Land Suitability Evaluation & Regional Potential Mapping

Development of Agriculture, Livestock, Fisheries, & Forestry Commodities
Manatuto Municipality

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

PERSON IN CHARGE

Eng. Marcos da Cruz, MAgSt

Minister of Agriculture, Livestock, Fisheries, and Forestry

Democratic Republic of Timor-Leste

FOREWORD

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

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

As an area endowed with abundant natural resources, Manatuto District faces significant challenges in optimizing land use, particularly in the context of limited resources and the impacts of climate change. This book has been prepared to provide structured and relevant solutions to the needs of land resource management in Manatuto, with a focus on food security, environmental sustainability, and poverty alleviation.

The data-based approach used in this study has successfully mapped the potential of Manatuto District for the development of key sectors, including food crops, estate crops, horticulture, and forestry. Furthermore, the strategies formulated in this book are intended to support sustainable rural economic growth in Manatuto, while at the same time opening opportunities for the creation of new jobs that are relevant for local communities.

Covering six main sub-districts, which include Barique/Natarbora Sub-District, Laclo Sub-District, Laclubar Sub-District, Laleia Sub-District, Manatuto Sub-District, and Soibada Sub-District, this book offers strategic guidance on the use of dryland, which dominates Manatuto District. The proposed land suitability zoning approach provides solutions to the challenges of land degradation, erosion hazards, and declining soil fertility. Beyond that, this book emphasizes the importance of integrating environmental conservation and modern technology to support sustainable land productivity.

We believe that the recommendations put forward in this book not only provide direct benefits for food security in Manatuto District, but also contribute to the achievement of the Sustainable Development Goals (SDGs), especially those related to eradicating hunger (SDG 2), climate change action (SDG 13) and biodiversity conservation (SDG 15).

I invite all stakeholders, from government and academia to the wider community, to use this book as a reference for land resource management and planning for the development of the agricultural sector. Through strong synergy and close cooperation, we can ensure that the development of the agricultural sector in Manatuto District proceeds in step with natural resource conservation, ecosystem sustainability and improved community welfare.

Finally, I would like to express my gratitude to all parties who have supported the preparation of this book. May this work serve as an important milestone in Timor-Leste's journey toward strong food security, inclusive economic development and a sustainable environment.

Respectfully,

Eng. Marcos da Cruz, MAgSt
Minister of Agriculture, Livestock,
Fisheries and Forestry
Democratic Republic of Timor-Leste

EXECUTIVE SUMMARY

A. GENERAL OVERVIEW OF THE AREA

This chapter presents an overview of Manatuto District as an important background for evaluating land suitability and the potential for developing agricultural, plantation, horticultural and forestry commodities. The information presented covers demography, soil types, land use and existing field conditions, using a data-based approach that is in depth and comprehensive.

1. Demography

Manatuto District has six administrative posts (Sub-Districts), namely Barique/Natarbora, Laclo, Laclubar, Laleia, Manatuto and Soibada. The area directly borders Aileu District to the north, Baucau District and Viqueque District to the east, Ainaro District to the west and the Timor Sea to the south. With an area of 1,785.95 km^2, Manatuto District has a population of 48,876 inhabitants distributed across different areas. Geographical conditions dominated by hills and forest make this district important for planning development based on conservation and sustainable natural resource management.

2. Soil Types: Basis for Land Suitability Evaluation

Manatuto District exhibits a diversity of soil types, including Mollisols, Vertisols, Inceptisols, Entisols and alluvial soils. Mollisols, which dominate the district area, are fertile soils rich in organic matter and are therefore highly suitable for agricultural activities. This diversity reflects substantial opportunities for developing agriculture based on land suitability. However, soils with characteristics that are vulnerable to erosion, such as Vertisols, require special attention. The implementation of intensive and well-targeted soil conservation strategies is critically important to ensure sustainable land productivity and to support sustainable agricultural development in this district.

3. Land Use: Dynamics of Ecosystems and Human Activities

Land use in Manatuto District is dominated by forest areas (87.79 %), followed by agricultural land, which includes dryland agriculture, rice fields and shifting cultivation areas (8.39 %). Forest areas dominate in Laclubar, Laleia and Laclo Sub-Districts, whereas agricultural land is concentrated mainly in Barique/Natarbora, Soibada and Manatuto Sub-Districts. This land use pattern indicates a balance between the ecological functions of forests and agricultural production potential, although integrated management is required to optimise the contribution to food security.

4. Slope Gradient: Risk and Potential

The 25-45 % slope class dominates most of the area in Manatuto District, particularly in Laclo Sub-District, followed by the 15-25 % slope class, especially in Barique/Natarbora Sub-District. These conditions create a high risk of erosion and limit land available for intensive agriculture, so land management requires conservation-oriented approaches such as terracing, ground cover vegetation and engineering structures to control surface runoff. In areas with steep slopes, conservation activities such as agroforestry or reforestation are more appropriate to reduce the risk of erosion and soil degradation.

5. Agroclimatic Zones: Grouping of Regional Potential

Manatuto District is dominated by agroclimate zone B (33.08 %), which has a monomodal rainfall pattern. This zone predominates in Manatuto and Laleia Sub-Districts. The next most extensive is agroclimate zone C (20.18 %), which is dominant in Laclubar Sub-District. This zone also has a monomodal rainfall pattern, but with a longer rainy season. These agroclimatic characteristics indicate that the district is suitable for farming systems that depend on a single main rainy season. Differences in land area in each Sub-District contribute to variability in productivity and in natural resource management strategies.

6. Field Conditions: Constraints and Potential

Manatuto District has designated the development of irrigated rice fields as a primary priority in agricultural development in order to strengthen food security and increase production efficiency through well-managed irrigation systems. In addition, the district has potential flagship commodities such as coffee and vanilla in Soibada Sub-District, although constraints in productivity and supply chains are still present. Aubeon Village in Barique/Natarbora Sub-District has demonstrated success in horticulture programs and the restoration of marginal land through partnerships with various stakeholders. Meanwhile, Laclo, Laleia and Manatuto Sub-Districts have strategic opportunities for the development of rice, forestry species (such as teak and sandalwood) and horticultural crops (orange, papaya, and banana). Given the high risk of natural disasters, sustainable land and water management becomes a key factor. Therefore, conservation-based and climate change adaptation approaches are required to support the resilience and sustainability of agricultural sector development in this district.

7. Utilization of *Chromolaena odorata*: From Challenge to Opportunity

Chromolaena odorata (Siam weed) is an invasive weed that has spread widely in Timor-Leste since the 1980s. This plant threatens agriculture by forming dense thickets that compete for nutrients, and it is harmful to livestock due to its content of toxic pyrrolizidine alkaloids. Ecologically, the invasion of this weed hampers the regeneration of native vegetation and increases the risk of land fires. Nevertheless, *C. odorata* has potential uses, including as a source of traditional medicine, organic fertilizer and vermicompost. Appropriate management approaches are needed to suppress its negative impacts while at the same time optimising the added value of its biomass.

B. RESEARCH METHODS

The research employed a survey-based approach that included field observation, interviews and laboratory analysis to evaluate land suitability comprehensively. The study used Homogeneous Land Units (HLU) as the basis for delineating areas, drawing on thematic maps such as land use, soil type, geology and slope gradient. Data analysis was supported by Geographic Information Systems (GIS) technology to produce accurate and informative map visualizations.

Research Procedure

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

   The physical and chemical soil parameters analyzed included:
   a) C-organic *(%)*: *Walkley* and *Black* Method.
   b) N-total *(%)*:*Kjeldahl* Method.
   c) Soil texture: Pipette Method.
   d) Soil pH: Potentiometric Method *(H_2O 1:2.5)*.
   e) P-available & K-available (ppm):
      - *Bray*-1 Method for pH < 7 (with conversion to mg/100 g).

- *Olsen* Method for pH > 7 (with conversion to mg/100 g).

f) Salinity: dS/m with a potentiometer *(H_2O 1:2.5)*.

g) Cation Exchange Capacity (CEC) (*cmol/(mg/100g)* and Base Saturation (BS) (%) with a *NH_4OAc 1N pH7*.

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-: $HClO_4$ digestion method.

j) Total Sulfur (ppm) and Available Sulfur (ppm) determined using the spectrophotometric method.

k) Soil Fertility Status: Classified using the PPT (1995) Method.

l) Erosion Hazard: field observation and the Universal Soil Loss Equation (USLE).

3. Stages of Land Suitability Classification

a) Actual Land Suitability

The initial classification was carried out to evaluate land suitability under existing conditions without improvement.

b) Land Improvement Recommendation

Improvement measures were identified to address limiting factors, including management of inputs such as fertilizers and soil and water conservation technique.

c) Potential Land Suitability

Suitability was evaluated after considering improvement measures in order to maximize land potential.

d) Zonation of Commodity Development Potential

Zonation was determined by integrating the Timor-Leste Agroecological Zones, based on land suitability and specific agroecosystems.

C. CHARACTERISTICS OF AGRICULTURAL AND FOREST LAND

1. Temperature

Air temperature is a key parameter in land suitability evaluation, analyzed through the integration of field measurements and the SRTM Digital Elevation Model (DEM) using the Braak approach. The >26 °C temperature category is the most dominant range in Manatuto District, especially in Barique/Natarbora Sub-District. This condition can increase evapotranspiration rates and reduce photosynthetic efficiency, thereby triggering a significant risk of land drought during the dry season. Rising air temperatures can also reduce agricultural production and increase the incidence of pests and diseases in crops.

2. **Rainfall**

The most dominant rainfall level in Manatuto District is 2,000-2,500 mm, occurring in Soibada Sub-District. This rainfall level reflects high agroclimatic potential for the development of rainfed farming systems, particularly for horticultural commodities that require stable soil moisture and a consistent water supply throughout the growing cycle.

3. **Dry Month**

The most common dry-month duration in Manatuto District is >6 months. This condition indicates a high level of vulnerability to drought risk and water deficit for agricultural activities. A prolonged dry season limits crop choices and can lead to drought, crop failure and an increased risk of fire.

4. **Elevation**

The average elevation of the district is 312.25 m above sea level, with variation from coastal areas to hilly zones. Differences in elevation affect agroecological conditions, including microtemperature, humidity and the types of soils that form. In lowland areas, land potential is more suitable for annual crops, whereas at higher elevation there are opportunities for plantation crops. Thus, altitude is an important factor in land use planning.

5. **Drainage**

Manatuto District is dominated by well drained conditions. This indicates soil structures with high porosity and textures that support efficient water movement. Such conditions enable optimal water infiltration without causing stagnation or excessive moisture, thereby supporting root growth and sustained soil microbiological activity.

6. **Coarse Fragment**

The most dominant coarse fragment category in Manatuto District is <3 %, particularly in Manatuto Sub-District. This reflects soil physical conditions that are highly favorable for intensive agricultural cultivation. Low coarse fragment content allows efficient tillage, increases water-holding capacity and enhances interactions between plant roots and nutrient.

7. Effective Soil Depth

Manatuto District predominantly has deep effective soil depth, in the 90-120 cm category, with the widest extent in Manatuto Sub-District. This indicates that soils in Manatuto District have high agronomic potential and support intensive cultivation systems. Relatively uniform soil depth also facilitates land suitability zonation and the application of mechanized agriculture, because no special treatment is required for restrictive layers.

