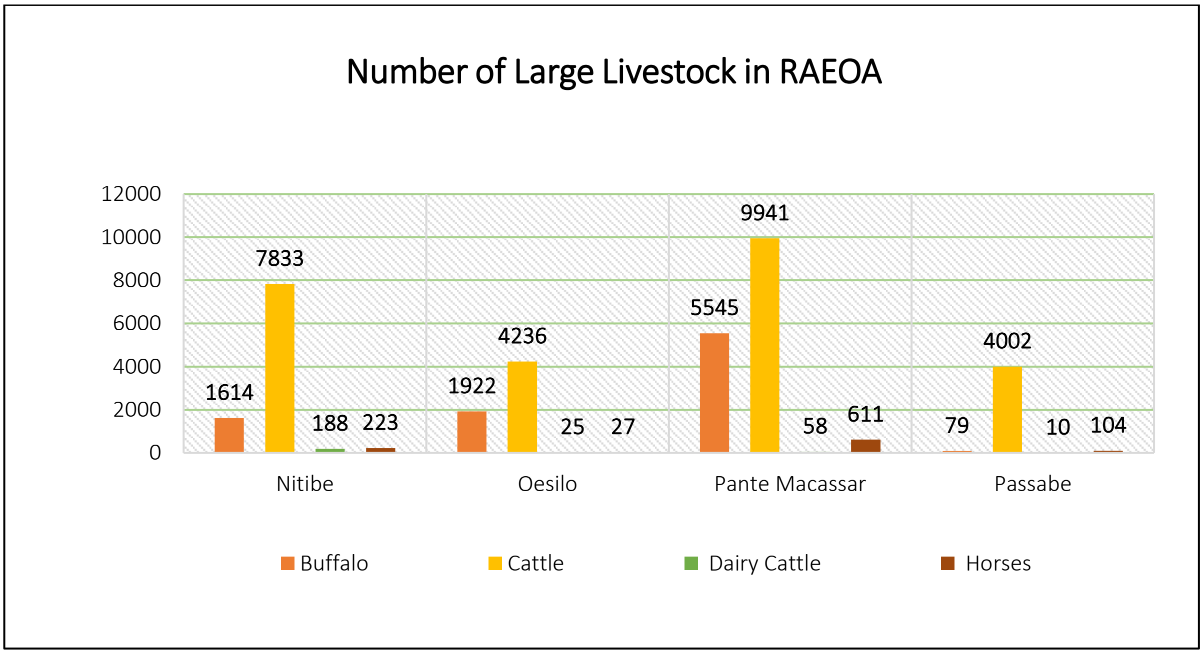


Figure 9.3 Number of Large Livestock in RAEOA Region
(Sumber: Timor-Leste Agriculture Census, 2019)

In RAEOA region, small livestock, particularly pigs, are the most commonly raised. Pante Macassar Sub-Region has the highest number of pig-keeping households, with 5,122 households (47.22%) raising a total of 19,234 pigs. In contrast, the lowest number is found in Passabe Sub-Region, with 1,943 households (13.77%) and 4,560 pigs (**Figures 9.4 and 9.5**).

The number of households raising goats shows significant variation. Pante Macassar Sub-Region has the highest number of goat-keeping households, with 2,307 households (50.33%) raising a total of 11,118 goats. The lowest number of goat-keeping households is found in Passabe Sub-Region, with 412 households (8.99%) and 1,493 goats (**Figures 9.4 and 9.5**).

Sheep are raised by a portion of households in RAEOA, although in limited numbers. Pante Macassar Sub-Region recorded the highest number of sheep-keeping households, with 45 households (48.39%), while the lowest number was recorded in Passabe Sub-Region, with 7 households (7.53%) (**Figures 9.4 and 9.5**).

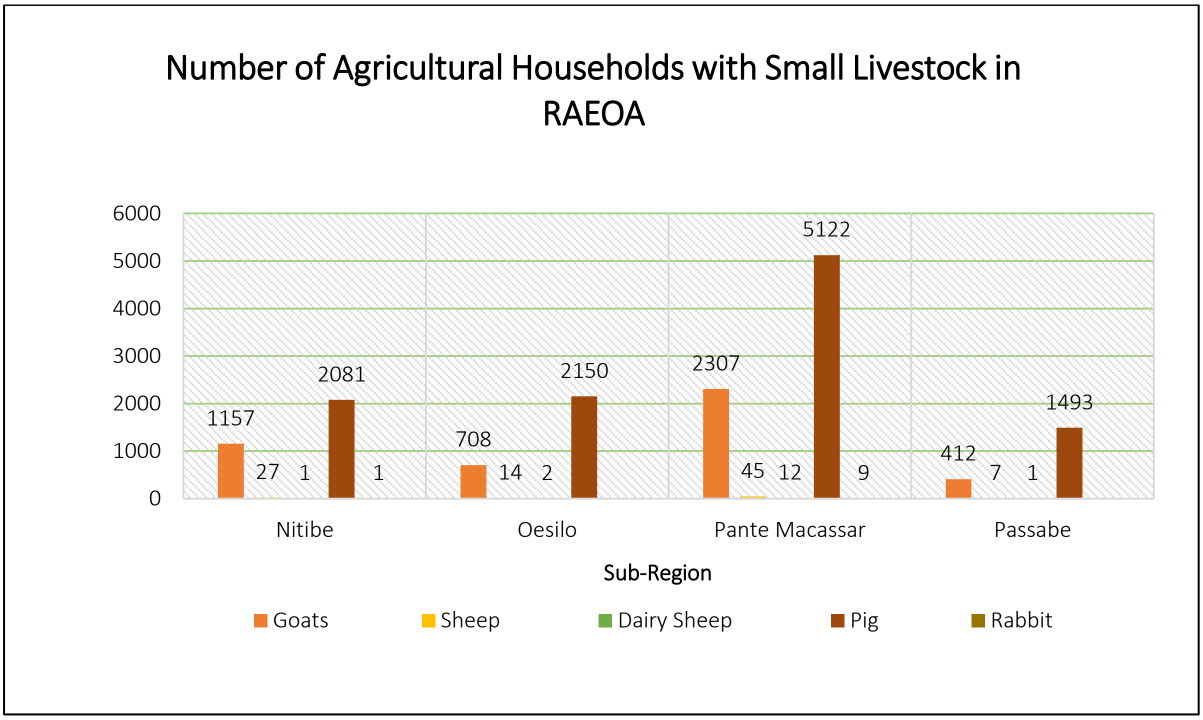


Figure 9.4 Number of Households with Small Livestock
(Source: Timor-Leste Agriculture Census, 2019)

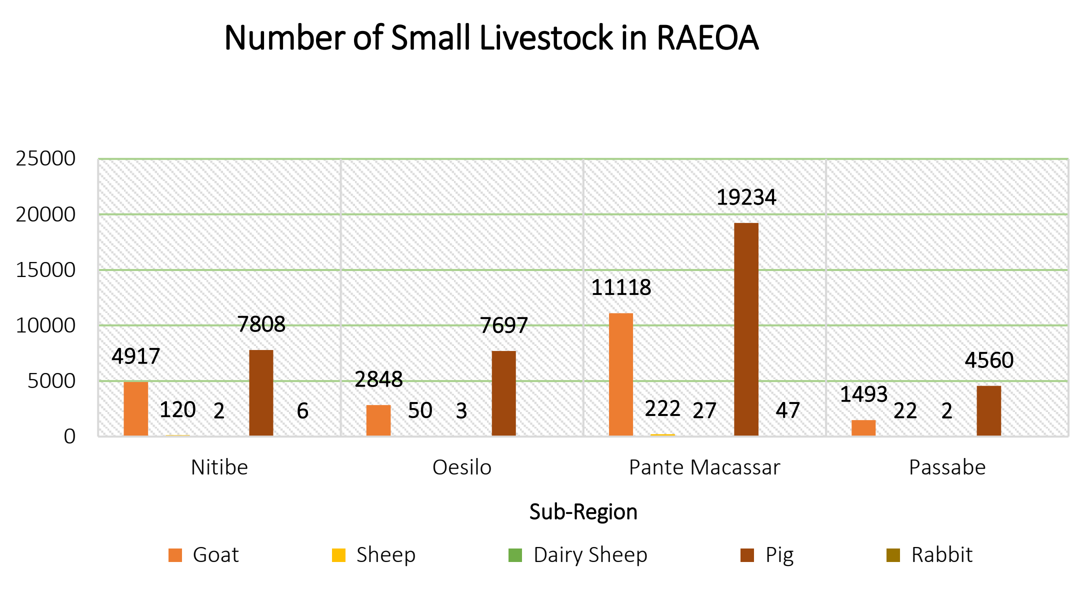


Figure 9.5 Number of Small Livestock in RAEOA Region
(Source: Timor-Leste Agriculture Census, 2019)

The number of households keeping poultry in RAEOA region shows significant variation between Sub-Regions, with chickens being the most commonly raised poultry species (**Figure 9.6**). Pante Macassar has the highest number of chicken-keeping households, with 5,166 households, or approximately 47.74%, raising a total of 53,554 chickens. Meanwhile, Passabe Sub-Region has the fewest chicken-keeping households, with 1,551 households (14.33%) and 16,731 chickens (**Figures 9.6 and 9.7**).

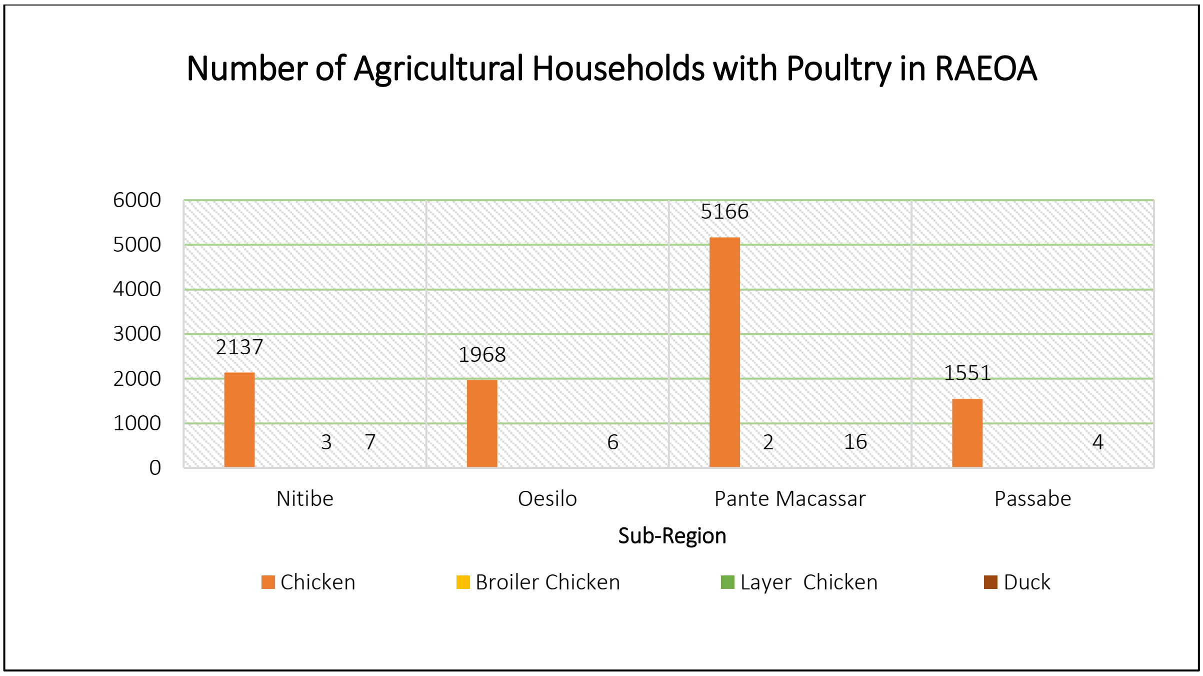


Figure 9.6 Number of Households with Poultry
(Source: Timor-Leste Agriculture Census, 2019)

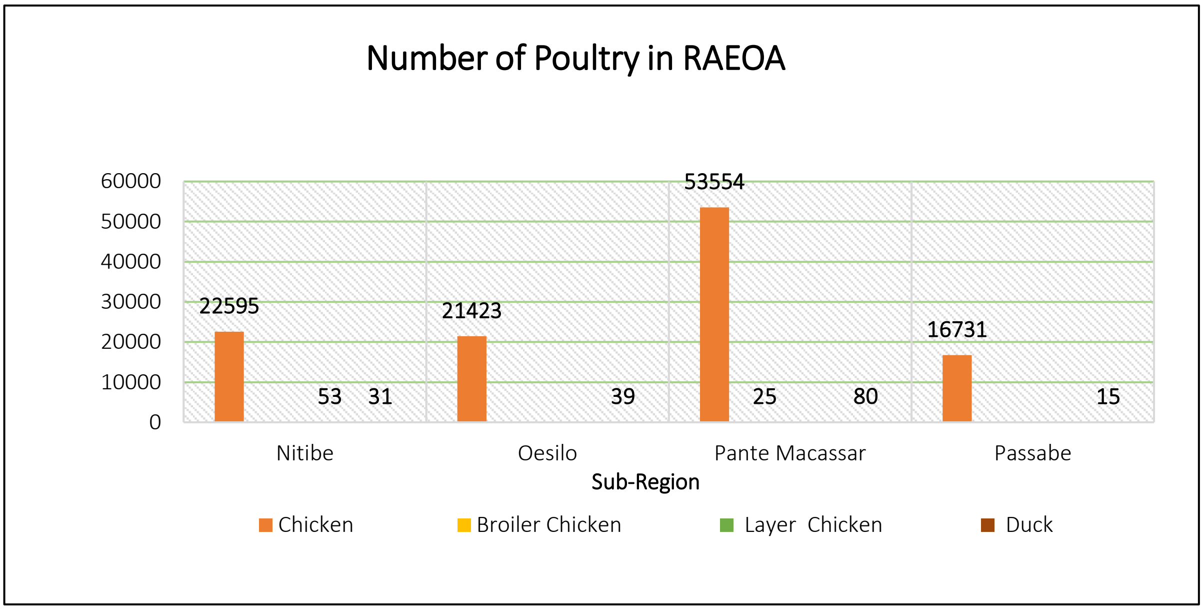


Figure 9.7 Number of Poultry in RAEOA Region
(Source: Timor-Leste Agriculture Census, 2019)

The potential of grazing lands is one of the key assets that can serve as a primary source of feed for livestock, especially for animals like cattle, goats, and sheep, which require high-quality grass to support growth and production in sustainable livestock farming. RAEOA region has two types of grazing lands: temporary and permanent grazing lands.

The largest area of permanent grazing land is found in the Nitibe Sub-Region, with a total of 3.83 ha, or 70.73% of the total permanent grazing area in this region. Next Pante Macassar Sub-Region has 1.05 ha (19.42%), and the smallest area is in Sub-Region RAEOA, with 0.53 ha (9.86%). Meanwhile, there is no permanent grazing land in Passabe Sub-Region.