8. Surface Rock

Areas in Manatuto District are dominated by surface rock contents of <5 %, particularly in Barique/Natarbora Sub-District. This proportion indicates that land in this zone has high potential for intensive agricultural development, because there are minimal physical obstacles that could interfere with tillage operations and crop growth.

9. Rock Outcrops

Rock outcrops in Manatuto District are dominated by the <5 % category, especially in Barique/Natarbora Sub-District. This shows that most of the district has soil surfaces that are relatively free from exposed rock, which is highly favorable for agricultural activities and infrastructure development, because it allows optimal soil tillage, improved water infiltration and efficient implementation of cultivation technology.

10. Flood Hazard

Manatuto District is dominated by areas in the no or non flood prone category. This indicates that most areas have relatively elevated topographic characteristics, efficient drainage systems and vegetation cover that effectively reduces surface runoff. However, Laleia Sub-District has the largest area in the very high flood hazard category. This highlights the need for priority interventions, both structural and non-structural.

11. Soil Texture

Soil texture in Manatuto District varies among Sub-Districts. In Barique/Natarbora, Laclo, Laclubar, Manatuto and Soibada Sub-Districts, soil texture is dominated by silt and clay fractions, so soils in these areas are classified as clay loam with fairly good water and nutrient retention capacity. In contrast, in Laleia Sub-District, soil texture is classified as silty clay loam with a very high silt fraction, so soils at this location have finer characteristics with high water-retention capacity, but still require special attention to drainage management.

The variation in soil texture among Sub-Districts reflects differences in soil physical properties that directly affect soil fertility and crop growth potential.

12. Soil pH

Soil pH in Manatuto District is generally neutral to slightly alkaline. Under neutral conditions, nutrients are optimally available and readily dissolved in water, facilitating plant uptake. In contrast, soils with higher pH are often associated with alkaline conditions that can inhibit nutrient uptake and deteriorate soil structure. Soil pH values are very important because they indicate soil fertility status.

13. N-Total

Total Nitrogen content in Manatuto District is classified as low. Soils with low to very low Total Nitrogen show limitations in nitrogen availability, which can inhibit plant growth, reduce leaf area and slow biomass formation. This variation demonstrates the importance of site-specific nitrogen fertilization management to improve soil fertility.

14. P- Available

Available Phosphorus content in Manatuto District is classified as very low. Under these conditions, phosphorus tends to be fixed by Al^{3+} or Ca^{2+} ions, so it is not biologically available. Therefore, appropriate phosphorus nutrient management strategies are essential to support crop growth in this district.

15. K- Available

Available Potassium content in Manatuto District ranges from very low to medium and varies among Sub-Districts. These differences are closely related to lithological conditions and soil texture, which influence potassium supply capacity. In Sub-Districts with finer soil textures, potassium tends to be more strongly bound so its availability is limited. This underscores the need for site-specific monitoring of soil potassium status to ensure sustainable agricultural productivity.

16. EC/Toxicity

Electrical conductivity (EC) values in Manatuto District range from low to high and differ among Sub-Districts. High EC in certain areas may indicate potential salinity problems that affect water availability for plants. Thus, land management needs to consider Sub-District-specific conditions to avoid risks of toxicity and declining soil productivity.

D. SOIL FERTILITY STATUS

Soil fertility status in Manatuto District is predominantly in the low category, covering 53.06 % (951.07 km²), followed by very low status at 28.21 % (505.66 km²), high status at 12.29 % (220.24 km²) and medium status as the smallest proportion at 6.45 % (115.59 km²). These conditions indicate that soils are limited in their ability to supply essential nutrients for crops, with direct implications for low agricultural land productivity.

This situation highlights the need for effective soil management strategies, such as the use of organic fertilizers, soil conservation techniques, and improved irrigation systems to increase productivity. Optimizing land with medium and high fertility status can support food security and community welfare. Collaboration among farmers, academics and government is essential in designing land management solutions in this district.

E. EROSION AND AGROFORESTRY-BASED CONSERVATION

1. Soil Erosion

Soil erosion plays an important role in land suitability evaluation and in the sustainability of land use. Soil erosion in Timor-Leste, including in Manatuto District, is influenced by key factors such as steep topography, unstable soil structure, limited vegetation cover and land management practices that do not follow conservation principles. The analysis shows that erosion hazard levels in Manatuto District vary from very slight to very severe. This results in the loss of fertile topsoil and a decline in soil productivity.

The main factors causing erosion in this area include:

a) Topography: dominant steep slopes, especially in Laclo Sub-District
b) Soil type dominant Inceptisols and Vertisols with clayey structure and texture that are susceptible to water erosion, which exacerbates erosion vulnerability.
c) Rainfall: high rainfall intensity that leads to severe to very severe erosion.
d) Limited vegetation cover: Contributes to the loss of topsoil due to surface runoff.
e) Anthropogenic: Land management that does not take conservation principles into account accelerates erosion.

These conditions underscore the need for conservation measures based on ecological approaches to manage land and minimise soil degradation.

2. Agroforestry-Based Conservation

Agroforestry-based conservation is an effective primary approach to addressing soil erosion in Manatuto District. Agroforestry integrates forest trees, agricultural crops and livestock to provide ecological benefits and sustainable land productivity. This approach focuses on:

a) **Increasing vegetation cover**: Reducing surface runoff and maintaining soil moisture.
b) **Improving soil fertility**: Through the contribution of organic matter from leaves and roots.
c) **Managing water sustainably**: By retaining water in the soil profile through deep root systems.

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

a) **Erosion mitigation**: Trees and crops act as natural barriers that protect soil from surface runoff.
b) **Increased water infiltration**: Tree root systems improve the capacity of soils to absorb water.
c) **Enhanced biodiversity**: Combinations of food crops and trees create more diverse and stable ecosystems.
d) **Improved agricultural productivity**: Through agroforestry components that support diversified yields.

Implementation of Agroforestry in Manatuto District

Agroforestry systems applied in Manatuto District vary according to agroecological zones. Examples of effective agroforestry-based conservation systems include:

a) **Alley cropping**: Planting crops between tree rows on steep slopes to control erosion.
b) **Live fences**: Using erosion-tolerant plants such as Vetiver Root as hedgerows to stabilise slopes.
c) **Live stakes**: Using perennial species such as Leucaena as live stakes to control erosion, combined with Pepper and other climbing crops.
d) **Layered planting**: Combining trees, shrubs and groundcover crops to stabilise soil and reduce runoff.

Conservation Recommendation

1. Expansion of agroforestry practices in erosion-prone zones, such as Laclo Sub-District.
2. Spatial data-based management to identify priority locations for conservation interventions.
3. Capacity building for farmers through training and adoption of modern agroforestry techniques.
4. Strengthening soil conservation policies by integrating agroecology-based approaches into spatial planning.
5. Strengthening soil conservation policies by integrating agroecology-based approaches into regional land use planning.

F. AGRICULTURAL LAND SUITABILITY

1. Land Suitability Evaluation

a) Barique/Natarbora Sub-District

- Wetland food crops have very high potential for development of Irrigated Rice. Dryland food crops are moderately suitable, including upland rice, peanut, sorghum, corn, cassava, soybean, wheat and others.
- Horticultural commodities that can be developed include shallot, chili, bell pepper, caisim, broccoli, tomato, tomato vegetable, rambutan, mango, watermelon, melon, avocado, durian, strawberry, grape, rose, aster and sunflower.
- Spice and medicinal crops such as vetiver root, lemongrass and vanilla can be developed.
- industrial crops with development potential include rubber, cacao, robusta coffee, tea, and kapok.

b) Laclo Sub-District

- Wetland food crops such as Irrigated Rice are very suitable for development. Dryland food crops are moderately suitable for development, including upland rice, sorghum, corn, soybean, mung bean, cowpea, and taro.
- Industrial crops that can be developed include tobacco, quinine, cotton, and oil palm.
- Horticultural crops with development potential include shallot, chili, bell pepper, caisim, green beans, cucumber, cabbage, guava, watermelon,

melon, avocado, durian, custard apple, pineapple, rose, aster and sunflower.
- Spice and medicinal crops that can be developed include ginger, candlenut, pepper and nutmeg.

c) **Laclubar Sub-District**
- Industrial crops that can be developed include robusta coffee, melinjo, cashew and others.
- Food crops with development potential include rainfed rice, upland rice, sorghum, corn, sweet potato, mung beans, cowpea, and taro.
- Horticultural crops with development potential include shallot, chili, bell pepper, caisim, green beans, cucumber, cabbage, orange, breadfruit, snakefruit, pineapple, aster, rose, and sunflower.
- Spice and medicinal crops with development potential include cinnamon, jatropha, aromatic ginger, and others.

d) **Laleia Sub-District**
- Wetland food crops such as irrigated rice are very suitable. Dryland food crops that can be developed include upland rice, peanut, sorghum, corn, cassava, mung beans, cowpea, and others.
- Horticultural crops such as caisim, cucumber, green beans, broccoli, rambutan, melon, papaya, longan, custard apple, strawberry, grape, aster, rose and sunflower can be developed. Industrial crops with development potential include clove, tobacco, and coconut.
- Spice and medicinal crops that can be developed include turmeric, aromatic ginger, and galangal.

e) **Manatuto Sub-District**
- Wetland food crops that are very suitable for development include Irrigated Rice. Dryland food crops that are moderately suitable for development include rainfed rice, upland rice, peanut, sorghum, corn, cassava, mung beans, and cowpea.
- Industrial crops with development potential include rubber, cotton, and kapok.
- Horticultural crops with development potential include bell pepper, eggplant, bitter melon, tomato vegetable, passion fruit, watermelon, melon, banana, strawberry, grape, rose, aster, and sunflower.

- Spice and medicinal crops that can be developed include galangal, cardamom, sesame, and others.

f) **Soibada Sub-District**

- Wetland food crops that are very suitable for cultivation include Irrigated Rice. Dryland food crops that are moderately suitable for development include upland rice, peanut, sorghum, corn, cassava, mung beans and cowpea.
- Horticultural crops with potential include shallot, chili, caisim, jackfruit, breadfruit, durian, strawberry, grape, aster, rose and sunflower.
- Spices that can be developed include pepper, candlenut, cinnamon and others.
- Industrial crops that can be developed include robusta coffee, tea, tobacco and others.

2. Agricultural Commodity Development Zones in Manatuto District

This study aimed to evaluate land potential and suitability for different land uses in Liquiçá District, Timor-Leste, as a basis for sustainable regional management planning. The analysis considered biophysical aspects, topography, soil types and the ecological and economic functions associated with each land use category.

a) **Irrigated rice fields,** the irrigated rice field zone covers 138.48 km² (7.77 %) at elevations of 0 to 100 m above sea level with slopes of 0-15 %. Entisols and alluvial soils are relatively fertile but prone to waterlogging, with a monomodal agroclimatic regime that allows one Rice growing season per year. The main risks are flooding and water deficit during the dry season.

b) **Rainfed rice fields,** this zone covers 167.14 km² (9.38 %) at elevations of 0 to 100 m above sea level with slopes of 0-3 % on alluvial plains. Young Entisols are sensitive to erosion and flooding, with a monomodal regime that allows only one Rice growing season. Water limitations render the land unproductive in the dry season.

c) **Dryland agriculture**, the dryland agriculture zone, covering 354.38 km² (19.89 %), lies at elevations of 0-1,000 m above sea level with slopes ranging from flat to steep. Entisols, Mollisols and Inceptisols have varying levels of fertility, with a monomodal regime that restricts cropping to one season and increases drought risk. Main commodities include Corn, Rice, Taro, Cassava, Sweet Potato, Porang and Breadfruit, while horticulture is based on tropical fruits (Banana, Mango, Papaya, Durian, Avocado and others) and high-value vegetables (Tomato, Pakchoi, Spinach, Long Beans, Caisim, Water Spinach and others) to support food diversification and local markets.

d) **Grazing area,** the grazing zone, covering 17.17 km² (0.96 %), is located on alluvial lowlands with shallow, nutrient-poor Entisols. A bimodal regime allows two periods of forage growth but the area is prone to drought. This zone is important as a forage base for dairy cattle, especially in Barique/Natarbora Sub-District. Suitable forage species include Elephantgrass, Setaria and legumes, with recommendations such as sprinkler irrigation, rotational grazing, forage banks and silvopasture systems.

G. FORESTRY POTENTIAL

Manatuto District has significant potential for the development of forestry commodities, with land suitability ranging from S2 (moderately suitable) to S3 (marginally suitable). *Leucaena* and *Melaleuca* are recommended for all Sub-Districts (S2), while Teak, Albizia and Acacia can still be developed with technical improvements (S3). In contrast, Altingia and Pine are not recommended due to temperature limitations.

The biophysical conditions of this district support agroforestry systems (31.81 %), protected forest (29.96 %) and mangrove forest (0.23 %), with a bimodal agroclimatic regime, dominant Mollisols and Entisols and characteristic lithology that give the area a dual function as an ecological buffer and a base for sustainable production. The main commodity is Coffee, particularly Robusta Coffee, which is more adaptive to local conditions and has the potential to drive the economy, while Arabica Coffee is suitable only for limited development with technical interventions.

Sandalwood (*Santalum album* L.) in Manatuto District has high strategic value because it produces timber and essential oil with economic value while also having cultural significance. Although it falls into the S3 class, its development remains promising through appropriate site selection, maintenance of host trees and adaptive silvicultural techniques. Supported by the national inventory program, Sandalwood has the potential to become a flagship commodity that strengthens community income, cultural identity and the sustainable conservation of local resources.

H. LIVESTOCK POTENTIAL

This study aimed to support the development of the Sentra KTS Natarbora as part of the national plan to increase Timor buffalo milk production in Manatuto District, Timor-Leste. The main focus is the provision of high-quality forage feed and the improvement of reproductive technologies to enhance milk productivity and farmer welfare. The recommendations are as follows:

1. Short-term recommendations emphasise the preparation of forage land using superior varieties such as Setaria grass and leguminous species including *gamal*, kaliandra and indigofera, with an ideal feed composition of 60 % grasses and 40 % legumes. The use of supplementary feed such as rice bran, concentrates or flushing feed is recommended for specific animal conditions to support optimal milk production.
2. Long-term recommendations include strengthening human resource capacity through training and education, particularly in reproductive technologies, to address constraints such as silent heat in buffalo that can hinder productivity. Certified artificial insemination (AI) training programs are expected to improve farmers' ability to detect estrus and optimise reproduction. With adequate facilities, the Sentra KTS Barique/Natarbora can adopt sexing methods to increase the probability of female births, thereby supporting the development of superior breeding stock and sustainable milk production.

I. FISHERIES AND AQUACULTURE POTENTIAL

This study aimed to evaluate land suitability for aquaculture development in Manatuto District, Timor-Leste, focusing on the assessment of actual and potential land conditions through field surveys, biophysical analysis and mapping using Geographic Information Systems (GIS). The evaluation identified major limiting factors such as topography, water quality, salinity and climatic conditions that influence land suitability for freshwater and brackish water aquaculture.

Field studies conducted in several Villages in Manatuto District identified various challenges in fisheries and aquaculture management. The main problems include shortages of fish feed, threats of water pollution and limited access to clean water. Each site has specific issues, so technical recommendations need to be tailored to local conditions in order to improve productivity, sustainability and economic resilience of communities in the fisheries sector. Several locations such as Grupo Radudu, Lacumesak Village and Aubeon Village face different constraints, including pond damage due to disasters, less favourable geographic conditions and suboptimal feed management. Aubeon Village is recommended as a pilot site for family-based freshwater aquaculture because of the availability of water sources throughout the year and the cost-efficiency of family labour-based production.

Policy recommendations include the establishment of local hatchery units, rehabilitation of pond infrastructure after disasters, regular technical training in culture management and facilitation of access to production inputs through conditional subsidies or group-based microcredit schemes. In addition, integrating the aquaculture sector into regional development planning and strengthening spatial data-based monitoring systems are also important to ensure sustainability and increased local capacity. With the implementation of these recommendations, aquaculture development in Manatuto District is expected to proceed in a sustainable, inclusive way and generate positive impacts on the local economy.

J. RESEARCH RECOMMENDATIONS

1. Agriculture

Agriculture in Manatuto District is developing with a wide range of commodities, including food crops, horticultural crops, industrial crops, spices, medicinal plants, forestry and forage feed. Irrigated rice fields are recommended in several Villages such as Haturalan, Sau and Ma'abat, while rainfed rice fields are suitable for development in Aiteas Village. Forage feed is dominant in Barique/Natarbora Sub-District, with crops such as Elephantgrass and gamal. The main food commodities are Corn, Rice, Sweet Potato, and Taro as key components of food security. Horticultural and industrial crops such as Coconut and Coffee have important economic potential. Forestry vegetation is directed both toward conservation and as a source of raw materials for industry. Technical recommendations focus on appropriate land management, such as contour planting and improved irrigation to address erosion and flooding. Strengthening farmer capacity through training in management and conservation is essential, supported by policies such as subsidies, infrastructure development and commodity zoning based on local potential. This integrated approach is expected to promote productive, sustainable, and adaptive agriculture and to increase farmer welfare and food security in Manatuto District.

2. Livestock

Development of the Sentra KTS Barique/Natarbora focuses on increasing Timor buffalo milk production by preparing high-quality forage land with species such as Setaria grass and leguminous species including gamal, kaliandra, and indigofera. A recommended feed composition is 60 % grass and 40 % legumes, supplemented with concentrate feed according to animal requirements. The government is expected to provide support through feed provision, reproductive training and certified artificial insemination technology to increase productivity. The application of sexing methods is also recommended to increase the probability of female births as superior breeding stock.

3. Fisheries

Aquaculture in several Villages in Manatuto District faces constraints such as shortages of fish feed, water pollution and limited access to clean water. Damaged pond infrastructure and high salinity are major obstacles to freshwater production. Technical interventions tailored to local conditions are needed, including pond rehabilitation, establishment of hatchery units and installation of simple aeration systems. Aubeon Village is recommended as a pilot site for family-based freshwater aquaculture. Policy recommendations include upgrading infrastructure, training in culture management, facilitating access to production inputs, integrating aquaculture into regional development plans and strengthening data-based monitoring. These measures are expected to increase productivity and the sustainability of the fisheries sector in the district.

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I. INTRODUCTION

New Context: ASEAN, SDGs, and Food Self-Sufficiency

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

In this new era, Timor-Leste faces major challenges in achieving food self-sufficiency and optimising the use of its natural resources. With population growth and increasing food demand, the country must develop sustainable strategies.

The attainment of the Sustainable Development Goals (SDGs), particularly food security (SDG 2), clean water management (SDG 6) and climate change mitigation (SDG 13), has become a strategic issue. In this context, Manatuto District offers significant potential due to its unique characteristics.

Administrative History: Development of the Regional Status of Manatuto

Historically, prior to the arrival of the Portuguese, Manatuto was under the authority of local traditional governance systems. In 1698, the Portuguese began to assert control through Governor António Coelho Guerreiro. Subsequently, in 1859, Manatuto was established as an independent district with its administrative center in Manatuto Vila, encompassing the kingdoms of Bubur-Susso, Kablaqui, Fulau, Faturo, and Turiscai. After World War II, the status of the area changed to a Civil Circumscription comprising Barique, Fatuberlihu, Laclo, Laclubar, and Laleia. This administrative structure remained in place during the period of Indonesian administration, and following the restoration of Timor-Leste's independence, Manatuto was officially designated as one of the Districts.

Regional Focus: Land Potential and Fertility Assets

Manatuto District is an administrative area with a strategic position, both geographically and ecologically. With a relatively low population density (an average of 28.6 inhabitants per km²), the district has extensive space for optimising agricultural land to increase food production.

Topographically, Manatuto has flat to gently sloping land covering 32.80 % of the total area. This substantial proportion is highly suitable for the development of a wide range of agricultural commodities. At the same time, areas with steeper slopes require the application of soil conservation techniques, such as terracing, in order to support sustainable agriculture.

Technical Foundation: Exceptionally Fertile Soil Capital

The greatest "capital" possessed by Manatuto District lies in its soil quality. The area is dominated by **Mollisols (43.09 %).** This is an exceptional asset, because Mollisols are recognised as among the most fertile and productive soils in the world, and are ideal for intensive agriculture.

This potential is reinforced by the presence of other productive soil types:

- **Vertisols (20.39 %)**, which have high water-holding capacity and strong potential for development as irrigated rice fields.
- The combination of Mollisols and Vertisols provides substantial opportunities for the development of food crops such as rice, as well as perennial crops with high economic value such as coffee and cacao.
- The presence of **Inceptisols (17.69 %), Entisols (14.57 %)** and **Alluvial soils (4.17 %)** adds further diversity in soil characteristics that can be utilised for agricultural diversification.

Opportunities for Integrated Sector Development

With fertile soils and diverse topography, Manatuto has strong opportunities for the integrated development of four key pillars:

1. **Agriculture:** Utilisation of Mollisols and Vertisols for intensive agriculture (rice, coffee, cacao), supported by irrigation technology and organic fertilisation.
2. **Forestry (Agroforestry):** In more sloping areas, agroforestry can be implemented as a conservation-based farming system. This helps maintain ecosystem balance, reduce erosion, and ensure long-term production sustainability (Nair, 2011).
3. **Livestock:** Extensive flat land, particularly in coastal areas, allows optimal use of grazing land for cattle and goats, which are key livestock commodities in Timor-Leste.
4. **Fisheries (Freshwater and Brackish Water):** The fisheries sector in coastal zones has substantial prospects for development through brackish water aquaculture (ponds) based on modern technologies such as biofloc systems, along with potential for inland freshwater fisheries.

Evaluation Objectives in This Book

The study underlying this book aims to evaluate land suitability and map the potential for regional development in Manatuto District. The primary focus is on the agricultural sector, with complementary exploration of the livestock and fisheries sectors (freshwater and brackish water) as integrated supporting components.

Through a comprehensive scientific approach, this book is expected to provide strategic recommendations for government, academia and other stakeholders in designing sustainable development policies and to make a tangible contribution to achieving national food security in Timor-Leste in the new ASEAN era.