For temporary grazing lands, Nitibe Sub-Region again records the largest area, with 3.13 ha (50.63%), followed by Pante Macassar Sub-Region with 3.04 ha (49.21%). Sub-Region RAEOA has the smallest area of temporary grazing land, with only 0.01 ha (0.16%). The distribution of grazing land area is presented in **Figure 9.8**.

For temporary grazing lands Nitiben Sub-Region again records the largest area, with 3.13 ha (50.63%), followed by Pante Macassar Sub-Region with 3.04 ha (49.21%). Sub-Region RAEOA has the smallest area of temporary grazing land, with only 0.01 ha (0.16%).

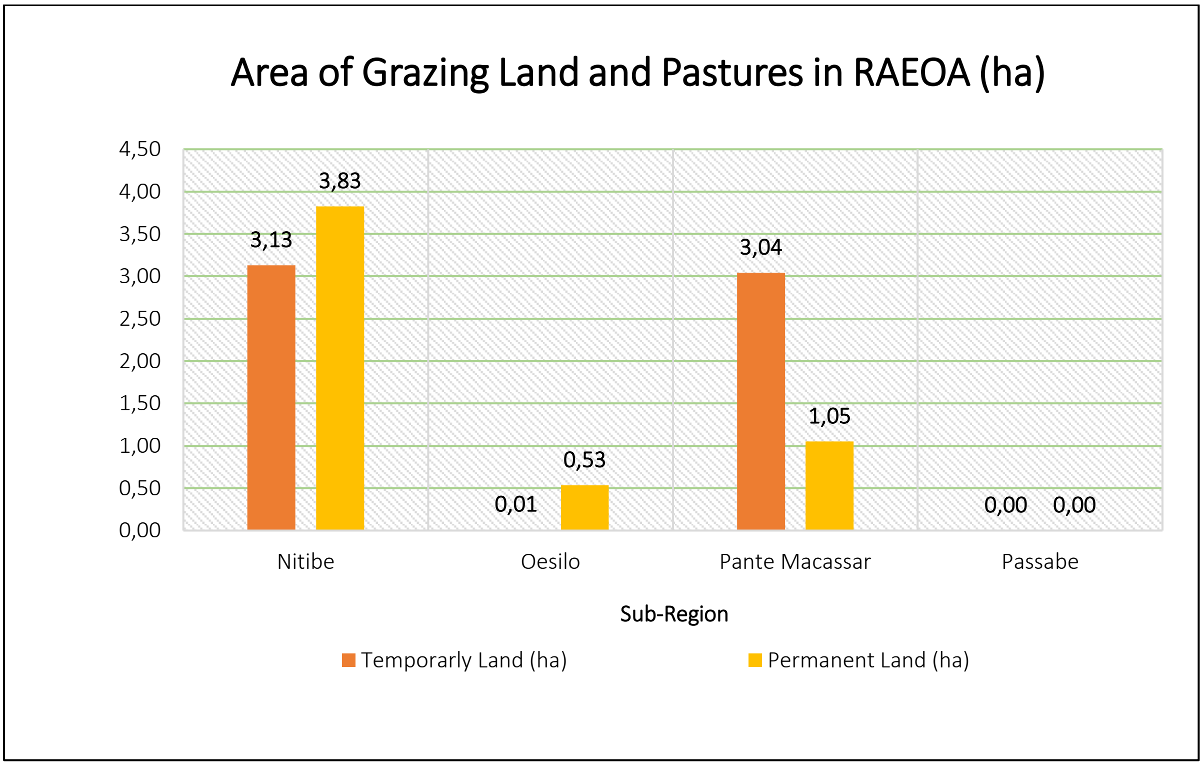


Figure 9.8 Grazing Land Area (ha) in RAEOA Region
(Source: Timor-Leste Agriculture Census, 2019)

B. Existing Conditions of the Survey Location

The Centro Produção Animal (CPA) Makelab, located in Taiboco Village, covers an area of 15 ha and currently manages around 60 goats, which are crossbred between local goats and Boer goats. The area has locally available forage (HPT), particularly Lamtoro trees, as the main source of feed. In addition to goat farming, a pigsty with a capacity of up to 200 pigs is under construction as part of the plan for diversifying livestock activities in the area.

Figure 9.9 Existing Conditions of the Survey Location
(Source: Research Documentation, 2025)

9.4 DISCUSSION

A. Evaluation of Forage Land Suitability for Livestock

Land suitability analysis for livestock forage in RAEOA region is a method used to evaluate the suitability of land for the growth of various types of forage and grasses on grazing lands within a specific area. This analysis aims to facilitate the development of forage resources while ensuring their optimal availability. According to Djaenudin *et al.* (2003), land suitability is defined as the extent to which land is appropriate for a specific use. Land suitability can be assessed based on current conditions (actual land suitability) or after improvements have been made (potential land suitability).

The land suitability evaluation in Timor-Leste uses a matching method that compares land characteristics and quality with suitability criteria based on the growth requirements of the evaluated plants. Several types of forage species mapped according to land resource potential include elephant grass (Pennisetum purpureum), legumes, and field grasses.

The results of the land suitability evaluation in the Nitibe, Oesilo, Pante Macassar, and Passabe regions show that these areas have potential for developing forage resources such as elephant grass, Setaria, legumes, and grazing fields, as presented in **Table 7.3 in Chapter VII of this book**. According to the table, actual land suitability for grazing varies from S2 (moderately suitable) to N (not suitable), with limiting factors including total nitrogen (N-total), available phosphorus (P), available potassium (K), slope, erosion, and surface rocks. Additionally, the dry season is a limiting factor for grazing. These constraints can be addressed through technical improvements such as adding NPK fertilizers, adding organic matter, planting slope-supporting plants, constructing terraces, implementing irrigation systems such as sprinklers, and clearing land. However, there are permanent limiting factors, such as rock outcrops, that cannot be improved.

To enhance the development of livestock farming, particularly forage resources in RAEOA region, several important steps need to be taken to improve both the quantity and quality of forage:

1. Planting Legume Forages

Planting legumes is a priority, as leguminous plants generally have higher nutritional content compared to grasses. However, since legumes have usage limitations, their proportion relative to grasses must be considered. Susetyo (1980) recommends an ideal grazing field composition of 60% grasses and 40% legumes. Furthermore, according to Skerman (1977), legumes play a role in preventing erosion, sometimes more effectively than forests, due to their strong and deep root systems.

2. Increasing Forage Species Diversity

Increasing the diversity of forage species, including both legumes and grasses, is an essential aspect of livestock feed development. The greater the diversity of forage species consumed by livestock, especially ruminants, the higher the likelihood of meeting their nutritional requirements. Some high-nutrient legume species that have potential for development include Indigofera, caliandra, Turi, and Stylo. A commonly found local legume is Lamtoro. However, caution must be exercised when feeding Lamtoro to pregnant livestock. Although it is nutrient-rich, Lamtoro leaves contain anti-nutritional compounds such as mimosine and cyanide acid, which can be toxic if consumed in excess. This can be mitigated by providing Lamtoro in moderate amounts, mixed with other feed, and ensuring it is air-dried to reduce the anti-nutritional substances.

B. Livestock Potential and Ecological Suitability

RAEOA region has a total area of 81,836.68 ha, with 39,594.86 ha allocated for livestock sector development. The optimal use of this potential requires empowerment of human resources and proper land utilization. One of the critical factors in determining the potential of a region for livestock development is ecological suitability or the environmental conditions of the area. Regions that do not meet ecological suitability indicators are categorized as less potential for livestock development. Therefore, the development of livestock enterprises in RAEOA must take into account ecological suitability.

After obtaining measurements from each field parameter, including geophysical parameters such as rainfall and temperature, as well as soil chemical parameters such as organic carbon (C-organic), total potassium (K-total), available potassium (K-Available), cation exchange capacity (CEC), base saturation (BS), and others, these are analyzed using Geographic Information System (GIS) applications to assess the ecological suitability for five types of livestock: sheep, beef cattle, dairy cattle, pigs, and buffalo. The GIS map of geophysical suitability for livestock is presented in **Figure 9.10.**

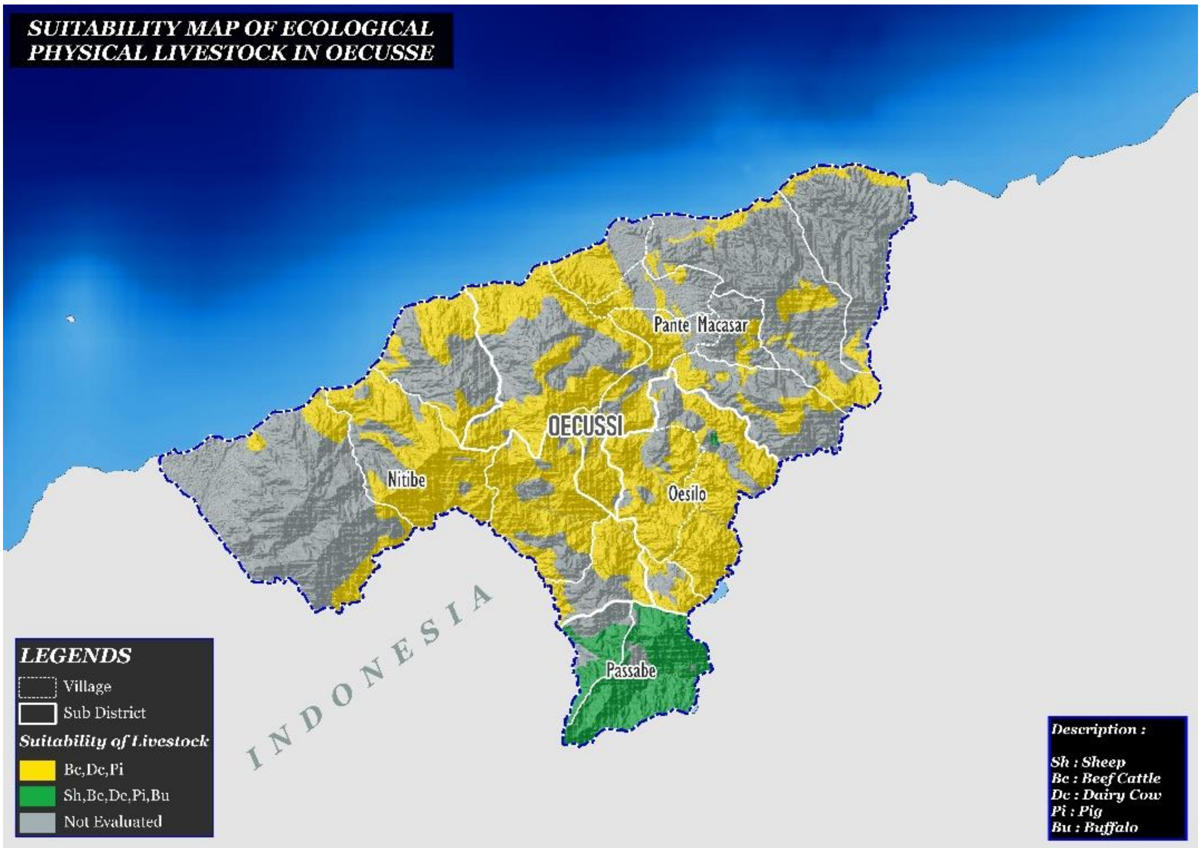


Figure 9.10 Map of Geophysical Ecological Suitability for Livestock in RAEOA Region

The land available for livestock development in RAEOA region includes areas designated for mixed gardens and grazing lands. These areas are considered available because they are assumed to be capable of producing livestock forage in the form of grasses, legumes, or crop residues. On the other hand, land categorized as unavailable for livestock development includes areas designated as forests and rice fields.

Technically, this limitation can be addressed with proper livestock housing that incorporates good air circulation and ventilation systems. However, for dairy cattle, temperature remains a critical factor that must be met for successful breeding.

Table 9.1 Area for Livestock Development (ha) in RAEOA

Sub-Region	Livestock Development Suitability Results for Large Livestock					Area(ha)
	Sheep	Beef Cattle	Dairy Cattle	Pigs	Buffalo	
Nitibe	N	S	S	S	N	13.447,02
Oesilo	N	S	S	S	N	7.450,71
Pante Macassar	N	S	S	S	N	13.623,61
Passabe	S	S	S	S	N	5.073,52

Based on the data analysis presented in **Table 9.1**, it is evident that the ecological suitability of land for the development of large livestock, including sheep, beef cattle, dairy cattle, pigs, and buffalo, shows spatial distribution variation in the study area. Nitibe and Pante Macassar Sub-region are the most dominant areas for large livestock development in RAEOA, followed by Oesilo Sub-region. In contrast, Passabe Sub-region occupies the smallest area for livestock development. Nitibe Sub-region, Oesilo Sub-region, and Pante Macassar Sub-region are suitable for the development of beef cattle, dairy cattle, and pigs, but not suitable for sheep and buffalo due to limiting factors such as rainfall. In Passabe Sub-region, the area is suitable for sheep, beef cattle, dairy cattle, and pigs, but not for buffalo due to the limiting factor of rainfall. The ecological suitability of land for poultry in the study area shows very high and uniform suitability, with a coverage of 100%. This reflects the biological characteristics of poultry, which have a wide capacity to adapt to various environmental conditions, allowing poultry farming to take place in almost all types of available land.

In support of the livestock sector development program, it is necessary to identify and map areas primarily for livestock farming and forage cultivation. RAEOA has an average environmental temperature of 25.59°C and annual rainfall of 1,248.76 mm, providing ecological potential that is conducive to supporting the sustainable operation of livestock farming optimally. This condition also supports the availability of livestock forage throughout the year. Environmental temperature plays a central role in determining thermal comfort and livestock productivity. Low environmental temperatures can cause cold stress in livestock, leading to an increase in body heat production and basal metabolic rate. If this condition persists without adequate feed support, the livestock's metabolic energy will decrease, reducing their ability to withstand extreme temperatures. This results in disrupted livestock growth, reduced productivity, and significantly increased disease risk.

On the other hand, excessively high environmental temperatures lead to reduced feed intake by livestock, as they opt to increase water intake instead. This reduction in nutrient intake directly impacts livestock production performance. Therefore, optimal environmental management, particularly adjusting temperature and humidity to appropriate levels, is a crucial prerequisite for sustainable livestock farming. These efforts aim to create conditions that support the physiological balance of livestock, thereby maintaining maximal productivity.

C. Socio-Economic Aspects in Community

For the communities in RAEOA, livestock plays a very important and multifunctional role, far beyond just being a source of food. Livestock has become an integral part of the subsistence farming system and the evolving civilization. It is still common to see communities using livestock, such as cattle, buffalo, and horses, as draft animals to plow fields. This use of livestock labor allows farmers to cultivate larger areas of land, significantly increasing agricultural productivity. In some cultures, livestock also holds social, economic, or ritual significance. For example, in some traditions, livestock is used as dowries or offerings in cultural ceremonies. Moreover, the number of livestock owned by an individual is often used as a measure of wealth and social status in the community.