II. GENERAL OVERVIEW OF THE AREA

2.1 DEMOGRAPHY

Manatuto District is one of the districts in Timor-Leste located in the central part of the country, bordered by the Timor Sea to the south, Aileu District to the north, Baucau and Viqueque Districts to the east, and Ainaro District to the west. Astronomically, Manatuto District lies at 8.03° - 9.06° S and 125.45° - 126.10° E. The Administrative Map of Manatuto District is presented in the figure below **(Figure 2.1)**.

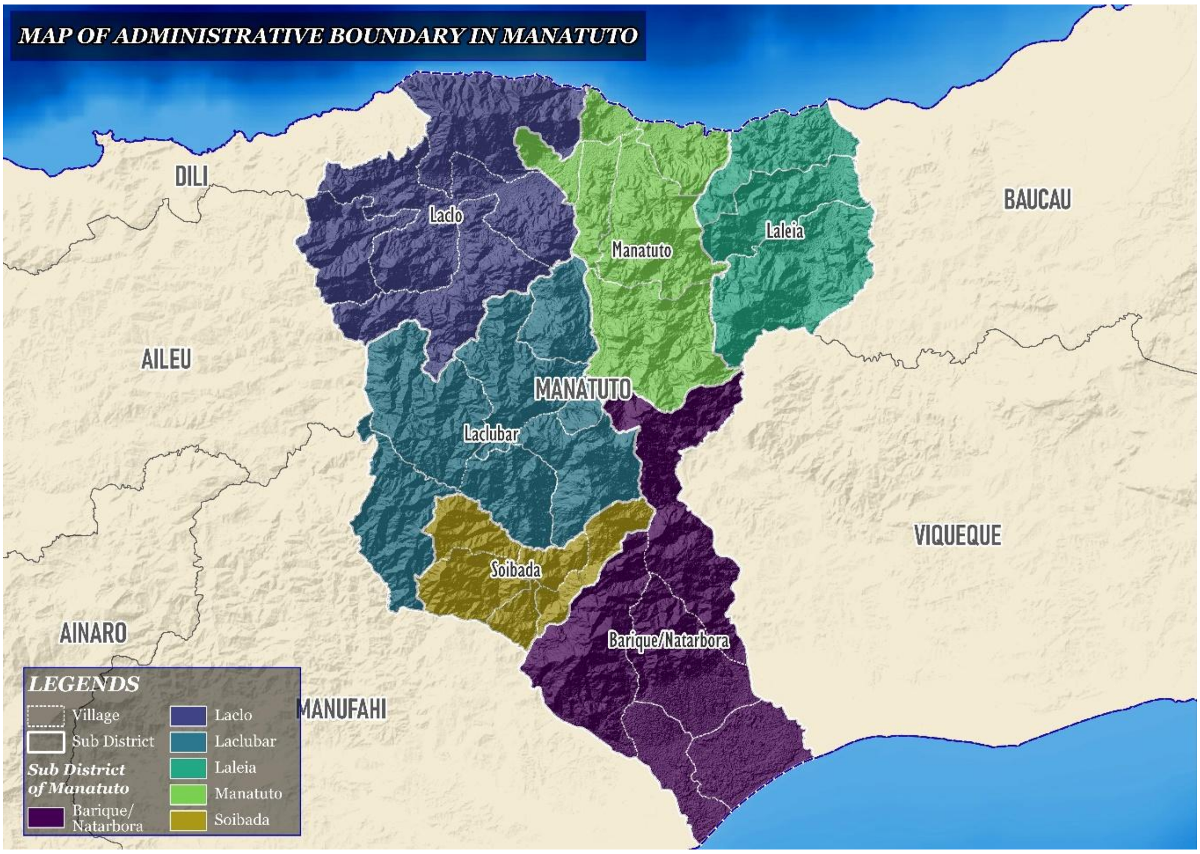


Figure 2.1 Administrative Area of Manatuto District

Manatuto District had a population of 48,876 based on the 2015 census projection for 2019. With a total area of 1.785,95 km², the population density was relatively low at approximately 27.36 people per km² (Administrasaun Munisípiu Manatuto, 2025). This indicates a sparsely populated district in which spatial and land-use patterns were strongly influenced by geographical conditions and historical factors. Area by Sub-District is presented in the table below **(Table 2.1)**.

Table 2.1 Area (ha) in Manatuto District

Sub-District	Area (ha)
Barique/Natarbora	39.653
Laclo	36.782
Laclubar	39.105
Laleia	22.563
Manatuto	27.077
Soibada	13.003

Historically, before the arrival of the Portuguese, the area was under traditional authority. In 1698, the Portuguese established control under Governor António Coelho Guerreiro. In 1859, Manatuto was designated as a separate district with its administrative center in Manatuto Vila, encompassing the kingdoms of Bubur-Susso, Kablaqui, Fulau, Faturo, and Turiscai. After World War II, its status changed to a Civil Circumscription comprising Barique, Fatuberlihu, Laclo, Laclubar, and Laleia. This structure persisted through the Indonesian occupation, and following the independence of Timor-Leste, Manatuto was designated as a District.

2.2 SOIL TYPES

Soil information in Manatuto District was classified according to soil taxonomy (using the 1992 soil taxonomy key). Classification was conducted to the Great Group level. There were 7 Orders, 16 Suborders, and 22 Great Groups.

Manatuto District was dominated by Mollisols covering 125,223 ha (43.09 %) distributed across the study area. Mollisols are fertile soils rich in organic matter and are ideal for agricultural activities. Other soils included Vertisols covering 36,330 ha (20.39 %), Inceptisols 31,523 ha (17.69 %), Entisols 25,965 ha (14.57 %), Alluvial soils 7,431 ha (4.17 %), and an unidentified soil type 152 ha. The distribution of soil types in Manatuto District is shown in **Figure 2.2**, soil types by Sub-District in **Figure 2.3**, and the distribution map in **Figure 2.4.**

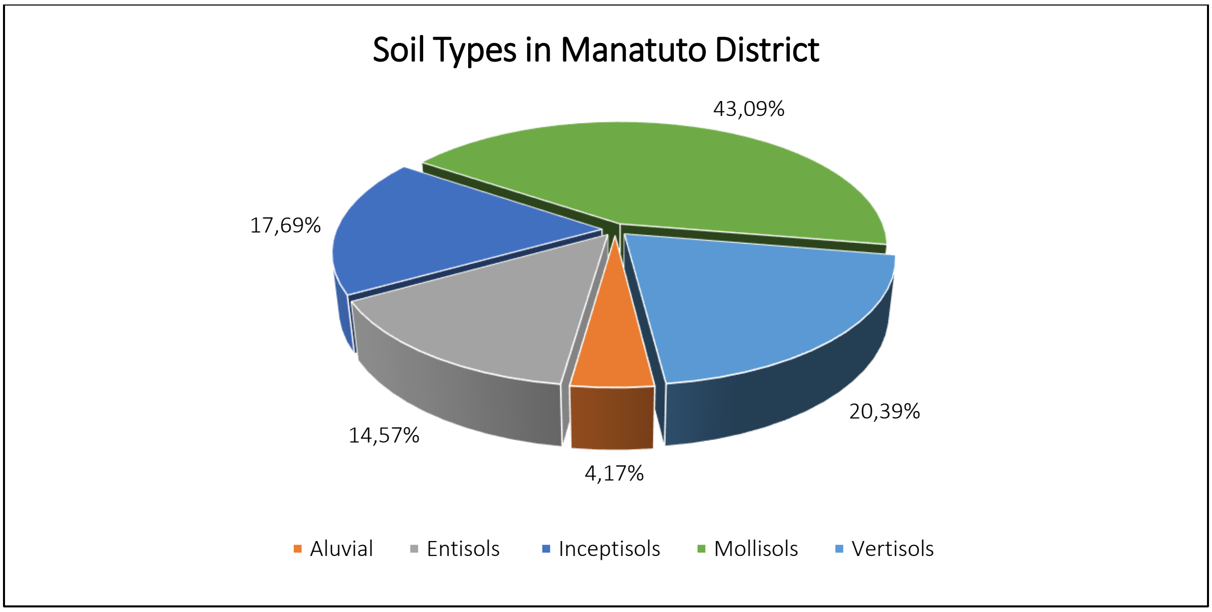
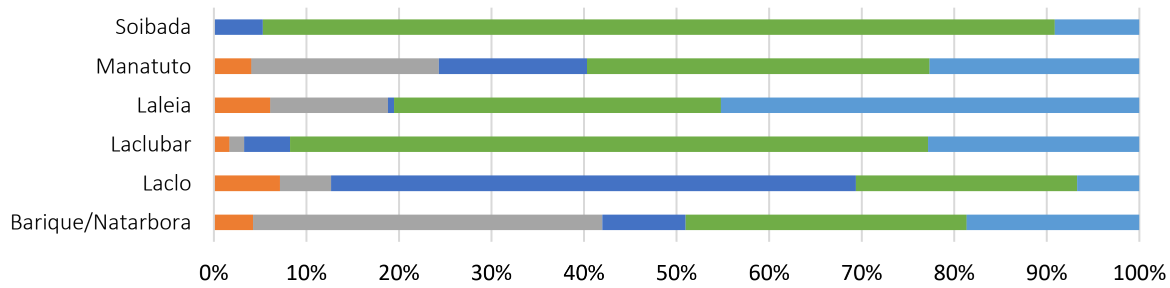


Figure 2.2 Soil Types in Manatuto District



	Barique/Natarbora	Laclo	Laclubar	Laleia	Manatuto	Soibada
Aluvial	0,94%	1,47%	0,37%	0,77%	0,62%	0,00%
Entisols	8,41%	1,14%	0,34%	1,61%	3,07%	0,00%
Inceptisols	2,00%	11,71%	1,09%	0,08%	2,43%	0,38%
Mollisols	6,76%	4,94%	15,13%	4,47%	5,62%	6,17%
Vertisols	4,15%	1,39%	5,01%	5,73%	3,45%	0,66%