Livestock farming in RAEOA is primarily still carried out through traditional, free-range grazing systems, also known as extensive systems. According to Williamson and Payne (1993), in extensive farming systems, livestock are kept freely and graze on available forage in the wild. In this system, animals are released with a composition of males and several females in one population. The main characteristic of extensive farming is the lack of barns and no additional feed is provided (Jamili, M. A., 2022). Extensive farming systems have advantages such as low labor requirements, short working hours, and livestock being able to forage in grazing fields and former agricultural lands. However, the drawbacks include difficulty in controlling feed intake, and livestock are more prone to diseases and death. Unsupervised and free-range livestock can also cause social issues, such as livestock theft and damage to farmers' crops.

The livestock farming system still relies heavily on traditional knowledge passed down through generations. The absence of large-scale livestock industries means that livestock production has not reached its maximum potential, with many aspects still needing improvement. The distribution of livestock within the community remains relatively low due to limited capital and poor breeding practices. This is because increasing livestock numbers requires significant financial investment and time. As a result, livestock is not seen as a primary income source, which has contributed to the low level of livestock production in the area (Serey *et al.*, 2014).

From interviews, it was found that RAEOA community received aid in the form of cattle and buffalo in 2014 from MAPPF. When RAEOA was still part of Indonesia, it was one of the regions with the highest productivity of Bali cattle. However, over time, due to poor supervision and lack of community education, this aid did not develop according to its original purpose. The community used the aid to meet household needs or as dowries (belis). As a result, attention to the sustainability of livestock breeding has been neglected, which could hinder sustainable development.

Another issue in the livestock sector is complex, spanning from the upstream to the downstream stages, as well as the infrastructure, which also needs to be developed. In terms of breeding, the community still uses natural mating systems without knowledge of artificial insemination (AI) technology, making sustainable breeding difficult. Additionally, the community lacks proper knowledge of livestock management practices. The community is also not educated on proper feed management to improve livestock productivity. In terms of marketing, farmers are only able to sell live livestock, making it difficult to increase the selling price of their products. Although access from Dili, the region capital, has improved, inadequate road infrastructure still remains a barrier for the community in marketing their livestock products to wider markets.

Given the numerous challenges faced, from pre-production to post-production, these issues need to be addressed in order to provide a foundation for designing a master plan for livestock development in RAEOA region. Recommendations for improvement include starting with education on breeding practices and introducing AI technology to the community. Furthermore, educating the community about the importance of livestock management is crucial. This will help motivate RAEOA community to approach livestock farming with an economic mindset, rather than treating it merely as family savings. The government should not only focus on education but also provide financial support in the form of loan programs to facilitate livestock businesses. Improving the marketability of livestock products can be achieved by educating the community and opening new marketing channels, beyond just the sale of live livestock.

X. FRESHWATER FISHERIES POTENTIAL

10.1 INTRODUCTION

Timor-Leste, as an archipelagic country, holds vast natural resource potential, particularly in the marine and fisheries sectors. ***Região Administrativa Especial de Oe-Cusse Ambeno*** **(RAEOA)**, as one of the administrative regions, offers a variety of topographic, soil, water quality, and climatic conditions that present significant potential for developing aquaculture, both freshwater and brackish. Aquaculture not only contributes to local food security but also opens up sustainable economic opportunities for surrounding communities.

However, the development of aquaculture enterprises requires in-depth land suitability studies. Selecting the appropriate location is crucial for the success of this industry, as each fish species has different tolerances to environmental factors such as topography and hydrology, soil conditions, water quality, and climate. Therefore, land suitability analysis is an essential first step in aquaculture planning.

This study aims to evaluate land suitability in RAEOA region based on a range of bio-physical parameters identified in an assessment matrix. The matrix includes four main factor groups: Topography and Hydrology, Soil Conditions, Water Quality, and Climate. Each factor is assigned a specific weight that reflects its importance in determining the land's suitability for aquaculture.

The use of the assessment matrix is key in determining whether the land in RAEOA region can support a sustainable and efficient aquaculture production system. This evaluation not only focuses on technical analysis but also incorporates aspects of local policy, community participation, and customary practices in water resource management, ensuring that the results can be optimally applied in the RAEOA. The study focuses solely on freshwater aquaculture, particularly on cultivation activities carried out by communities in lowland and coastal areas.

10.2 RESEARCH METHODS

This study began with a literature review, data collection, data analysis, and preparation of recommendations. In general, the work was divided into stages that included: (a) literature review and regional–demographic information, (b) identification of aquaculture land suitability variables, (c) design of the aquaculture land suitability matrix and parameters, (d) aquaculture land suitability assessment (weighting and scoring), (e) field survey, (f) laboratory soil analysis, and (g) land suitability analysis, as shown in the diagram in **Figure 10.1.**

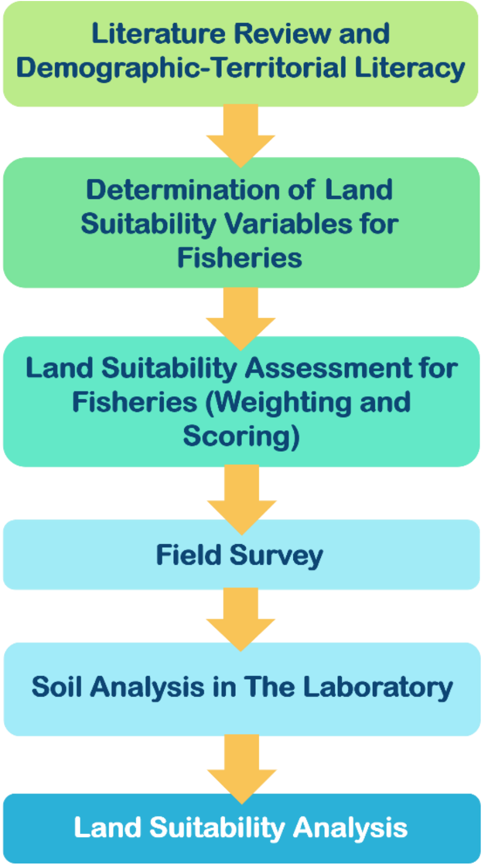


Figure 10.1 Flowchart of the research process for land suitability in the aquaculture sector

A. Literature Review and Regional–Demographic Information

Data and information collection primarily comprised a review of secondary sources available from: (a) government-funded projects, (b) reports of local and regional non-governmental organizations (NGOs), and (c) other reference journals using the keywords “Timor-Leste” and “aquaculture Timor-Leste.” All reference data were research outputs and assessments from the past 5 to 10 years to obtain the theoretical basis, research methods, and findings relevant to the problems studied.

Collection of regional information included a review of the geographic conditions of the study area, comprising: (a) the base map (RBI) of Timor-Leste administrative boundaries, (b) the hydrology map, (c) the most recent Population Census report (2022), and (d) the most recent Agricultural Census report (2019) for Timor-Leste.

B. Determination of Aquaculture Land Suitability Variables

Based on the literature review, the factors influencing land for fisheries activities, particularly aquaculture, were identified as: (a) topography, (b) soil conditions, (c) water quality, and (d) climate. The variables were determined based on several assumptions, which are presented in **Table 10.1.**

Table 10.1 Considerations for factors assumed in determining variables for aquaculture land suitability

Factors / Variables	The applicable assumptions (employed in this study)
Topography	The fisheries sector requires specific elevation conditions to operate and to determine the design of aquaculture ponds.
Soil Conditions	The simplest medium for aquaculture operations is the earthen pond, in which the soil is in direct contact with the water and strongly influences water quality.
Water Quality	Water is the medium in which fish live, and fish carry out all metabolic and non-metabolic activities in the pond water.
Climate	Water availability derives not only from springs but also from the hydrological cycle, which depends on the rainy season.

C. Design of the Aquaculture Land Suitability Matrix and Parameters

Land potential assessment for specific uses is carried out through land evaluation using certain methods, which will serve as the basis for decision-making on land use, such as for ponds (Mustafa *et al.*, 2007). Land evaluation is based on the analysis of the relationship between land and land use, as well as estimating the required inputs and desired outputs.

Two main aspects of land evaluation are: (a) physical resources, including soil, water, topography, and climate; and (b) socio-economic resources, including farm size, management level, availability of labor, market location, and other human activities. Physical resources are considered relatively stable, while socio-economic resources are more variable and dependent on social and political decisions. For pond aquaculture, land evaluation criteria are limited to physical resources only. Important aspects to consider in pond aquaculture land evaluation include water sources, soil quality, and infrastructure availability (Chanrantchakool *et al.*, 1995). Ecological, topographical, soil, and biological aspects must meet the requirements for pond aquaculture evaluation (Poernomo, 1979). Engineering aspects, soil quality, water quality, and infrastructure facilities are considered by Karthik *et al.* (2005) in pond aquaculture land evaluation.

Specific growth, survival, and production requirements are needed for all types of commodities, including land-based aquaculture (Mustafa *et al.*, 2007b; 2008). Minimum, optimal, and maximum range boundaries are established for growth or land use requirements for each commodity. These requirements serve as the basis for establishing land suitability classes, which are linked to land characteristics to determine land suitability. The land characteristics that are optimal for the commodity or land use needs define the boundary for the highly suitable class (S1). Land quality below optimal defines the boundary between the moderately suitable class (S2) and/or marginally suitable class (S3). Physically unsuitable land (N class) lies outside these boundaries. The factors/sub-models and variables used as land suitability criteria for various pond commodities are explained in the following section.

Table 10.2 Relationship between parameters, data acquisition, and data sources

No	Factor, Parameter	Unit	Instrument	Measurement Method
1.	Topography - Slope gradient	%	Remote Sensing/ Cliamtology	Ex Situ / Digital
2.	Soil Conditions			
	- Clay content	%	Gravimetric tools	Laboratory
	- pH_F-pH_{FOX}	-	Spectrophotometer	Laboratory
	- Organic carbon	mg/L	Spectrophotometer	Laboratory
3.	Water Quality			
	- Temperature	°C	Multimeter EZ-9901	In Situ
	- Salinity	ppt	Refractometer	In Situ
	- pH	-	Multimeter EZ-9901	In Situ
	- Total Dissolved Solid (TDS)	mg/L	Multimeter EZ-9901	In Situ
	- Ammonia	mg/L	Tetra-Kit (TAN conversion)	In Situ
	- Dissolved Oxygen (DO)	mg/L	DO-meter	In Situ
4.	Climate			
	- Annual rainfall	mm/year	Remote Sensing/ Climatology	Ex Situ / Digital
	- Dry months	-	Remote Sensing/ Climatology	Ex Situ / Digital

a. Topography

The influence of topography, such as landform or slope gradient, on the pond's water exchange capacity has been reported, particularly for traditionally (extensively) and semi-intensively managed ponds. Generally, land in coastal areas is classified as flat, although certain areas are classified as gentle or undulating. Flat land is recommended for pond aquaculture (Chanrantchakool *et al.*, 1995). Despite the often-flat nature of pond areas, elevation above the highest high-water mark can hinder gravity-fed water intake. Conversely, elevation below the lowest low-water level can complicate pond drainage or water discharge (Liu *et al.*, 2021). Therefore, the optimal pond elevation minimizes excavation but allows for the desired pond depth. Additionally, pond construction costs can be minimized while maintaining the fertility of the pond base. The ideal pond base elevation is one where the pond can be drained at any time and filled by gravity within 5 days from each tidal cycle (Bose *et al.*, 1991; Pulido-Calvo *et al.*, 2023). Compared to ponds for milkfish and tilapia, shrimp ponds, particularly for vannamei shrimp, require greater water depth.

b. Soil Conditions

Soil properties change gradually over long periods. Chemical and physical weathering, even under ideal conditions, requires hundreds or even thousands of years to develop mature, fully developed soil. Therefore, in selecting soil quality criteria for pond aquaculture, variables that strongly affect aquaculture production are chosen, but these variables are stable or difficult to change.

Pyrite (FeS_2) is a compound found in high concentrations in acid sulfate soils. In its natural reduced state, pyrite does not pose a problem in aquaculture. However, when pyrite is exposed to air during pond construction, oxidation of pyrite occurs, leading to a drastic decrease in soil pH and a sharp increase in the solubility of toxic elements, which consequently reduces pond productivity. Therefore, pyritic layers should be avoided when selecting locations for pond aquaculture.

Soil texture refers to the proportion of clay, silt, and sand in the soil. Pond soil texture strongly affects porosity and the growth of *klekap*, which can become a food source for fish and shrimp. Ponds with coarse-textured soils like sand and sandy loam have high porosity, and as a result, they cannot retain water. Pond soils often have fine textures, with clay content ranging from 20% to 30% to prevent lateral seepage (Boyd, 1995). The ideal soil texture for ponds includes clay, clay loam, clayey silt, silty loam, and sandy clay loam (Ilyas *et al.*, 1987).

pH_F is the pH measured directly in the field, while pH_{FOX} is the pH measured after oxidation with 30% hydrogen peroxide. Both are characteristic variables of acid sulfate soils. The difference between pH_F and pH_{FOX} ($pH_F - pH_{FOX}$) can be used as an indicator of the acid potential in acid sulfate soils. In this case, The greater the value of pH_F-pH_{FOX}, the higher the potential acidity in acid sulfate soils.

Most soils are mineral soils but contain organic matter. Organic matter in ponds can affect soil stability, oxygen consumption, nutrient availability, and habitat suitability for pond organisms. Surface soils (0 to 0.2 m) of mineral soils used in agriculture rarely contain 5% to 6% organic matter, and in tropical and subtropical regions, organic matter content is typically lower (Boyd, 1995). For soils with high clay content (>60%), Boyd (1995) considers organic matter content below 8% to be slight, meaning it is beneficial and easy to manage for pond aquaculture. However, very high organic matter content can reduce the environmental quality of pond ecosystems. Its decomposition produces toxic compounds, which are a negative impact of organic matter.

c. Water Quality

Since the organisms cultured in ponds live in the water, water quality is a critical factor in the success of aquaculture. Good water quality supports the life of aquatic organisms and their food sources throughout the culture stages. Important water quality variables for pond aquaculture include turbidity, temperature, salinity, pH, and NH_3.

Water clarity in ponds is determined by the degree of turbidity, which results from the suspension of organic particles, colloidal soil, or plankton density. In newly established ponds on peat or acid sulfate soils, water clarity may decrease due to suspended particles or iron hydroxide ($Fe(OH)^3$) compounds or organic acids and tannins leached from plant root residues, resulting in brownish-black colored water (Poernomo, 1988). The optimal temperature for vannamei shrimp growth is 28°C to 30°C (Ponce-Palatox *et al.*, 1997). The ideal water temperature for milkfish culture is 27°C to 31°C (Ismail *et al.*, 1993). The optimal water temperature for tilapia culture is 25°C to 30°C (Stickney, 2000; Hossain *et al.*, 2007), with tolerance for temperatures between 15°C and 37°C (Wiryanta *et al.*, 2010).

Salinity refers to the total dissolved solids in saltwater when carbonates have been converted into oxides, bromides and iodides replaced by chlorides, and organic material has been fully oxidized (Boyd, 1995). The direct effect of salinity on aquatic organisms is through its impact on osmotic pressure and fluid content within the organisms (Poxton, 2003). In coastal waters, salinity values are greatly affected by freshwater input from rivers. Vannamei shrimp, milkfish, and tilapia are euryhaline organisms; however, since they are farmed commercially, maintaining an optimal salinity range is necessary. Vannamei shrimp typically grow best at 15 to 20 ppt salinity (Bray *et al.*, 1994). Milkfish grow optimally at 15 - 30 ppt salinity (Ismail *et al.*, 1993). Tilapia can live in a broad range of salinity, making them suitable for both freshwater and brackish water aquaculture (Watanabe, 2000; Hossain *et al.*, 2007).

The tolerance limits of aquatic organisms to pH vary and are influenced by factors such as dissolved oxygen, alkalinity, the presence of ions, and the organism's stage of development. Milkfish grow optimally at a pH range of 7.0 to 8.5 (Ismail *et al.*, 1993). According to Swingle (1968), the ideal pH for aquatic organisms is between 6.5 and 9.0, while values between 9.5 and 11.0 or 4.0 and 6.0 result in low production. pH values below 4.0 or above 11.0 are toxic to fish.

Ammonia can exist in molecular form (NH_3) or as ammonium ions NH_4 , with NH_3 more toxic than NH_4 (Poernomo, 1988). NH_3 can penetrate cell membranes faster than NH_4. NH_3 concentrations of 0.05 to 0.20 mg/L inhibit the growth of aquatic organisms in general. When NH_3 levels exceed 0.2 mg/L, the water becomes toxic for certain fish species (Sawyer & McCarty, 1978). Stickney (2000) noted that tilapia are relatively tolerant to high ammonia concentrations. Fish cannot tolerate excessive NH_3 levels as it disrupts oxygen binding by blood, potentially causing hypoxia or carps mortality.

d. Climate

The long-term average weather conditions, known as climate, play an essential role in pond aquaculture. Key climatic elements for pond aquaculture include rainfall. Rainfall between 2,000 and 3,000 mm/year, with 2 to 3 dry months, is optimal for pond aquaculture (Mustafa *et al.*, 2011). The dry months, as defined by the Schmidt & Ferguson (1951) climate classification, are those with rainfall < 60 mm. Pond preparation is one of the activities that must be done before stocking. During pond preparation, pond drying is carried out to improve soil physical properties, enhance organic matter mineralization, and remove toxic substances like hydrogen sulfide, ammonia, and methane. Therefore, certain dry months are necessary each year for proper pond preparation.

D. Land Suitability Assessment for Aquaculture

The land evaluation guideline used in this study is the FAO Land Evaluation Framework (FAO, 1976). Specifically, for pond aquaculture, Hardjowigeno *et al.* (1996) developed land suitability criteria for brackish water fishponds, which also referred to the FAO (1976) land evaluation framework. However, the land suitability criteria presented are still quite limited. Land suitability classification involves comparing land quality with the requirements for the desired land use.

The land suitability assessment for selecting fish pond locations is carried out by constructing a land suitability matrix based on a weighting system. The suitability of the parameters for earthen pond aquaculture is divided into four levels for each parameter: Highly Suitable (S1), Moderately Suitable (S2), Marginally Suitable (S3), and Not Suitable (N). The land suitability classification structure, according to the FAO (1976) framework, consists of four categories, as:

Table 10.3 Land Suitability for Pond Aquaculture Parameters

Class Code	Class Quality	Land Description
S1	Highly Suitable	The land has no severe limiting factors for sustainable use or only has minor limiting factors that do not significantly affect production or lead to increased inputs in general.
S2	Moderately Suitable	The land has moderately severe limiting factors that require significant management efforts to maintain. These limiting factors will reduce productivity and profits, and increase required inputs.
S3	Marginally Suitable	The land has very severe limiting factors that make it difficult to maintain the necessary management levels. These limiting factors will significantly reduce productivity and profits, requiring increased inputs.
N	Not suitable	Land in this class has limiting factors so severe that they prevent continued use for the planned purpose.

Parameters that are expected to have a greater influence as limiting factors for aquaculture organisms are given higher weights. The land suitability criteria are formulated based on the required parameters, referencing the suitability matrix (**Table 10.6**). The assignment of weights and scores in **Table 10.2** takes into account the impact of the variables determining the success of fish farming (Hastari *et al.*, 2017). Scores are assigned with values of 1 (N), 2 (S3), 3 (S2), and 4 (S1). An example of the calculation/score is shown in **Table 10.4.**

Table 10.4 Land Suitability Scoring Calculation

Factor and Variable	Weight	Score	Weight × Score	Final Evaluation
Slope Gradient (%)	0.12	4	0.48	4 (Highly Suitable)
Clay (%)	0.12	4	0.48	
pH_f-pH_{fox}	0.08	4	0.32	
Organic Carbon	0.02	4	0.08	
Temperature (°C)	0.05	4	0.2	
Salinity (ppt)	0.1	4	0.4	
pH	0.07	4	0.28	
TDS (*Total Dissolved Solid*)	0.07	4	0.28	
DO	0.15	4	0.6	
Ammonia (mg/L)	0.06	4	0.24	
Annual Rainfall (mm/year)	0.06	4	0.24	
Dry Months	0.1	4	0.4	

E. Field Survey

The field survey team aims to validate the literature study against real-time field conditions. The areas visited include 14 Districts, with consultations held with local stakeholders at various locations. The field visits were focused on observing locations recommended by local stakeholders, including: (a) the President Authority of the *Munisípiu* (PAM), which is the district head equivalent to a governor in the District; (b) the *Servisu Munisípiu de Agrikultura* (SMA), the agricultural agency equivalent to the agricultural office in the District; and (c) the Field Fisheries Extension Agent, who directly interacts with fishpond farmers and aquaculture practitioners in the local area. These parties serve as links in the field survey activities for aquaculture farmers and also point out potential locations for aquaculture development. The recommended potential locations are listed in **Table 10.5**.

Table 10.5 Field Survey Activities Based on Regions in RAEOA

No.	Schedule	Sub-Region	Village	Purpose (Ownership)
1	18 May 2025	Pante Macassar	Costa	Non-Business (Goverment)
2	18 May 2025	Pante Macassar	Sacato	Business (Individual)

The selection of locations for the field visits and the scheduling of consultations with local stakeholders was carried out collaboratively by the survey team, taking into account:

a) The balance between districts with potential for inland freshwater and coastal aquaculture development;
b) The inclusion of districts that have been identified by the Ministry as having aquaculture development potential.

F. Soil Analysis in the Laboratory

Soil conditions in coastal and aquatic ecosystems (such as ponds, estuaries, or mangrove forests) are interconnected. The physicochemical properties of the soil affect: (a) water column quality (pH, salinity, heavy metal content); (b) nutrient availability; and (c) habitat suitability for organisms such as fish, shrimp, mollusks, macroalgae, and mangrove plants. Soil analysis, integrated with an understanding of aquatic habitats, provides added value in the planning of conservation, aquaculture, and rehabilitation of aquatic ecosystems, as shown in Table 10.6.

Table 10.6 Soil Analysis Parameters and Their Relationship and Significance to Aquatic Commodity Habitats

Soil Parameter	Purpose & Significance	Relationship with Water Quality	Impact on Aquatic Commodity Habitat
Clay Content	Clay fraction plays a key role in soil physical properties such as water retention, permeability, and nutrient retention. High clay content enhances the soil's ability to store nutrients but can hinder aeration.	Affects water infiltration and retention as well as sediment transport.	High clay → ideal habitat for mollusks, but poor for demersal fish that need coarse substrates.
pH_F-pH_{FOX}	The difference between pH_F and pH_{FOX} indicates latent acidity potential. A significantly lower pH_{FOX} indicates potential acid sulfate soils, which is important for wetland restoration or land use planning.	Indicator of latent soil acidity → affects water column pH.	Low pH → physiological stress on fish and shrimp; affects metal bioavailability.
Organic Carbon	Organic carbon is a primary indicator of soil fertility and quality. High organic carbon content suggests healthy soil conditions and has potential as a carbon sink (blue carbon), especially relevant in mangrove and wetland ecosystems.	Source of organic nutrients in remineralization processes → influences DO and primary productivity.	Determines soil fertility for aquaculture and the growth substrate for macroalgae and seagrasses.

G. Aquaculture Land Suitability Analysis

The observations in the field and the results from laboratory analyses are then tabulated into data on aquaculture land characteristics. The land suitability for aquaculture is analyzed by matching the land characteristic data with the habitat requirements for fish and other aquaculture commodities. This results in land suitability classes based on the criteria of Mustafa *et al.* (2012). The land suitability classification is analyzed down to the unit land level. Potential land suitability is determined by considering the inputs and management actions applied to each aquaculture unit, assuming that efforts are undertaken. As an example, the land suitability criteria for tilapia farming are presented in **Table 10.7**, which is the most dominant fish commodity in almost every aquaculture pond in Timor-Leste, and the land suitability criteria for carp farming are presented in **Table 10.8.**

Table 10.7 Land Suitability Criteria for Tilapia Farming (*Oreochromis niloticus*)

Usage Requirements/ Parameters	Suitability Class			
	S1	S2	S3	N
Topography				
- Slope Gradient (%)	< 0,1	0,1-1,0	1,0-2,0	> 2,0
Soil Conditions				
- Clay Content (%)	10-20	20-30	30-60	< 10 > 60
- pH_F-pH_{FOX}	< 1,5	1,5-3,5	3,5-6,0	> 6,0
- Organic Carbon	1,5-2,5	0,5-1,5	< 0,5 2,5-8,0	> 8,0
Water Quality				
- Temperature (°C)	28-30	20-28 30-35	12-20 35-40	< 12 > 40
- Salinity (ppt)	< 10	10-25	25-35	> 35
- pH	7,5-8,5	6,0-7,5 8,5-9,5	4,0-6,0 9,5-11,0	< 4,0 > 11,0
- TDS (ppm)	<1000	1000–1500	1500–2000	>2000
- Ammonia (mg/L)	< 0,3	0,3-0,4	0,4-0,5	> 0,5
- DO (mg/L)	>5	4–5	3–<4	<3
Climate				
- Annual Rainfall(mm/year)	2.500-3.000	2.000-2.500	1.000-2.000 3.000-3.500	< 1.000 > 3.500
- Dry Months	1-2	2-3	3-5	< 1 > 5

Source: Mustafa (2012)

Table 10.8 Land Suitability Criteria for Carp Farming (*Cyprinus carpio*)

Usage Requirements/ Parameters	Suitability Class			
	S1	S2	S1	N
Topography				
- Slope Gradient (%)	< 0,1	0,1-1,0	1,0-2,0	> 2,0
Soil Conditions				
- Clay Content (%)	10-20	20-30	30-60	< 10 > 60
- pH_F-pH_{FOX}	< 1,5	1,5-3,5	3,5-6,0	> 6,0
- Organic Carbon	1,5-2,5	0,5-1,5	< 0,5 2,5-8,0	> 8,0
Water Quality				
- Temperature (°C)	24-28	22≤24 28-30	20≤22 30-32	< 20 > 32
- Salinity (ppt)	< 10	10-25	25-35	> 10
- pH	6,5-8,5	6,0≤6,5 8,5-9,0	5,5≤6,0 9,0-9,5	< 5,5 > 9,5
- TDS (ppm)	<1000	1000–1500	1500–2000	>2000
- Ammonia (mg/L)	< 0,05	0,05-0,1	0,1-0,5	> 0,5
- DO (mg/L)	>5	4–5	3–<4	<3
Climate				
- Annual Rainfall (mm/year)	2.500-3.000	2.000-2.500	1.000-2.000 3.000-3.500	< 1.000 > 3.500
- Dry Months	1-2	2-3	3-5	< 1 > 5

Source : Mustafa (2012)

10.3 EXISTING CONDITIONS AND OBSERVATION RESULTS

Região Administrativa Especial Oé-Cusse Ambeno **(RAEOA)**, previously known as Oecusse, has considerable potential for fisheries and aquaculture, particularly due to its strategic position along the northwestern coast of Timor-Leste. This geographical advantage provides direct access to marine water resources and opportunities for the development of capture fisheries and aquaculture systems based on coastal, brackish-water, and freshwater environments.

Based on data from the Directorate of Fisheries, Aquaculture, and Marine Resource Management in 2022, aquaculture production in RAEOA in 2019 was recorded at 45,812 kg. However, in 2020 production declined to 30,124 kg, which is assumed to have been caused by technical constraints and limited supporting infrastructure. Along with enhanced technical support and increased capacity of local human resources, production began to recover from 2021 onwards, reaching 31,509 kg, increasing to 32,287 kg in 2022, and projected to reach 33,145 kg in 2023. This increase reflects progress in aquaculture management systems, the adoption of more efficient farming technologies, and active involvement of local communities in fisheries development. With integrated policy support, RAEOA has substantial potential to develop aquaculture as one of the strategic sectors for strengthening food security, reducing poverty, and promoting sustainable economic development in the region.

A. Capture Fisheries

The fisheries sector in the ***Região Administrativa Especial Oé-Cusse Ambeno*** **(RAEOA)** has significant potential for development, particularly because the area is coastal and has abundant marine resources. According to reports from the Ministry of Agriculture and Fisheries of Timor-Leste, various efforts have been made in recent years to support growth in this sector, such as the development of fisheries infrastructure, training for fishers, and the provision of more adequate fishing gear. Local community participation is also an important factor in increasing catches and improving management efficiency. In addition, more sustainable approaches have begun to be implemented to maintain the balance of marine ecosystems. With government support and community participation, the fisheries sector in RAEOA has the potential to become one of the main pillars in food provision and in improving the economy of coastal communities.

1. Number of Fishing Households

RAEOA shows a condition that reflects an unequal distribution of fishing households among Sub-Regions, as illustrated in **Figure 10.2** and **Figure 10.3**. Based on the number of fishing households, Pante Macassar is recorded as the area with the highest concentration, with 343 households, followed by Nitibe with 107 households, while Oesilo has only 7 households and Passabe has no fishing households at all. In percentage terms, the dominance of Pante Macassar is very evident, contributing 75.05 % of all fishing households in RAEOA, while Nitibe contributes 23.41 %, and Oesilo only 1.53 %. Passabe records 0 %, indicating the absence of registered household fishing activity in that area.

This situation indicates that household-based fisheries activities in RAEOA are highly concentrated in the main coastal zone, particularly in Pante Macassar, which has a strategic geographic position and better infrastructure and access to marine resources. In contrast, inland areas or those farther from the coast show very low levels of involvement. This imbalance needs to be taken into account in planning a more inclusive and equitable development of the fisheries sector, so that the potential of underdeveloped areas can be optimized through policy interventions, improved access, and strengthening of local community capacity.