Figure 2.3 Area by Soil Type by Sub-District

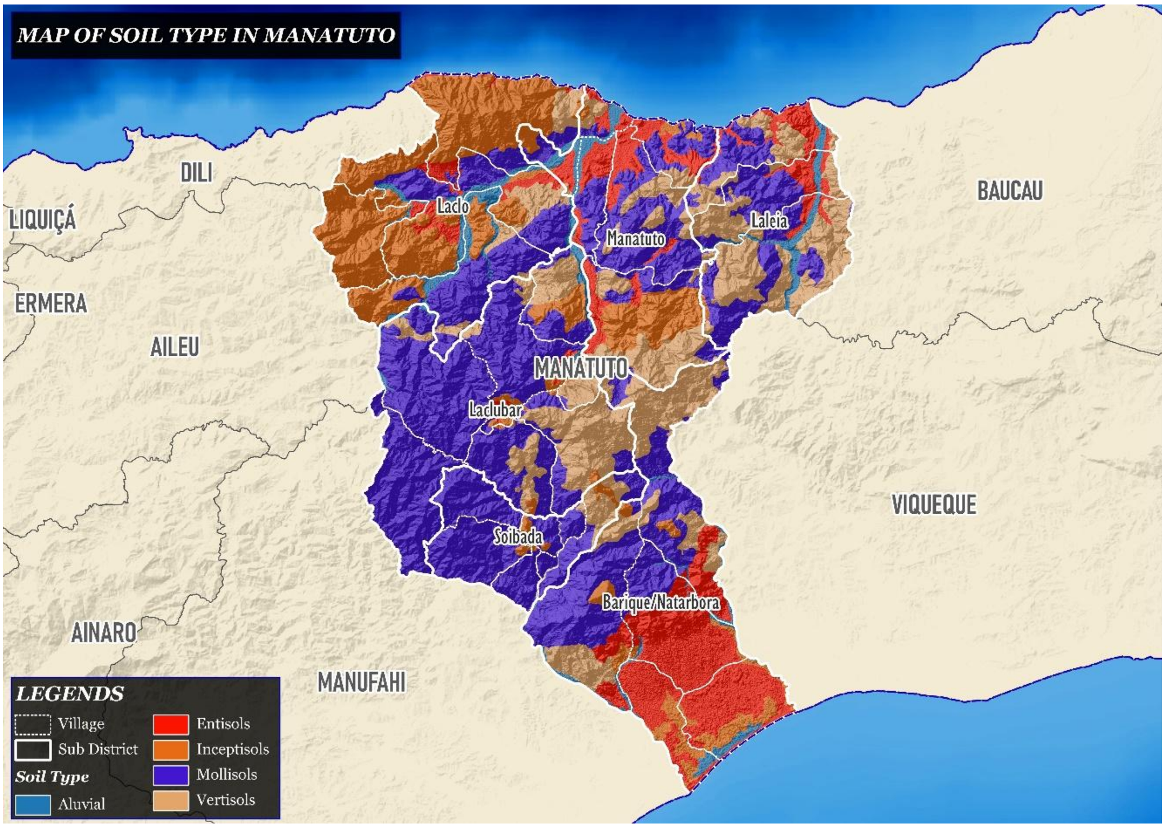


Figure 2.4 Soil Type Map of Manatuto District

2.3 GEOLOGICAL FORMATIONS

The distribution of geological formations in the study area showed significant diversity, reflecting the complex geological history of Manatuto District. Each geological formation contributed uniquely to soil development and influenced the potential and limitations of land for agricultural development. The analysis showed that the Aitutu Formation (24.88 %) dominated the area, followed by the Lolotoi Formation (19.08 %), Suai Formation (6.37 %), Bobonaro Formation (3.13 %), Cribas Formation (3.06 %), Maubisse Formation (2.11 %), Dilor Formation (1.71 %), and Barique/Natarbora Formation (0.19 %), as shown in Figure 2.5.

The Aitutu Formation occurred across much of Manatuto, covering 24.88 % or 44,329 ha. Lithologies included Calcilutite, Marl, Calcareous Shale, and Calcarenite. These characteristics indicate deposition in a deep-marine environment relevant to understanding the area's geological history and soil capability.

The Lolotoi Formation covered 19.08 % of Manatuto District, equivalent to 33,995 ha, with complex lithology including metamorphic and sedimentary rocks. This reflects a long geological process and produces variable soil characteristics, ranging from soils prone to erosion to soils with good water-holding capacity. This formation is often found in mountainous areas with steep topography and requires intensive conservation measures to maintain soil stability (Rossiter, 1996).

The Suai Formation covered about 6.37 % of Manatuto District or 11,349 ha. It was distributed in three Sub-Districts: Barique/Natarbora, Laleia, and Manatuto. The Bobonaro Formation covered about 3.13 % or 5,575 ha and occurred in two Sub-Districts, Barique/Natarbora and Laleia. The Bobonaro Formation consists of massive limestone, chert, and calcareous shale derived from deep-marine environments, characterized by high hardness and low permeability. Soils derived from this parent material tend to be nutrient-poor.

Other formations included the Cribas Formation, distributed in 4 Sub-Districts with a total area of approximately 5,450 ha across Barique/Natarbora, Laclubar, Laleia, and Manatuto. The Maubisse Formation covered about 2.11 % or 3,766 ha across Laclo, Laclubar, and Laleia. Geologically, the Maubisse Formation comprises reefal limestone, reflecting biogenic carbonate depositional systems formed in shallow tropical marine environments. Weathered soils are generally shallow, stony, and alkaline but have very good drainage, making them more suitable for non-conventional land uses such as perennial crop cultivation or drought-tolerant agroforestry systems. The Dilor Formation occurred only in Manatuto Sub-District, covering 3,055 ha. The Barique/Natarbora Formation covered 343 ha or about 0.19 % of Manatuto District, located in Barique/Natarbora Sub-District.

This geological diversity formed an important basis for land suitability evaluation. Each formation directly influenced soil physical and chemical properties such as texture, structure, water-holding capacity, and erosion susceptibility (Brady & Weil, 2017; Lal, 2019). As noted by Brady and Weil (2017), geological formations directly affect soil characteristics, which ultimately determine land-use potential.

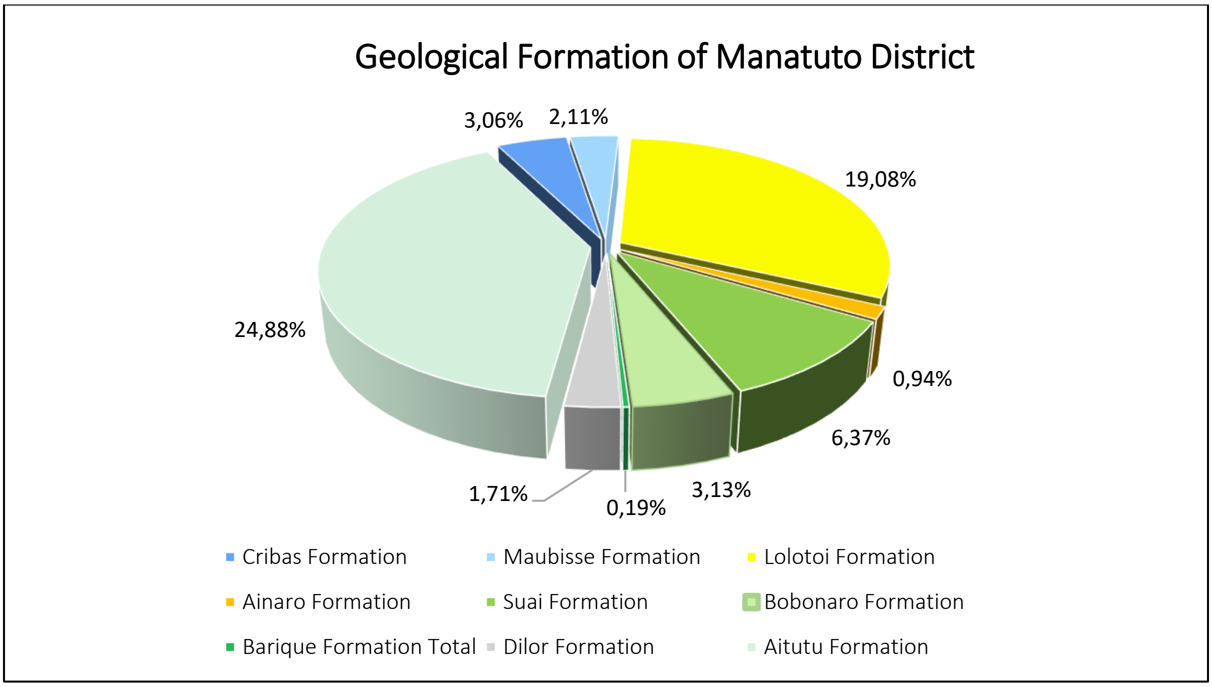
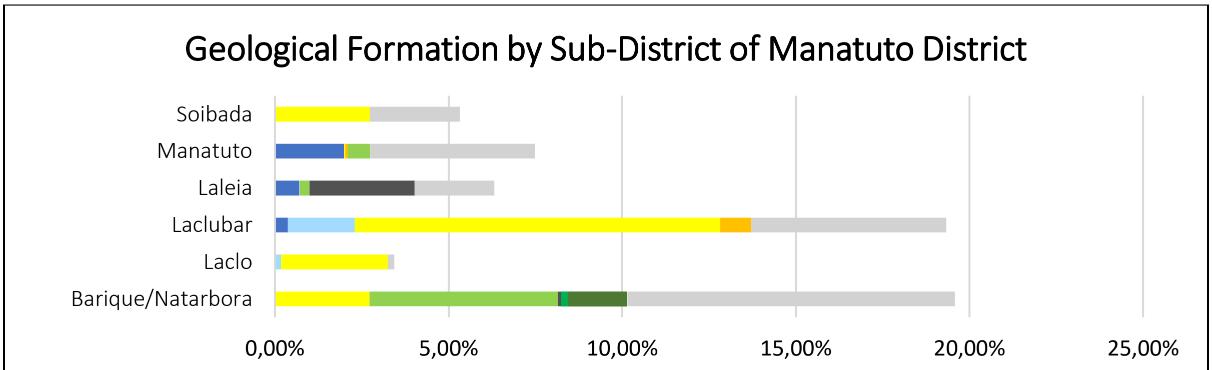


Figure 2.5 Geological Formations of Manatuto District



	Barique/Natarbora	Laclo	Laclubar	Laleia	Manatuto	Soibada
Cribas Formation	0,00%	0,00%	0,37%	0,70%	1,99%	0,00%
Maubisse Formation	0,00%	0,18%	1,93%	0,01%	0,00%	0,00%
Lolotoi Formation	2,72%	3,07%	10,53%	0,00%	0,04%	2,73%
Ainaro Formation	0,00%	0,00%	0,88%	0,00%	0,06%	0,00%
Suai Formation	5,43%	0,00%	0,00%	0,28%	0,66%	0,00%
Bobonaro Formation	0,10%	0,00%	0,00%	3,03%	0,00%	0,00%
Barique Formation	0,19%	0,00%	0,00%	0,00%	0,00%	0,00%
Dilor Formation	1,71%	0,00%	0,00%	0,00%	0,00%	0,00%
Aitutu Formation	9,42%	0,20%	5,62%	2,30%	4,74%	2,60%