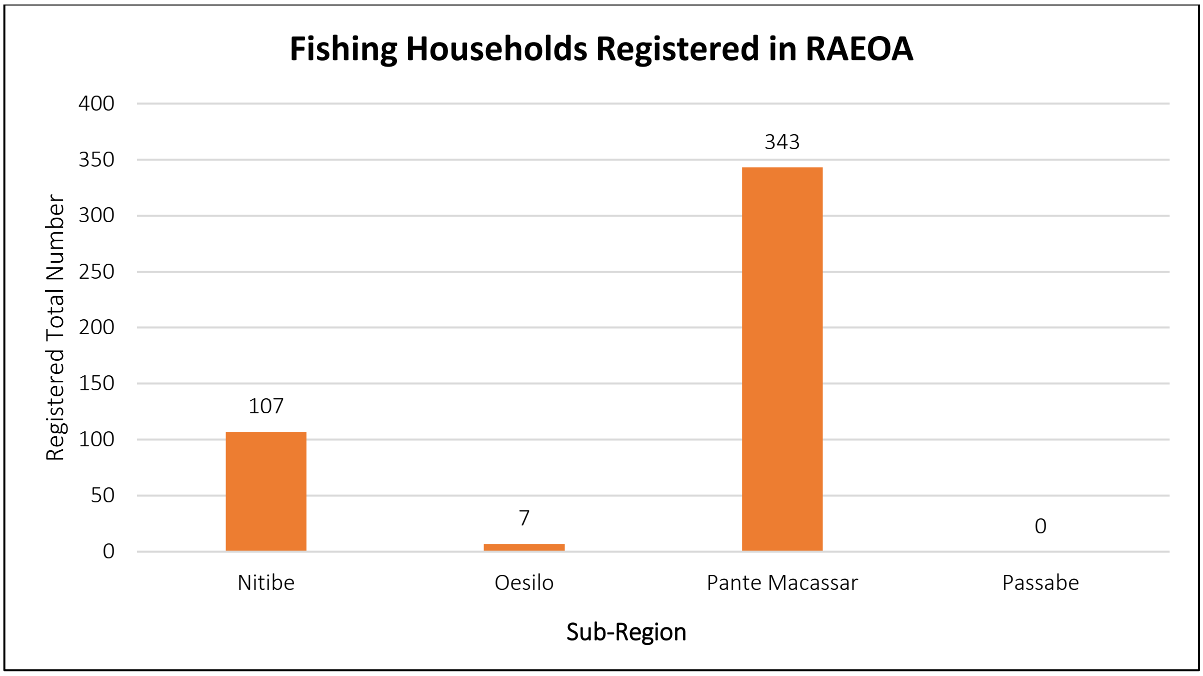


Figure 10.2 Number of Fishing Households in RAEOA
(Source: Timor-Leste Agriculture Census, 2019)

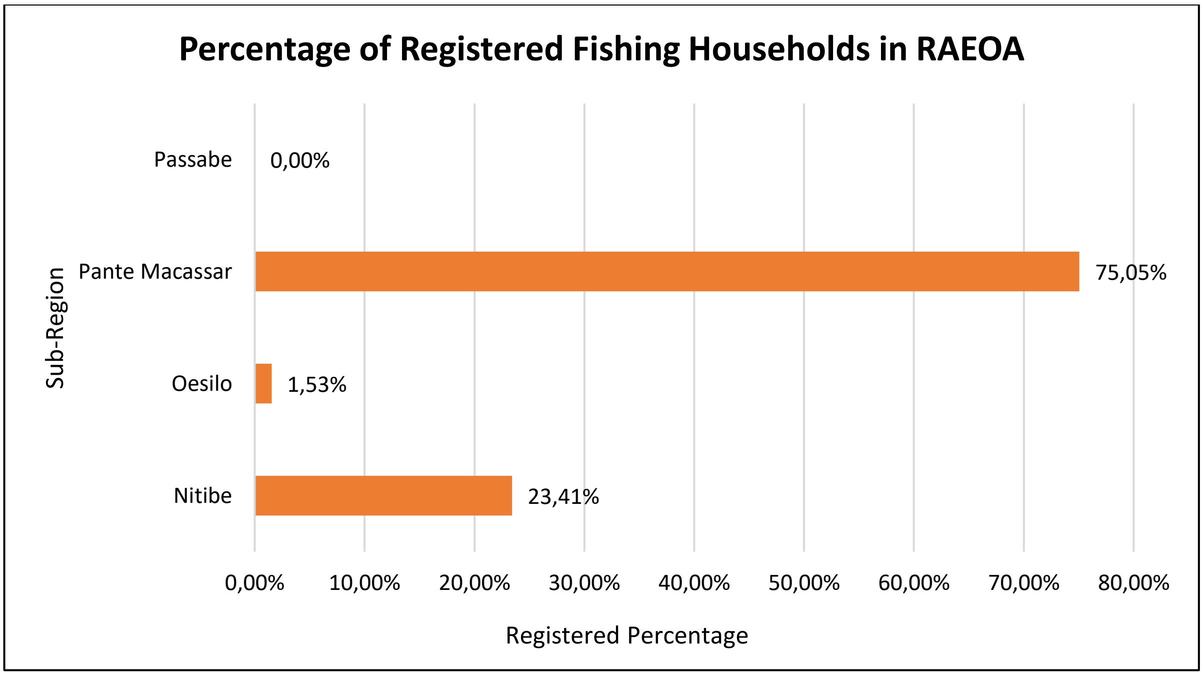


Figure 10.3 Percentage of Fishing Households in RAEOA
(Source: Timor-Leste Agriculture Census, 2019)

2. Households Involved in Fishing Activities

RAEOA shows a relatively active pattern of household involvement in fishing activities, with participation highly concentrated in certain areas. Based on **Figure 10.4**, the highest participation is recorded in Pante Macassar Sub-Region, particularly in the category of “consumption and occasional sales,” with 198 households (70.71 %), followed by the category of “consumption and social obligations” with 163 households (84.02 %), and “direct sales” with 51 households (85.00 %). Nitibe Sub-Region ranks second, with 76 households (27.14 %) in the category of consumption and occasional sales, 28 households (14.43 %) for consumption and social obligations, and 7 households (11.67 %) for direct sales.

Meanwhile, Oesilo shows very low participation, with 6 households (2.14 %) in the consumption and occasional sales category, 2 households (1.03 %) for consumption and social obligations, and 2 households (3.33 %) for direct sales. Passabe is almost not involved at all, with only 1 household (0.52 %) recorded in the category of consumption and social obligations, and zero in the other categories.

These data indicate that fishing activities in RAEOA are heavily dominated by Pante Macassar Sub-Region, reflecting a high dependence on the fisheries sector and considerable local economic potential from this activity. Conversely, the low level of involvement in areas such as Oesilo and Passabe suggests disparities in access to aquatic resources and supporting infrastructure.

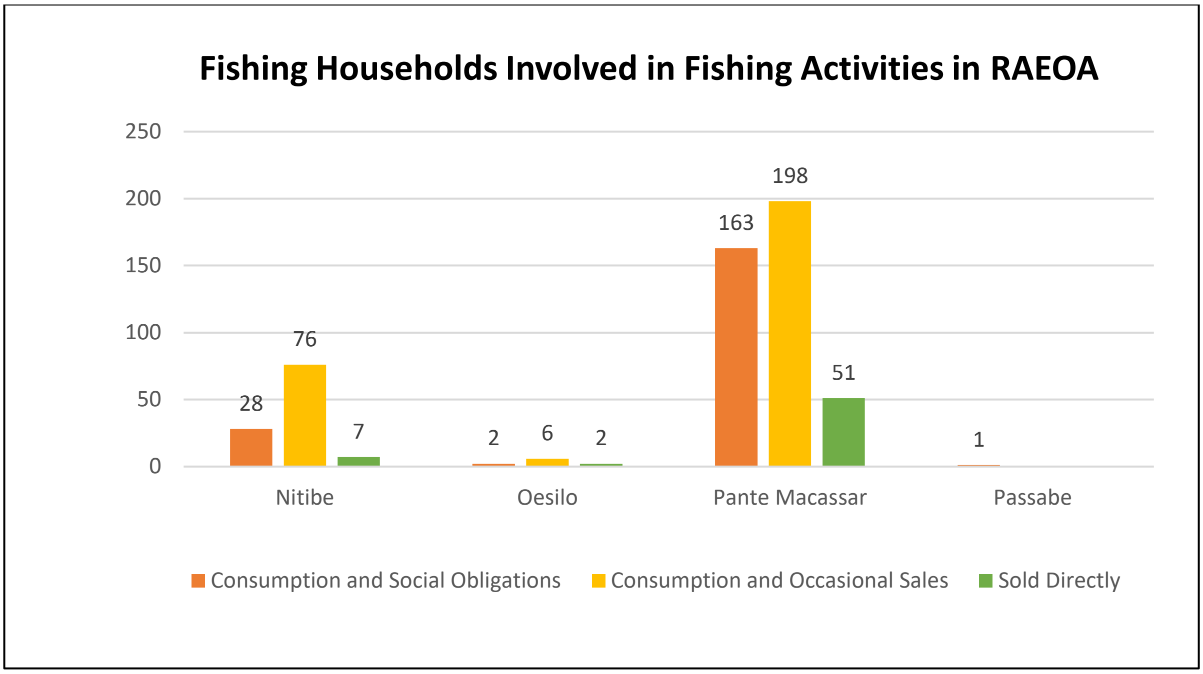


Figure 10.4 Number of Households Involved in Fishing Activities
(Source: Timor-Leste Agriculture Census, 2019)

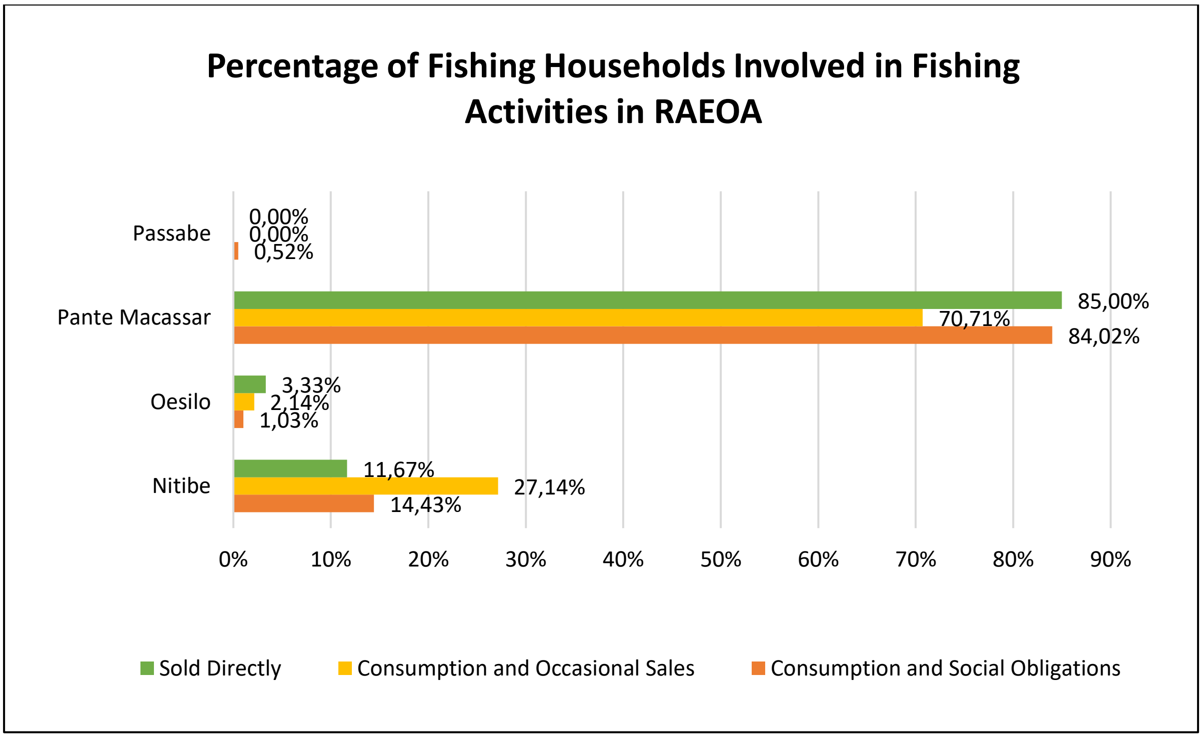


Figure 10.5 Percentage of Households Involved in Fishing Activities
(Source: Timor-Leste Agriculture Census, 2019)

B. Aquaculture

Aquaculture in the ***Região Administrativa Especial Oé-Cusse Ambeno*** **(RAEOA)** has considerable potential for development, particularly because the area has direct access to the sea and several coastal zones that can be used for aquatic farming. Based on data from the Directorate of Fisheries, Aquaculture, and Marine Resource Management in 2022, per capita consumption of aquaculture fish in RAEOA in 2019 was recorded at 0.42 kg per person per year. However, in 2020 there was a sharp decline to 0.29 kg per person, and this figure is projected to remain stable up to 2023.

This decline is believed to be associated with reduced production due to limited farming facilities, changes in farming practices, and other external impacts. Nevertheless, the stability of consumption in recent years indicates potential to re-optimize aquaculture activities, through infrastructure improvements, technical training for farmers, and policy support from local government. With appropriate management, the aquaculture sector in RAEOA can become an important alternative for providing animal protein, strengthening food security, and supporting the coastal community economy.

1. Proportion of Land for Aquaculture

RAEOA has a varied distribution of aquaculture land in each Sub-Region, with clear dominance in certain areas. Based on **Figure 10.6** and **Figure 10.7**, Nitibe Sub-Region has the largest aquaculture land area, at 23.337 ha (51.47 %), making it the main center of aquaculture activities in RAEOA. Passabe Sub-Region ranks second, with 11.75 ha (25.92 %), followed by Oesilo with 6.782 ha (14.96 %). Pante Macassar, meanwhile, has the smallest aquaculture land area, with only 3.471 ha (7.66 %).

This distribution shows that, geographically, aquaculture development potential in RAEOA is more concentrated in inland areas such as Nitibe and Passabe, which appear to have larger and more suitable land availability for aquaculture activities. In contrast, Pante Macassar, although the main center of capture fisheries, has limited potential for aquaculture development. This is likely due to the community's strong dependence on capture fisheries as a primary livelihood, low interest in aquaculture enterprises, and limited knowledge and mastery of aquaculture technology among local communities. Therefore, aquaculture development strategies in RAEOA need to focus on strengthening community capacity through technical training, extension, and infrastructure provision, in order to promote more sustainable and equitable diversification of fisheries activities across the administrative area.

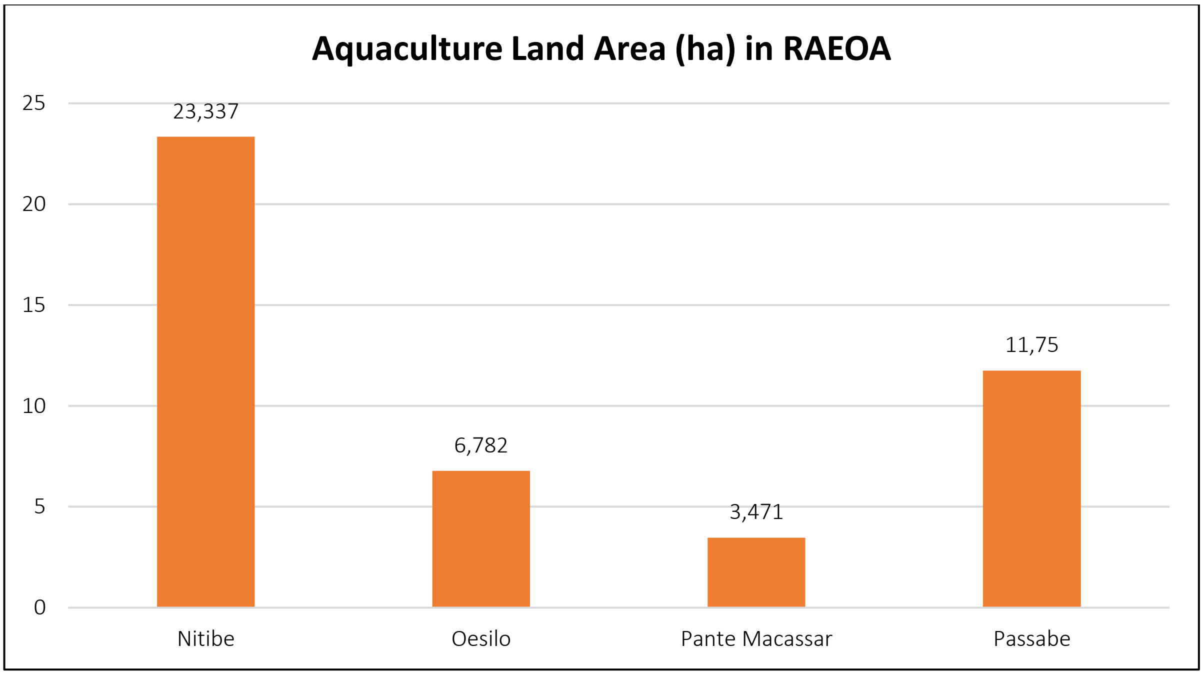


Figure 10.6 Aquaculture Land Area in RAEOA
(Source: Timor-Leste Agriculture Census, 2019)

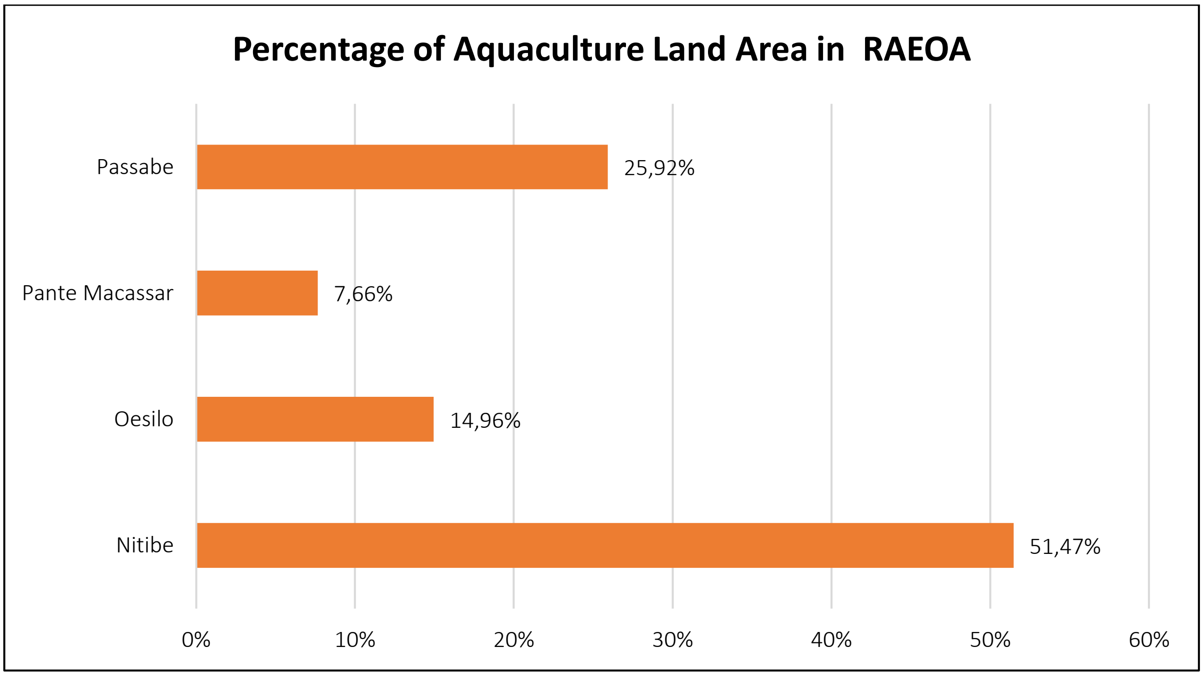


Figure 10.7 Percentage of Aquaculture Land Area in RAEOA
(Source: Timor-Leste Agriculture Census, 2019)

2. Aquaculture Households

RAEOA shows varying levels of household participation in aquaculture activities across Sub-Regions, with a distribution that reflects differences in conditions and community interest in each area. Based on **Figure 10.8** and **Figure 10.9**, Pante Macassar Sub-Region records the highest number of aquaculture households, with 82 households (58.16 %), followed by Nitibe with 35 households (24.82 %), and Oesilo with 22 households (15.60 %). Passabe has only 2 households recorded as engaging in aquaculture (1.42 %). The dominance of Pante Macassar in terms of household participation indicates a higher level of awareness and initiative in developing aquaculture, even though this area has the smallest aquaculture land area compared to other Sub-Regions.

This condition shows that high participation does not always correlate directly with land availability, but is also influenced by factors such as market access, the availability of basic infrastructure, and the role of government or supporting institutions at the local level. Conversely, the low number of aquaculture households in Passabe, despite its relatively large land area (25.92 % of total aquaculture land in RAEOA), indicates the presence of non-physical constraints on aquaculture development. These constraints may include low interest in farming enterprises, strong dependence on capture fisheries, and limited knowledge, technical skills, and access to aquaculture technology. Therefore, aquaculture development strategies in RAEOA need to focus not only on land optimization, but also on household empowerment through training, extension, and facilitated access to technology that can stimulate increased participation throughout the area.

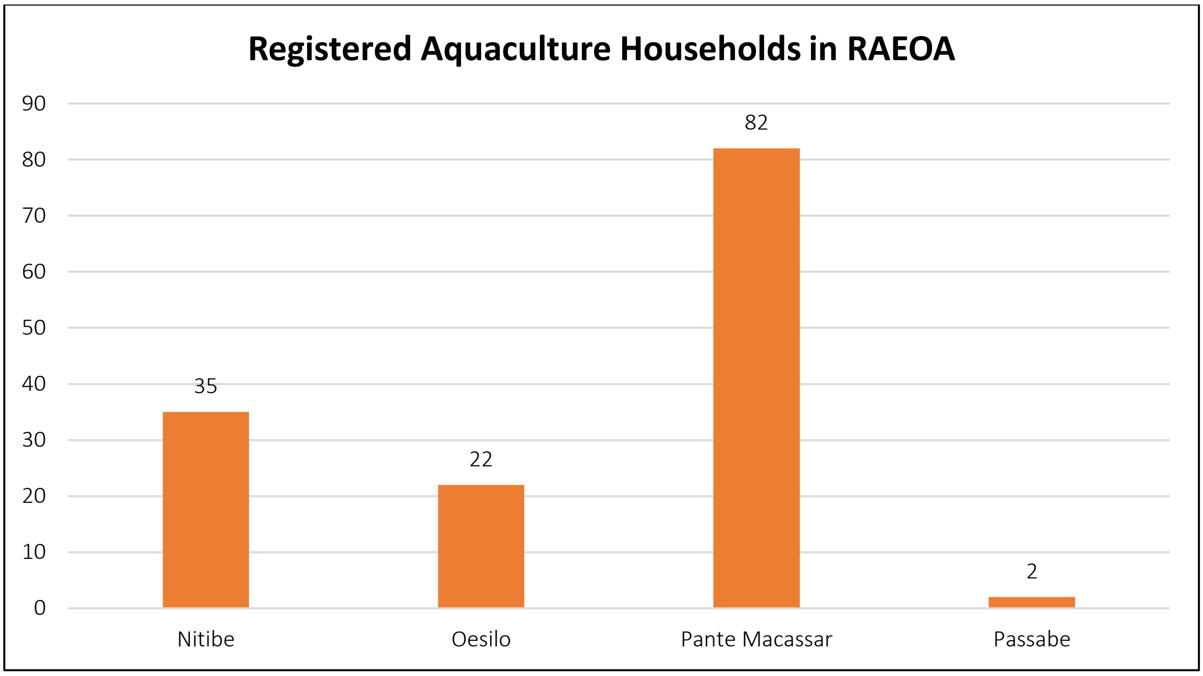


Figure 10.8 Number of Aquaculture Households Recorded in RAEOA
(Source: Timor-Leste Agriculture Census, 2019)

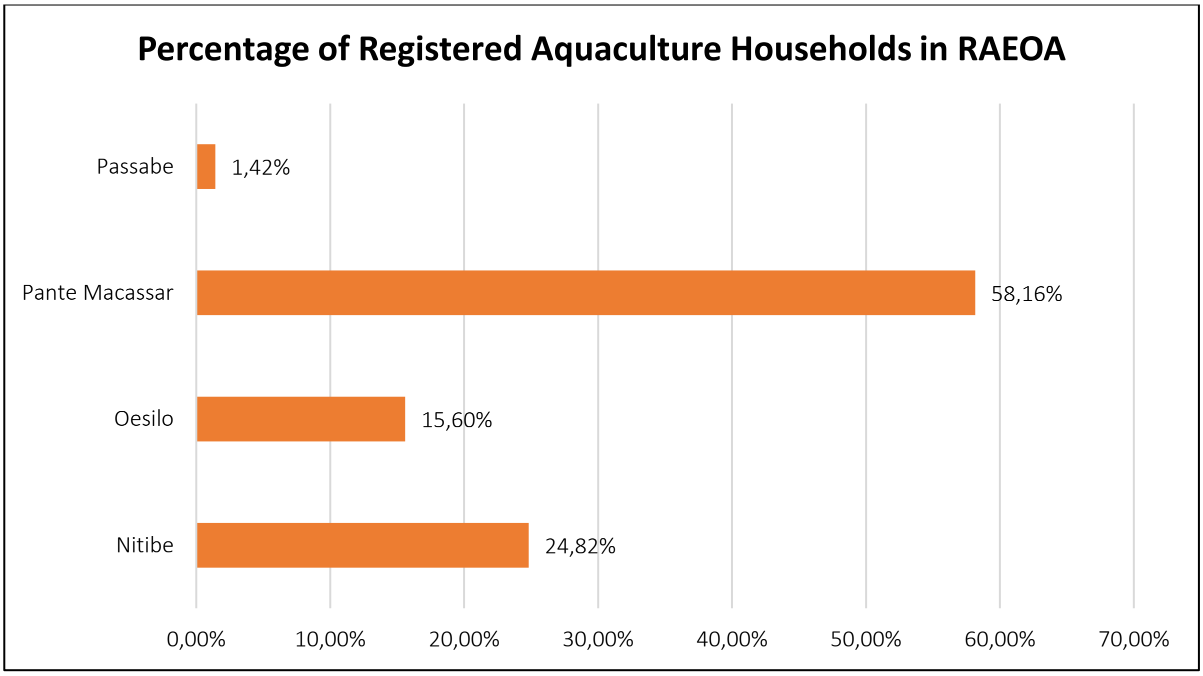


Figure 10.9 Percentage of Aquaculture Households Recorded in RAEOA
(Source: Timor-Leste Agriculture Census, 2019)

3. Aquaculture Systems

RAEOA currently shows aquaculture systems that are still concentrated on fish ponds, which dominate in almost all areas. Data indicate that Pante Macassar Sub-Region has the highest number of fish ponds, with 70 units or around 80 % of all aquaculture systems in the area. This is followed by Nitibe with 24 units (around 77 %), and Oesilo with 14 units (around 78 %). Other systems such as fish cages, brackish-water ponds, rice–fish systems, and hatcheries are present only in very limited numbers. For example, in Pante Macassar there are only 7 units of brackish-water ponds (around 62.5 %) and 1 unit each of fish cages, rice–fish systems, and hatcheries.

In other areas such as Nitibe and Oesilo, some diversity of systems is also found, although in small proportions, such as 2 units of brackish-water ponds in Nitibe (6 %) and 1 unit of fish cages in Oesilo (5.6 %). Meanwhile, Passabe is the area with the least aquaculture activity, recording only 4 pond units and 1 brackish-water pond, with no other systems present. Overall, this condition indicates that aquaculture development in RAEOA is still focused on a single dominant system, namely fish ponds, and has not yet shown an even distribution in terms of both the number and types of systems among Sub-Regions.