Figure 2.6 Geological Formations by Sub-District in Manatuto District

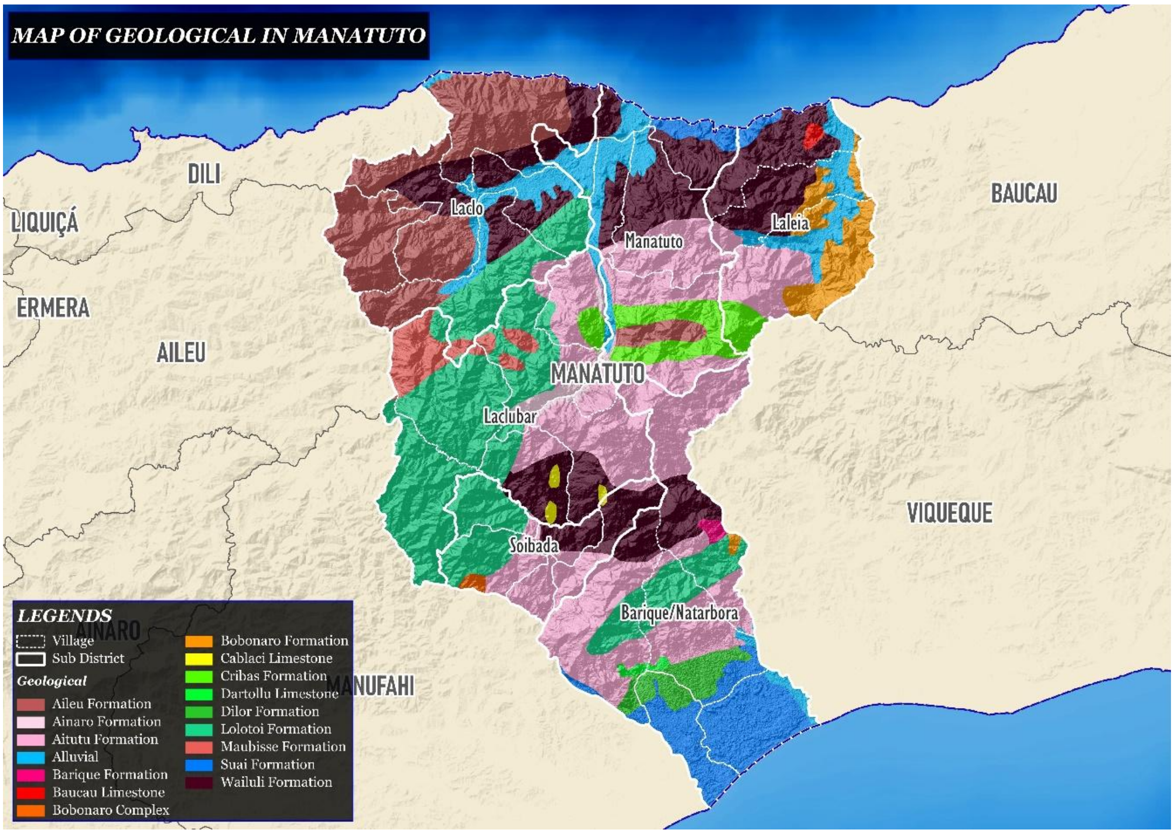


Figure 2.7 Map of Areas by Geological Formation

2.4 LAND USE

The distribution of land use in Manatuto District showed a complex and diverse pattern reflecting both ecosystem characteristics and associated human activities. These data provide an essential basis for evaluating land suitability for agricultural commodities, balancing environmental sustainability and land productivity.

Agricultural land in Manatuto District accounted for 8.39 % of the total area and consisted of dryland, rice fields, and shifting cultivation areas. Dryland arable for food crops occurred only in Manatuto Sub-District, covering 5.80 % of the total area. Rice fields had the largest coverage in Manatuto Sub-District at 0.69 %, whereas Laclubar Sub-District covered only 0.02 %. Rice fields were not found in Soibada Sub-District.

Commercial agricultural land covered 0.61 % of the total area in the form of smallholder estate crops in Barique/Natarbora (0.59 %) and Laclo (0.2 %) Sub-Districts, and was absent in Laclubar, Laleia, Manatuto, and Soibada Sub-Districts.

Unused dry areas such as grassland occurred only in Laclo and Manatuto Sub-Districts, covering 0.66%. These areas support grazing and natural ecosystems.

Forest land dominated 87.79 % of Manatuto District, reflecting important ecosystem functions in environmental conservation. Dry lowland mixed forest covered 2.24 % of the area and occurred only in Laleia Sub-District. Highland forest with single species covered 10.84 % of the total area, with the largest distribution in Laclubar Sub-District at 8.94 %, followed by Barique/Natarbora at 1.46 %, Soibada at 0.43 %, and Manatuto Sub-District at 0.01 %. These forests stabilize soils in hilly areas and support the hydrological cycle. Lowland forest with single species dominated most forest land at 44.77 %. Laclo Sub-District had the largest distribution, covering 17.39 %, followed by Manatuto at 10.70 %, Laleia at 9.26 %, and Laclubar at 7.42 %.

River areas occurred across all Sub-Districts, with the largest distribution in Laclo (0.74 %), followed by Barique/Natarbora (0.48 %), Laleia (0.45 %), Manatuto (0.42 %), and Soibada (0.06 %). Rivers are important for meeting water needs of communities and ecosystems.

Village settlements and mixed gardens occurred in Laclo Sub-District with 0.07 %. This category provides opportunities to diversify land for local community activities. Urban areas were found only in Laclubar Sub-District, covering 0.07 %. These areas are centers of social and economic activity that support infrastructure development and public services. Area by land-use type is shown in **Figure 2.8.**

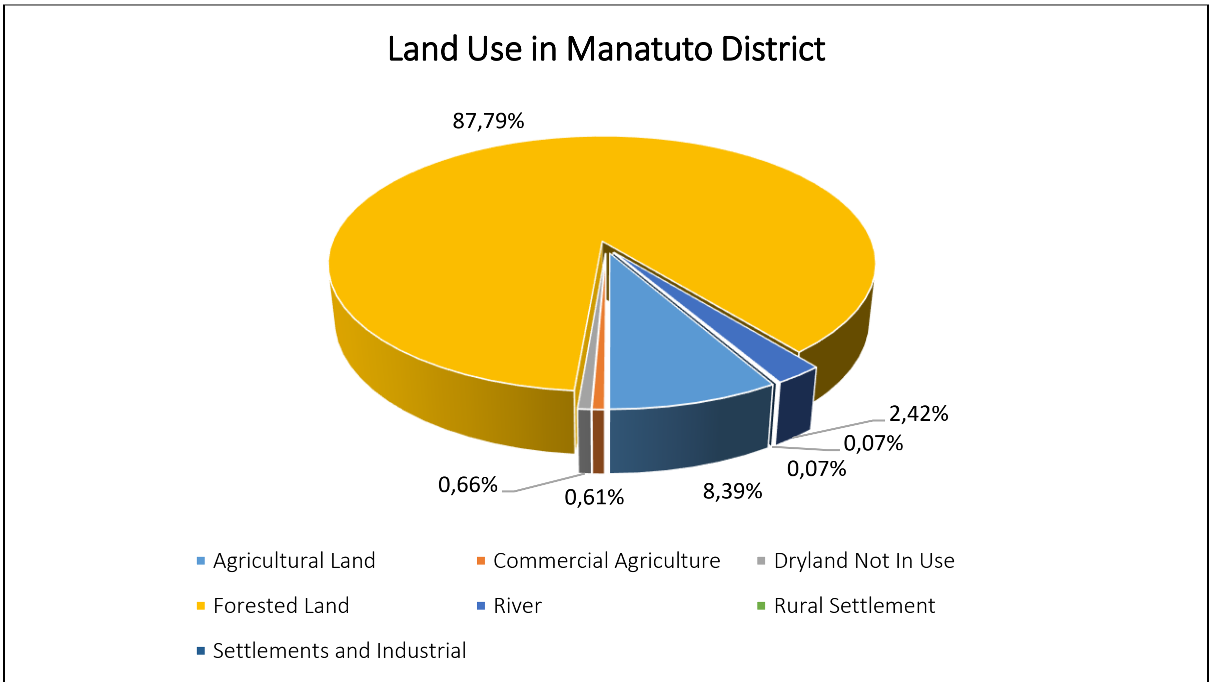


Figure 2.8 Land Use in Manatuto District

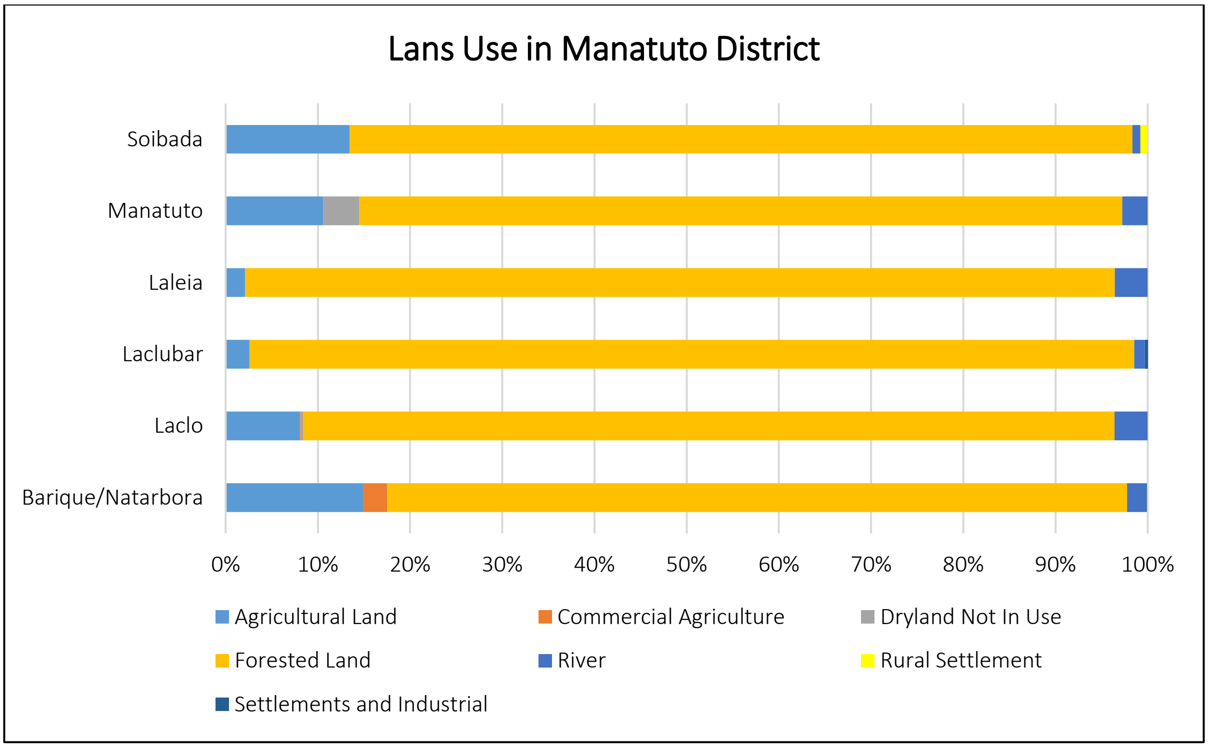


Figure 2.9 Area of Each Land-Use Type (%) in Manatuto District

Overall, land use in Manatuto District indicates both challenges and opportunities. Forest dominance provides an opportunity to develop sustainable forest commodities, while scattered agricultural land requires sustainable intensification strategies. With support from the Ministry of Agriculture, Fisheries, Livestock, and Forestry of Timor-Leste, integrated, data-driven planning is required to optimize land use, increase agricultural productivity, and support national food security sustainably.