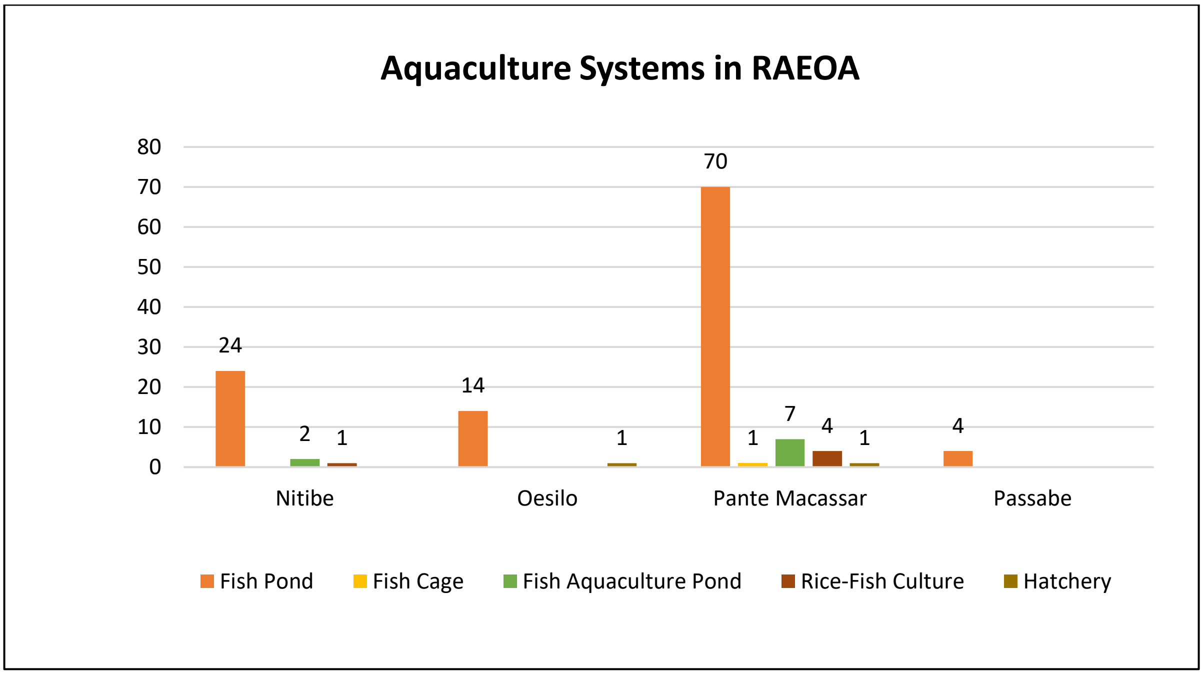


Figure 10.10 Number of Aquaculture Systems in RAEOA
(Source: Timor-Leste Agriculture Census, 2019)

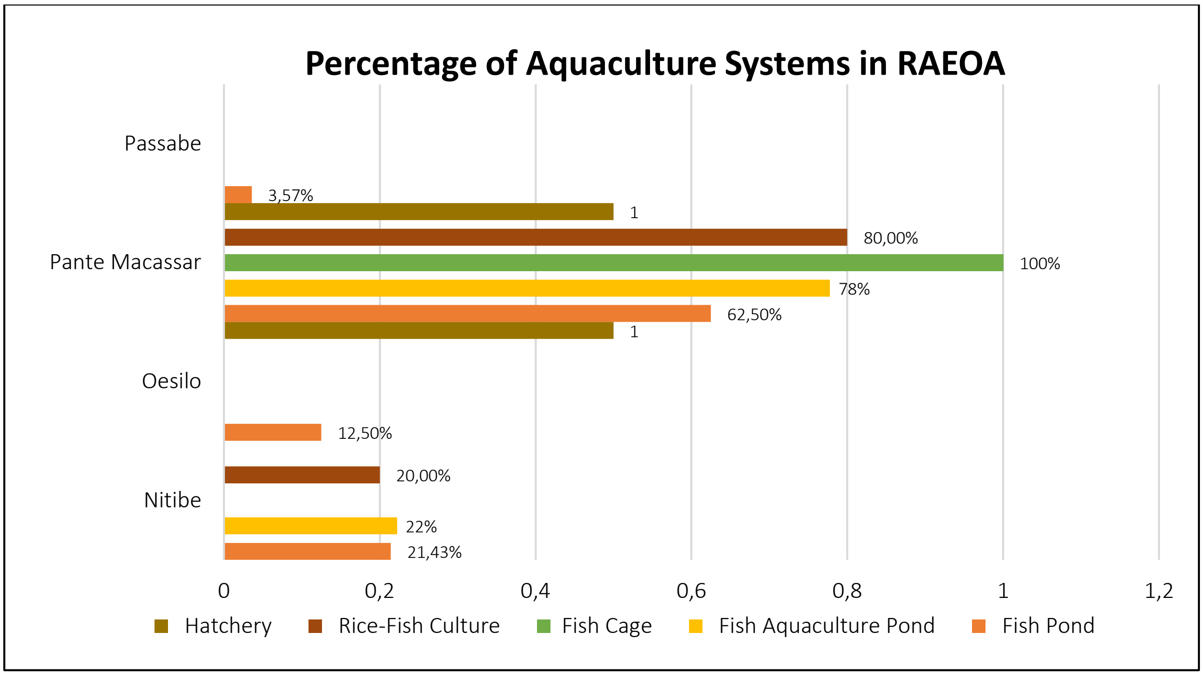


Figure 10.11 Percentage of Aquaculture Systems in RAEOA
(Source: Timor-Leste Agriculture Census, 2019)

C. Field Observation Results

RAEOA has unique aquaculture development potential that is strongly determined by contrasting site characteristics between locations. Observations were conducted at two main sites, namely Costa and Sacato, which respectively represent freshwater and brackish-water ecosystems.

In Costa, Pante Macassar Sub-Region, there is a fish hatchery that utilizes local freshwater resources. Water quality measurements show conditions that are highly suitable for freshwater aquaculture. Salinity is at 0 ppt, with low TDS (234 mg L^{-1}), ideal temperature, and very high dissolved oxygen levels (9.71 to 16.67 mg L^{-1}). In addition, the water contains no ammonia, nitrite, or nitrate, which are important indicators for successful fish rearing in intensive systems. Although pH is slightly acidic (6.20), this condition can still be managed through simple techniques, making Costa a highly potential site for freshwater fish seed production and grow-out.

Conversely, the Sacato site, located on the coast, shows characteristics of brackish to fully marine water. Very high salinity, reaching 32 ppt, accompanied by extreme TDS values of 29,700 mg L^{-1} and hardness levels up to 1,000 ppm, makes this area unsuitable for freshwater aquaculture. However, these conditions indicate high potential for the culture of marine or brackish-water species such as milkfish, grouper, or tiger shrimp. The main challenge in Sacato lies in the need for farming systems and environmental management that comply with marine aquaculture standards.

Figure 10.12 Observation of Aquaculture Ponds in RAEOA
(Source: Researcher's Documentation, 2025)

The sharp contrast in water quality between Costa and Sacato highlights the importance of appropriate site selection in planning aquaculture development in RAEOA. Locations such as Costa should be prioritized as centers for freshwater seed production and grow-out, while coastal areas such as Sacato can be directed towards the culture of high-value marine species.

10.4 COMPREHENSIVE LAND SUITABILITY ANALYSIS FOR AQUACULTURE

A. Land Suitability for Aquaculture in RAEOA

Land suitability refers to the degree of suitability of an area for a specific use, in this case for aquaculture. This concept assesses whether the land has physical, chemical, and climatic characteristics that can support the optimal and sustainable development of aquatic commodities. Land suitability evaluation is conducted under two conditions: current condition (as it is) and potential condition (after improvement).

Current land suitability is determined using field survey data that reflect the land's capacity in its natural state, without additional interventions. At this stage, improvement measures and management levels to overcome constraints or limiting factors are not yet considered. Determination of the current suitability class is carried out by assessing each land quality based on limiting factors, followed by scoring until a final evaluation value is obtained. The results provide a realistic picture of the challenges present in the field.

In contrast, potential land suitability describes the degree of appropriateness of the land after improvements are made. For example, land that is only marginally suitable (S3) under current conditions can be improved to moderately suitable (S2) or highly suitable (S1) through appropriate measures, such as topographic modification or adjustment of water quality. Potential suitability evaluation is carried out by considering feasible improvement efforts on limiting factors, so that the land suitability class is expected to increase.

Technological advances make it possible to improve land with low suitability in the current condition to a higher level in the potential condition. However, not all limiting factors can be fully addressed, because some land characteristics require technologies that are not yet available or demand very high levels of management. Therefore, in land-use planning for aquaculture, the main focus is directed toward potential land suitability. This evaluation provides an overview of the maximum potential of a land area and serves as the basis for planning effective and sustainable land use, as well as determining the improvement measures needed to achieve optimal aquaculture production.

B. Results of Aquaculture Land Suitability Evaluation in RAEOA

Land suitability analysis is a fundamental step in designing sustainable resource management strategies for aquaculture development. The evaluation process is conducted using an integrated approach that combines geospatial data, field observations, and physical and chemical analyses of water and soil in the laboratory. This approach allows a more accurate identification of both the potential and bio-physical limitations of the land for the development of various aquaculture commodities.

The data obtained are then analyzed based on the growth requirements of each aquatic commodity, both under current conditions and potential conditions after various land improvement measures, such as topographic modification, water quality management, or the application of adaptive farming techniques. Through this process, comprehensive information is generated to determine commodity development priorities, identify limiting factors, and formulate relevant technical solutions.

This scientific approach underpins the land suitability evaluation in RAEOA and provides strategic guidance for maximizing land productivity while maintaining the sustainability of aquatic resources in each area. Field and laboratory data used as references for the evaluation are presented in relevant supporting documents, so that the results can be scientifically and practically justified. The soil distribution map for aquaculture land in RAEOA is presented in **Figure 10.13.**

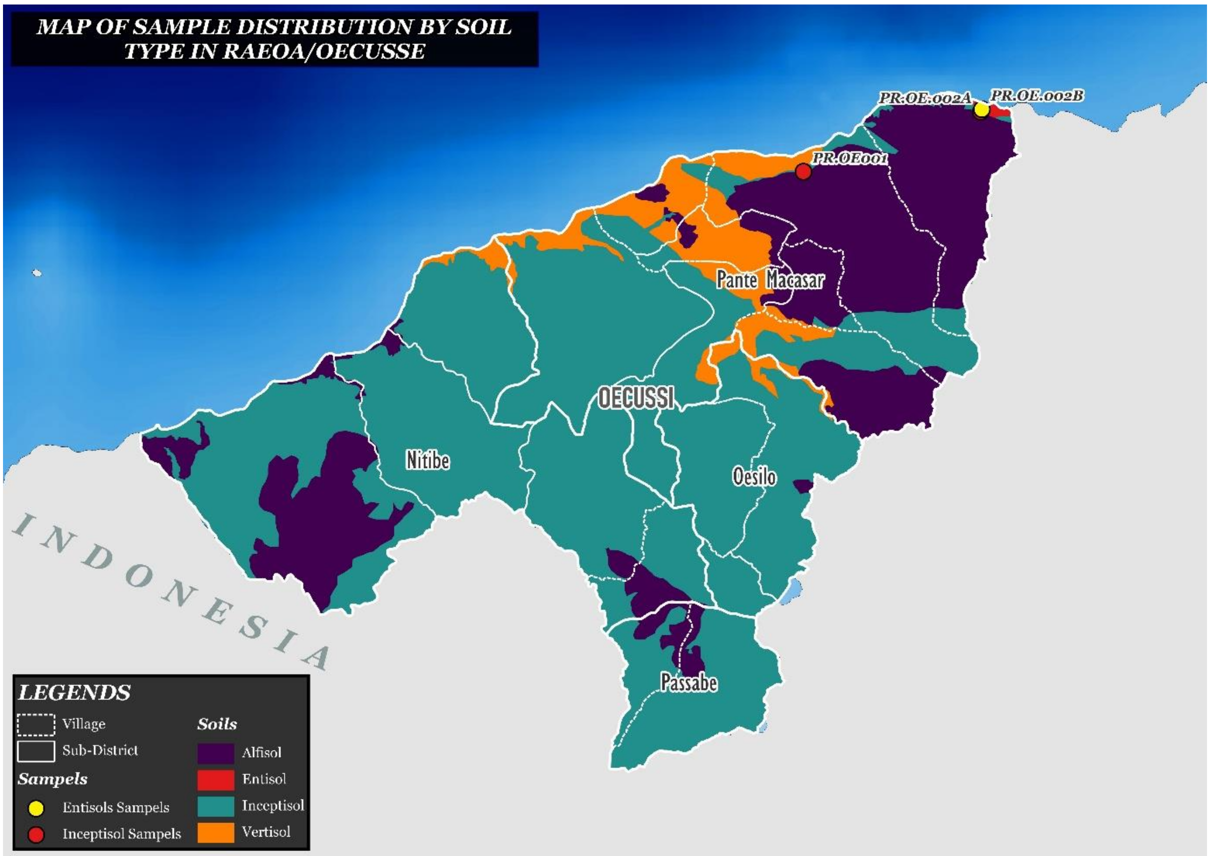


Figure 10.13 Soil Distribution Map on Aquaculture Land in RAEOA

a. Land Suitability Evaluation for Pante Macassar Sub-Region

Pante Macassar Sub-Region is located in the coastal area of **RAEOA (*Região Administrativa Especial Oé-Cusse Ambeno*)**. This geographic position offers substantial opportunities for aquaculture development, both for freshwater and brackish-water commodities. However, the results of the land suitability evaluation show several important limiting factors, particularly related to topography and climate, which affect the feasibility of farming activities.

For freshwater commodities such as gourami, catfish, carp, and tilapia, the main factors limiting current suitability are slope gradient and the length of dry months. Steep slopes make the construction of conventional ponds technically unfeasible due to erosion risk and difficulties in water distribution. The use of terraced pond systems is the recommended solution, allowing the suitability class to improve from Not Suitable (N) to Marginally Suitable (S3). Meanwhile, prolonged dry months are a permanent climatic constraint that cannot be improved. Adaptive measures, such as the construction of small reservoirs, rainwater harvesting ponds, and the application of water-use efficiency practices, can only reduce negative impacts without changing the land suitability status. Another limiting factor is suboptimal water pH for several species (gourami, catfish, tilapia, and carp), which requires management such as the use of zeolite or periodic water replacement.

For brackish-water commodities such as milkfish, mangrove crab, and vannamei shrimp, the dominant limiting factors are low salinity and dry months. Unstable salinity has serious impacts on brackish-water organisms, especially mangrove crab, which is highly sensitive to salinity levels. Technical improvements can be made through seawater mixing or salinity control systems that regulate seawater inflow. Although these interventions require higher costs and more complex management, they are relatively feasible in Pante Macassar because it is directly adjacent to the sea.

Overall, the evaluation results indicate that Pante Macassar Sub-Region has significant opportunities for aquaculture development. However, development should prioritize freshwater commodities such as carp and catfish, which are relatively more adaptive and face fewer and more manageable limiting factors. Brackish-water aquaculture also remains viable, but technical and cost considerations must be taken into account so that aquaculture activities can operate efficiently and sustainably.

Table 10.9 Land Suitability Analysis for Aquaculture Commodities in Pante Macassar Sub-Region

Commodity	Current Land Suitability Limiting Factors	Current Final Evaluation	Potential Land Suitability Limiting Factors	Potential Final Evaluation
Gourami (*Ospronemus gouramy*)	N: Slope gradient, dry months S3: pH	3.32	N: Dry months S3: Slope gradient	3.46
Catfish (*Clarias batrachus*)	N: Slope gradient, dry months S2: pH	3.37	N: Dry months S3: Slope gradient	3.46
Carp (*Cyprinus carpio*)	N: Slope gradient, dry months S2: High temperature, pH	3.22	N: Dry months S3: Slope gradient	3.46
Tilapia (*Oreochromis niloticus*)	N: Slope gradient, dry months S2: pH	3.27	N: Dry months S3: Slope gradient	3.46
Milkfish (*Chanos chanos*)	N: Slope gradient, dry months S3: Low salinity S2: pH, rainfall	3.01	N: Dry months S3: Slope gradient S2: Rainfall	3.4
Mangrove crab (*Scylla serrata*)	N: Low salinity, dry months S3: pH, slope gradient	3.02	N: Dry months S2: Slope gradient	3.58
Vannamei (*Litopenaeus vannamei*)	N: Slope gradient, dry months S3: Low salinity S2: pH	3.07	N: Dry months, Slope gradient	3.46

C. Aquaculture Land Improvement Efforts

The results of the current land suitability evaluation in RAEOA show various limiting factors that make most areas fall into the not suitable or only marginally suitable classes for aquaculture. To improve these land suitability classes, improvement measures or corrective actions are required for the limiting factors, insofar as technically feasible. Land improvement efforts in aquaculture include all technical interventions aimed at improving the bio-physical conditions of the land and the quality of the aquatic environment so that they better match the optimal requirements of the cultured commodities. These improvements may involve habitat modification (for example, improving pond physical conditions), manipulation of water quality, and provision of supporting infrastructure.

According to **Table 10.10**, there are different types of improvement efforts with varying levels of management difficulty. Management difficulty levels are grouped into three categories: low, medium, and high. These levels form the basis for estimating how far current land quality suitability can be improved to potential suitability, as shown in **Table 10.11**.

Table 10.10 Recommended Improvement Measures for Limiting Parameters

No	Parameter	Improvement Measures	Management Difficulty Level
1	High Temperature	- Planting shading trees - Using roof with hapa/paranet nets - Building indoor ponds	- Low - Medium - High
2	Low Salinity	- Conventional seawater mixing - Seawater mixing with pump system	- Medium - High
3	Water pH	- Regular water changes - Use of zeolite	- Medium - High
4	DO	- Use of simple gravity aeration system - Use of aerator pumps/wheel	- Low - High
5	Slope Gradient	- Use of stepped pond system	- High
6	Rainfall	- Cannot be improved	

Description :

- *Low management difficulty: Can be carried out by farmers at a relatively low cost.*
- *Medium management difficulty: Can be carried out by intermediate-level farmers, requiring moderate capital and moderate aquaculture techniques.*
- *High management difficulty: Can only be carried out with relatively high capital, typically by the government or large to medium-sized companies.*

Table 10.11 Assumptions for Improving Actual Land Quality to Potential, Based on Management Difficulty Levels

No.	Land Quality/Characteristic	Management Level		
		Low	Medium	High
1.	**Topography**			
	- Slope Gradient	–	–	+
2.	**Soil Conditions**			
	- Clay Content	–	+	++
	- pH_F-pH_{FOX}	–	+	++
	- Organic Carbon	–	+	++
3.	**Water Quality**			
	- Temperature	+	--	+++
	- Salinity	+	++	+++
	- pH	+	++	+++
	- Total Dissolved Solid (TDS)	+	++	+++
	- Ammonia	+	++	+++
	- Dissolved Oxygen (DO)	+	++	+++
4.	**Climate**			
	- Annual Rainfall	--	--	--
	- Dry Months	--	--	--

Description :

\- *Not feasible for improvement*

\+ *Improvement is possible, and the suitability class will increase by one level (S3 to S2)*

++ *Improvement will increase the suitability class by two levels (S3 to S1)*

+++ *Improvement will increase the suitability class by three levels (N to S1)*

XI. RECOMMENDATION

11.1 RECOMMENDATIONS FOR AGRICULTURAL SECTOR

The results of the biophysical evaluation in the ***Região Administrativa Especial de Oecusse-Ambeno*** (RAEOA) indicate that several villages have land characteristics that support the development of various sustainable agricultural systems.

1) Land Potential and Distribution of Rice Fields (Irrigated & Rainfed)

Irrigated rice fields are found in Lela-Ufe Village and Bene-Ufe Village (Nitibe Sub-Region), as well as Costa Village, Cunha Village, Lalisuc Village, and Naimecco Village (Pante Macassar Sub-Region). Rainfed rice fields are found in Usi-Tacae Village (Oesilo Sub-Region), Costa Village (Pante Macassar Sub-Region), and Usi-Taco Village (Nitibe Sub-Region); the cropping pattern is heavily influenced by the seasons, requiring simple water management systems to increase planting indices.

2) Main Food Commodities and Diversification

Cassava, corn, upland rice, peanuts, mung beans, sorghum, porang, taro, cowpeas, and yardlong beans are spread across the entire Sub-Region. This diversification strengthens food security and serves as the basis for adaptive crop rotation and intercropping systems that are resilient to variations in rainfall.

3) Horticulture and Economically Valuable Fruits

Vegetables (eggplant, water spinach, mustard greens, chili, chayote, snow peas, broccoli, lettuce, carrots, petsai, long beans, green beans, spinach) and fruits (mango, orange, guava, pineapple, banana, soursop, papaya, lemon, fig, watermelon, sweet orange) show potential for local market supply. Focus should be placed on cooler microclimate pockets and well-drained soils to maintain quality and harvest continuity.

4) Forest Vegetation as a Landscape Buffer

In Bene-Ufe Village and Suni-Ufe Village (Nitibe Sub-Region), there are trees such as tamarind, teak, leucaena, sago, bamboo, mahogany, casuarina, kesambi, red teak, moringa, *Eucalyptus, redwood*, kapok, and quinine. This coverage helps to prevent erosion, supply organic matter, and stabilize the microclimate for surrounding cultivated lands.

5) Strategic Industrial Commodities

Coconut, areca nut, robusta coffee, nipa palm, candlenut, betel, and tobacco have high economic value. Strengthening cultivation, post-harvest handling, and market access will drive added value in the region.

6) Forage Crops and Livestock Integration

Elephant grass, turi, *leucaena*, and legumes are available throughout the Sub-Region. The management of pastures (fencing-rotation) and cut-and-carry systems in sensitive zones helps maintain forage regeneration and improves livestock performance.

7) Technical Constraints in Each Sub-Region

a) **Nitibe Sub-Region:** Knowledge of fertilization, feed, and cultivation techniques is still limited; recurring attacks from locusts and caterpillars; fertilizer use depends on economic capacity; distribution of quality seeds is uneven. Field schools, balanced fertilization demonstration plots, and strengthening the seed system are needed.

b) **Oesilo Sub-Region:** Water availability is low, making the region highly dependent on rainfall; fertilization is inconsistent; marketing is not structured (sales occur when sufficient volume is available). Usi-Tacae Village shows suboptimal mung bean growth due to unsystematic land management. Reservoirs and piped irrigation technology are priorities for irrigation.

c) **Pante Macassar Sub-Region:** The cropping pattern is generally one season (corn–cassava) with no fertilization; turi is planted every two years; rainfed rice fields limit rice frequency. If water is available, rice can be grown twice with organic fertilizers, but application knowledge is still low. Brown planthopper, rice bug, and tungro virus in Membramo rice varieties are serious issues, exacerbated by low organic matter in the soil in Lifau Village.

d) **Passabe Sub-Region:** Corn is always affected by pests; robusta coffee has low yields and experiences leaf drop; fertilizer and water are limited, market access is difficult, and land conservation is weak. In Abani Village, corn does not reproduce well, and some lands have not been terraced; poor road infrastructure hampers marketing.

8) Water and Irrigation Recommendations at the Region Scale

Develop/revitalize village reservoirs, shallow wells, storage tanks, and small channels; implement simple piped irrigation systems for rice fields and vegetable plots; promote water-efficient irrigation (drip/sprinkler) for horticulture and fruit orchards. In Lela-Ufe Village, Bene-Ufe Village (Nitibe Sub-Region), and Costa Village, Cunha Village, Lalisuc Village, and Naimecco Village (Pante Macassar Sub-Region), securing water during the dry season is key to increasing planting indices.

9) Land Improvement and Soil Fertility

Implement balanced fertilization based on soil tests, add organic matter (compost/manure), use mulch and cover crops, and apply minimum tillage on slopes. This package will enhance water-holding capacity, improve soil structure, and stabilize yields.

10) Cropping Systems: Rotation, Intercropping, and Commodity Zoning

Direct irrigated rice fields to villages with proper water management; focus on sorghum–legumes in drylands of Suni-Ufe Village and Taiboco Village; upland rice–cereal crops on hilltops with soil and water conservation; intensive horticulture in cool pockets; fruit orchards on deep, well-drained soils. Implement a rice–cereal–legume rotation to break pest cycles and maintain soil fertility.

11) Integrated Pest Management (IPM)

Establish synchronized planting calendars, use tolerant varieties, conduct regular pest monitoring, and apply biological control methods; limit chemical insecticides to economic threshold levels. Specifically for rice in the Pante Macassar Sub-Region, focus on preventing brown planthopper, rice bug, and tungro virus through land sanitation, healthy seeds, and controlled nitrogen fertilization.

12) Robusta Coffee Rehabilitation

Restore shade (e.g., Albizia or other local hardwood trees), carry out production pruning, scheduled fertilization, and apply organic mulch; do not neglect the maintenance of existing coffee orchards even when diversifying into other crops (e.g., vanilla).

13) Access, Marketing, and Institutional Support

Improve farm access roads and small bridges, provide collection points for produce, and establish mini cold chains for horticultural crops; form or strengthen Sub-Region

cooperatives for crop contract agreements and input financing. This will reduce logistics costs and improve farmers' bargaining power.

14) Strengthening Human Resources and Extension Support

Organize field schools (soil, water, IPM, post-harvest) in each Sub-Region; establish demonstration plots for priority commodities; designate local champions in each Village to promote the adoption of best practices and ensure the sustainability of training programs.

15) Implementation Phases (Quick Wins → Medium-Term)

a) *Quick wins*: small reservoirs and line piped irrigation, simple fertilization standard operating procedures, rotational grazing management, demonstration plots for sorghum and upland rice, rice field sanitation.

b) Medium-Term: communal reservoirs, block-scale terracing, agroforestry (spices–fruits–protective trees), cold-chain for horticulture, strengthening cooperatives and marketing contracts.

11.2 RECOMMENDATIONS FOR THE LIVESTOCK SECTOR

Based on the geospatial analysis, the *Centro Produção Animal* (CPA) Makelap in Taiboco Village has significant potential to be developed as a center for breeding superior livestock. The main objective is the region

Dissemination of livestock breeding stock. The high land suitability for the production of quality forage for livestock is a key factor in ensuring a sustainable supply of optimal nutrition for the growth of breeding stock.

Supporting micro-ecological conditions, including stable temperatures, minimize heat stress on livestock, thereby improving reproductive efficiency and growth rates of the breeding stock. Additionally, the availability of water sources and gentle topography facilitate sanitation management and hygienic housing systems. The genetic potential of local livestock, which has adapted to the local environment, can be enhanced through genetic selection programs to produce high-quality breeding stock. The integration of agroclimatology, natural resources, and genetic improvement programs makes the *Centro Produção Animal* (CPA) Makelap in Taiboco Village (Nitibe Sub-Region) a strategic location to support animal food security and region livestock development.

11.3 RECOMMENDATIONS FOR THE FISHERIES SECTOR

Aquaculture activities in the RAEOA show significant potential in supporting food security, creating job opportunities, and boosting the local economy. According to 2019 TLAC data, 80 households have been involved in various aquaculture systems such as pond culture, pen systems, rice-fish farming, and hatcheries, particularly concentrated in the Pante Macassar and Nitibe Sub-Regions.

Land suitability analysis indicates that most of the proposed aquaculture species face major constraints such as land slope and long dry periods, particularly for freshwater species like gourami, catfish, carp, and tilapia. For brackish water species like milkfish, mangrove crab, and vannamei shrimp, low salinity and pH are additional limiting factors. However, there are significant opportunities to improve suitability in potential scenarios through technical interventions and environmental engineering, as reflected by increased weighted scores for all species (average >3.4 on a scale of 1 to 4).

Based on the actual and potential evaluation results, the Pante Macassar Sub-Region is ready to serve as a pilot location for aquaculture development, particularly for pond and shrimp farming systems. Cortez Village has the advantage of an operational fish hatchery (OFH) that can support the supply of freshwater fish seeds. The availability of water sources, location accessibility, and community involvement in fisheries activities make Cortez an ideal location for freshwater aquaculture development, particularly for gourami, catfish, carp, and tilapia species. The recommended farming models include earthen ponds and flat tarpaulin ponds with support from simple recirculation or biofloc systems.

Meanwhile, Sacato Village, located along the coast, has environmental characteristics suitable for brackish water aquaculture development. This location has demonstrated traditional aquaculture activities and has the potential to be enhanced through integrated pond farming approaches. Recommended species for development in Sacato include milkfish, mangrove crab, and vannamei shrimp, with farming systems based on plastic ponds, utilizing tidal flows, and adjusting salinity.

To support the development of productive and sustainable aquaculture in the RAEOA, several strategic policies are recommended as follows:

1. The government needs to strengthen basic infrastructure, such as access to clean water, micro-irrigation systems, and road access to production sites.
2. Encourage investment in the development of integrated ponds and ponds with appropriate technology.
3. Implement integrated technical training for aquaculture groups in Cortez and Sacato.
4. Develop field-based training modules (field schools) focused on location-specific aquaculture techniques.
5. Establish Fish Farmers Groups (Pokdakan) in each potential Village to facilitate access to technical and financial assistance.
6. Assign permanent extension workers or NGO partners as local technical facilitators.
7. Develop a roadmap for aquaculture development based on spatial data and land suitability analysis.
8. Set production targets, prioritize locations, and implement cross-sectoral support programs (fisheries, agriculture, infrastructure, cooperatives).
9. Develop partnerships with the private sector for marketing harvests and cold chain supply.

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RAEOA area has highly diverse agricultural development potential that can be advanced comprehensively through an integrated approach. Land zoning indicates that irrigated rice fields currently cover about 3.80 %, while rainfed rice fields account for 8.39 %. Dryland farming dominates with an area of 38.92 %, followed by agroforestry at 18.78 %. Protected forest areas occupy 28.68 % of the territory, whereas mangrove forest covers only 0.03 %. The potential for irrigated rice field expansion is further supported by the Tono irrigation system in Pante Macassar, which can enhance food production. Food crops suitable for development include irrigated rice, upland rice, rainfed rice, and cowpea as staple food sources. Horticulture also presents significant opportunities, both for vegetables such as shallot, chili, and broccoli, and for fruits such as citrus, salak, and pineapple. Spices and medicinal plants with development potential include greater galangal and cardamom In the forestry sector, economically valuable timber species such as teak, mahogany, agathis, and sandalwood can be developed, with sandalwood as an endemic flora of RAEOA possessing both high conservation and economic value.

The livestock sector in RAEOA also shows significant progress, particularly in goat production. Forage feed commodities such as elephant grass, setaria, and legumes are available to support herd productivity. The Centro Produção Animal (CPA) Makelab, located in Taiboco Village, manages 15 ha of land with a population of about 60 goats resulting from crosses between local goats and Boer goats. In addition, the fisheries sector has potential divided between inland and coastal areas. Cortez Village supports freshwater aquaculture with commodities such as gourami, catfish, common carp, and Nile tilapia, while Sacato Village, located on the coast, serves as a center for brackish water aquaculture of milkfish, grouper, mud crab, and whiteleg shrimp. This combination demonstrates considerable opportunities for integration among agriculture, livestock, and fisheries. Both villages are located in the Pante Macassar Sub-Region. Comprehensive multisector management can be realized through integrated farming systems based on the five farming principles, integration of crop farming with livestock, and aquaculture intensification. To support implementation, five villages Nipani, Lalisuc, Costa, Lifau, and Taiboco are recommended as pilot sites for integrated agricultural development. This model is expected to strengthen food security, reinforce the sustainability of production systems, and serve as a relevant example of integrated agricultural development in the context of Timor-Leste's accession to ASEAN.