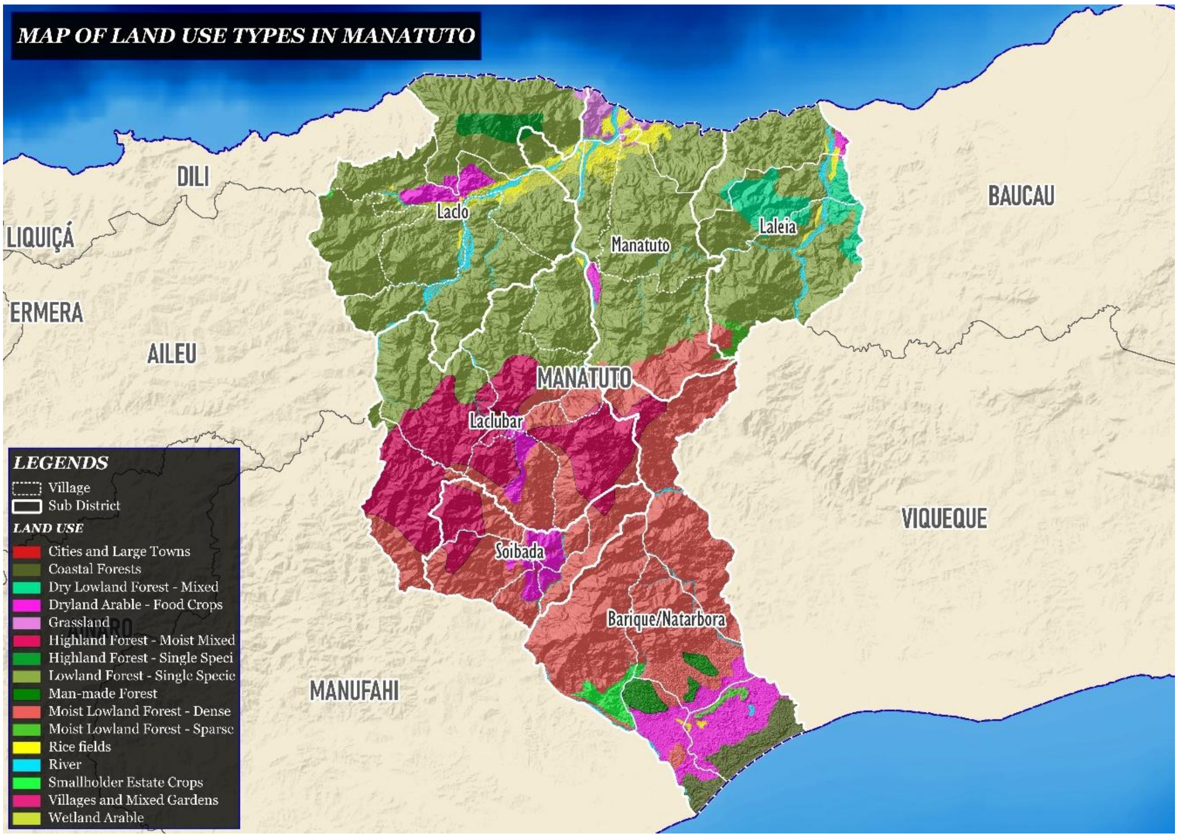


Figure 2.10 Land-Use Map of Manatuto District

2.5 SLOPE GRADIENT

The distribution of slope gradient classes in Manatuto District provides important information on topography with implications for land management, soil erosion potential, and natural resource conservation. Slope classes were grouped into five categories: flat (0-8 %), gentle (8-15 %), moderately steep (15-25 %), steep (25-45 %), and very steep (>45 %). This variability reflects the complexity of the area and influences the potential and challenges of land management for agriculture.

Flat slopes (0-8 %) accounted for a significant proportion in several Sub-Districts. Barique/Natarbora Sub-District had the largest flat area, 113,87 km^2 or 6.39 % of the total area. These areas are suitable for intensive agriculture such as irrigated rice due to minimal erosion risk and easier accessibility. Other Sub-Districts with large flat areas included Manatuto (3.65 %) and Laclo (2.65 %) as shown in **Figure 2.11.**

Gentle slopes (8-15 %) were relatively evenly distributed across Sub-Districts, with the largest area in Barique/Natarbora Sub-District at 60,56 km^2 or 3.40 %. These conditions allow flexible land management for both agriculture and settlements. Manatuto (2.42 %) and Laclo (2.04 %) Sub-Districts also had extensive gentle slopes, supporting mixed activities between agriculture and conservation.

Moderately steep slopes (15-25 %) dominated much of Manatuto District, especially Barique/Natarbora Sub-District, which covered 83,30 km² or 4.68 % of the total area. These slopes can still be used for agriculture if soil conservation techniques such as terracing are applied. Manatuto and Laclubar (4.12 %) also had significant areas in this category, indicating potential for intensive land management with attention to erosion risk.

Steep slopes (25-45 %) were relatively extensive in Laclubar Sub-District, covering 148,03 km² or 8.31 %. Areas with these gradients are generally more suitable for conservation activities such as agroforestry or reforestation to reduce erosion and land degradation. Laclo (7.45 %) and Barique/Natarbora (5.89 %) Sub-Districts also had substantial steep areas that require conservative management approaches.

Very steep slopes (>45 %) covered smaller but still significant areas in several Sub-Districts. Laclubar had the largest area in this category, 127,91 km² or 7.18 %. These areas have major limitations for intensive agriculture and are more suitable for environmental conservation and water resource protection. The distribution of slope gradients provides important insights for location-specific land-use planning. Flat to gentle areas have high potential for intensive agriculture and infrastructure, whereas steep to very steep areas require intensive soil conservation to prevent erosion, such as ground cover vegetation, terracing, or water-control structures. Slope gradient classes are closely linked to erosion risk; steep and very steep slopes have high erosion risk, especially where soils are unstable. The slope gradient map of Manatuto District is presented in Figure 2.13.

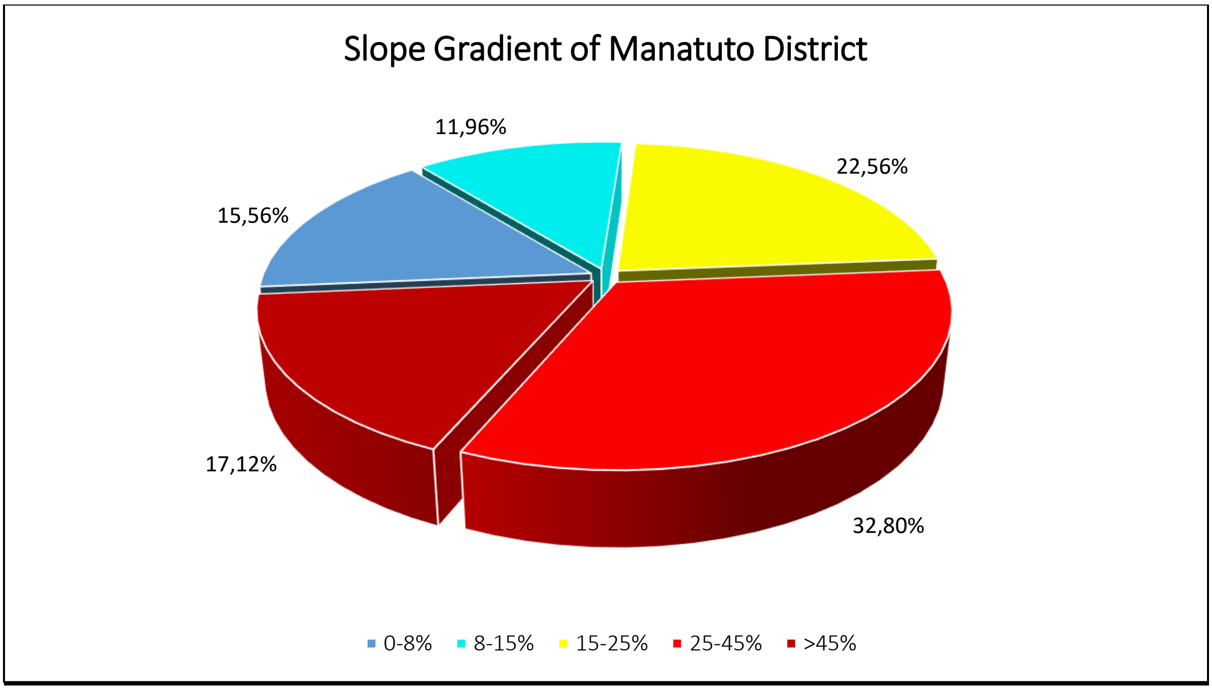
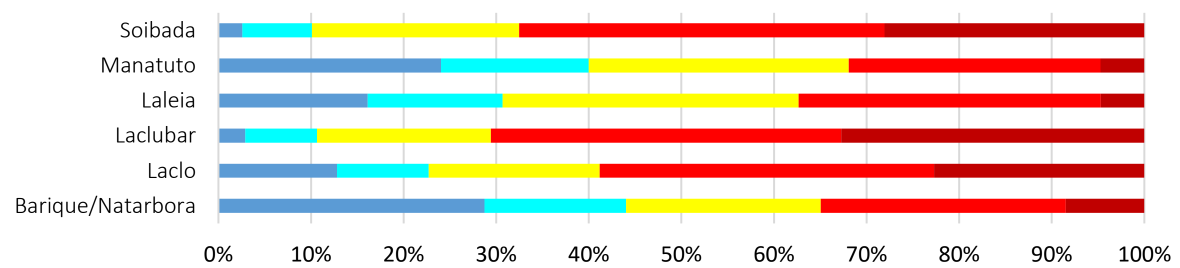


Figure 2.11 Slope Gradient in Manatuto District



	Barique/Natarbora	Laclo	Laclubar	Laleia	Manatuto	Soibada
0-8%	6,39%	2,65%	0,64%	2,04%	3,65%	0,19%
8-15%	3,40%	2,04%	1,70%	1,84%	2,42%	0,55%
15-25%	4,68%	3,82%	4,12%	4,05%	4,27%	1,63%
25-45%	5,89%	7,45%	8,31%	4,13%	4,14%	2,88%
>45%	1,89%	4,69%	7,18%	0,60%	0,72%	2,05%

0-8% 8-15% 15-25% 25-45% >45%

Figure 2.12 Slope Gradient by Sub-District in Manatuto District

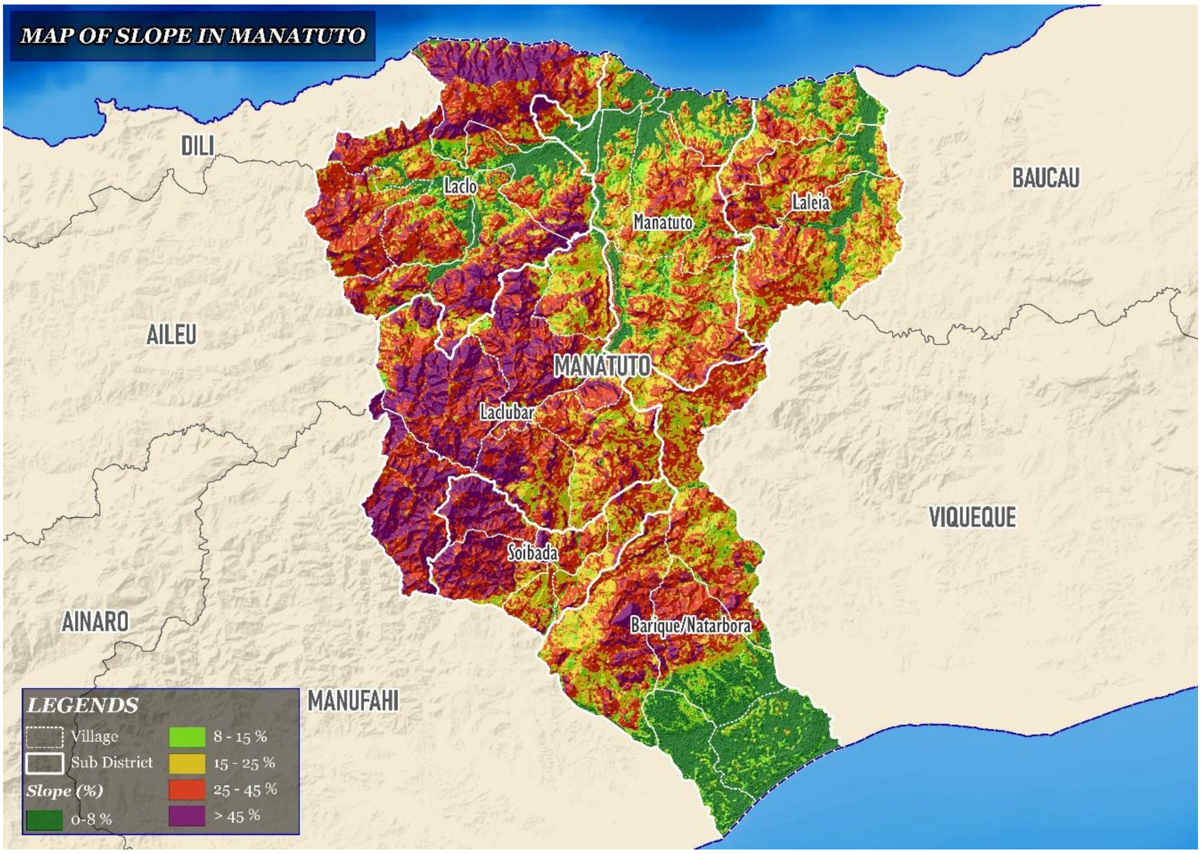


Figure 2.13 Slope Gradient Map of Manatuto District

2.6 AGROCLIMATIC ZONES

Agroclimatic zones in Manatuto District were classified based on elevation and rainfall patterns, as summarized in the Agricultural Land Use Information System (ALGIS), which adopts Fox's theory (2003). The classification divides the area into six main agroclimatic zones, each characterized by rainfall pattern, elevation, commodities, and livestock potential. This approach is relevant to natural resource management and provides a scientific framework for sustainable land suitability evaluation (Molyneux *et al*., 2013; Williams *et al*., 2017). Agroclimatic zones in Manatuto District are shown in **Figure 2.14**, the distribution by Sub-District in **Figure 2.15**, and the distribution map in **Figure 2.16**.

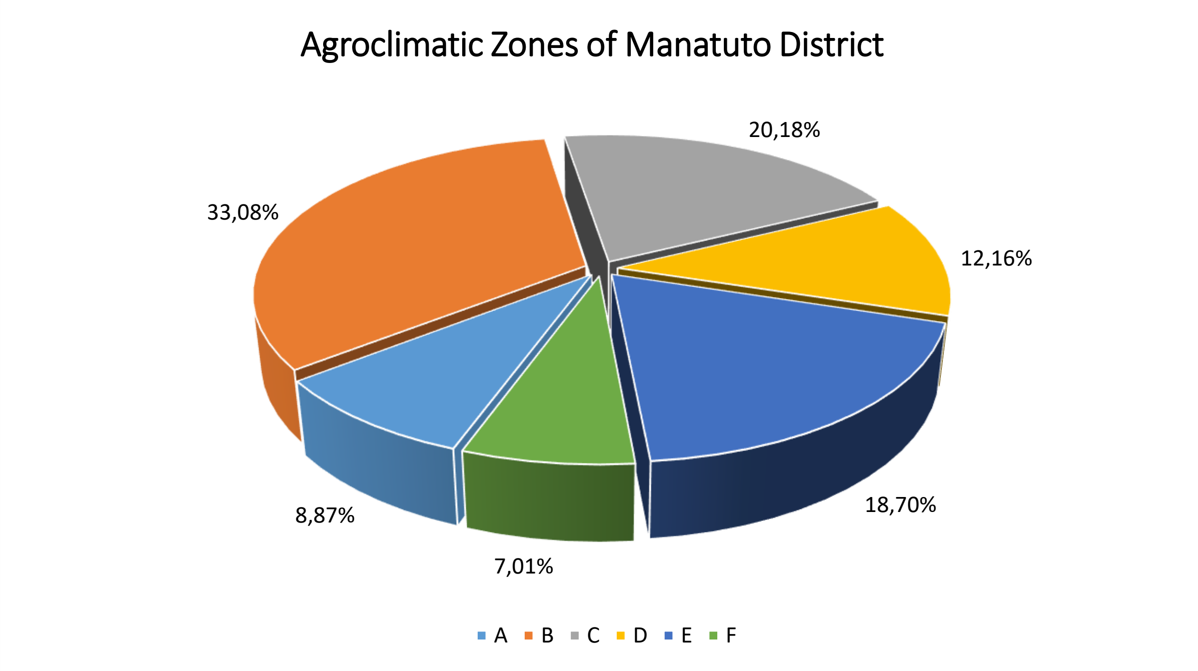
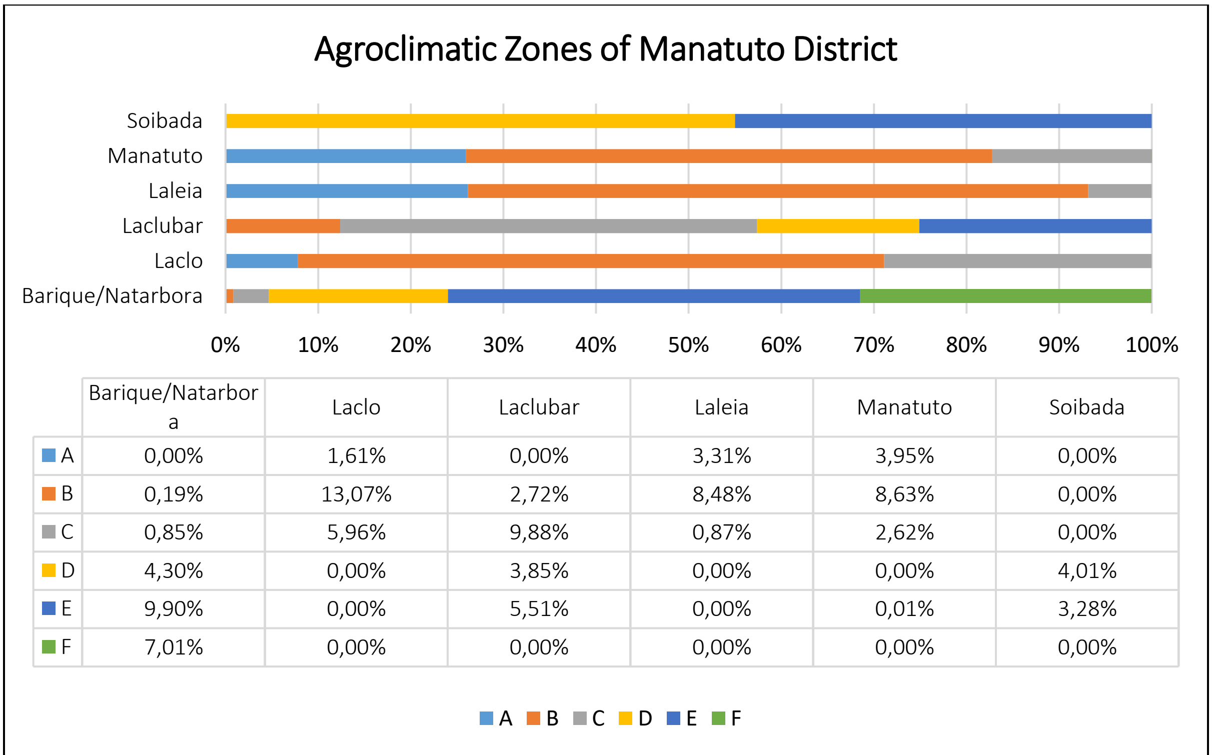


Figure 2.14 Agroclimatic Zones of Manatuto District



	Barique/Natarbora	Laclo	Laclubar	Laleia	Manatuto	Soibada
A	0,00%	1,61%	0,00%	3,31%	3,95%	0,00%
B	0,19%	13,07%	2,72%	8,48%	8,63%	0,00%
C	0,85%	5,96%	9,88%	0,87%	2,62%	0,00%
D	4,30%	0,00%	3,85%	0,00%	0,00%	4,01%
E	9,90%	0,00%	5,51%	0,00%	0,01%	3,28%
F	7,01%	0,00%	0,00%	0,00%	0,00%	0,00%

Figure 2.15 Agroclimatic Zones by Sub-District in Manatuto District

Zone A encompasses the northern lowlands below 100 m. The zone has a monomodal rainfall pattern influenced by the northwest monsoon, with a rainy season lasting 4-5 months from November to March. This zone occurs in Manatuto, Laleia, and Laclo Sub-Districts, with the largest area in Manatuto Sub-District at 70.35 km^2 (3.95 % of its total area), followed by Laleia at 59.02 km^2

(3.31 %) and Laclo at 28.73 km² (1.61 %). The variation in area illustrates the distribution of land resources available for different agricultural commodities consistent with rainfall patterns.

Zone B includes the northern slopes at 100-500 m, with a monomodal rainfall pattern and a rainy season lasting 5-6 months (October to March). This zone occurs in Barique/Natarbora, Laclo, Laclubar, Laleia, and Manatuto Sub-Districts. Manatuto Sub-District has the largest area in this zone, 1,536.9 km² (8.63 % of its total area), followed by Laleia at 1,511.3 km² (8.48 %). Laclo has 2,328.2 km² (13.07 % of its area). Laclubar has 483.9 km² (2.72 %), and Barique/Natarbora has the smallest area at 3.41 km² (0.19 %). These agroclimatic characteristics indicate suitability for farming systems dependent on a single main rainy season. Differences in area across Sub-Districts contribute to variability in productivity and natural resource management strategies.

Zone C is located in the northern highlands above 500 m. It also has a monomodal rainfall pattern, with a longer rainy season lasting 6-7 months (October to April). This zone occurs in Barique/Natarbora, Laclo, Laclubar, Laleia, and Manatuto Sub-Districts. The largest area is in Laclubar Sub-District, 1,760 km² (9.88 % of its total area). Laclo has 1,062.7 km² (2,62 % of its area). Manatuto has 466.4 km² (2.62 %). Laleia has 154.8 km² (0.87 %), and Barique/Natarbora has 151.5 km² (0.85 %). Although they share the same zone, limited area is a consideration for rainfed agricultural development. Larger areas provide opportunities for more productive systems, especially for commodities relying on stable rainfall.

Zone D encompasses the southern highlands above 500 m. It has a bimodal rainfall pattern due to the influence of the northwest monsoon and the southeast trade winds, with the longest rainy period reaching 9 months (November-April and May-July). This zone occurs in Barique/Natarbora, Soibada, Laclubar, and Manatuto Sub-Districts. The largest area is in Barique/Natarbora Sub-District at 766.5 km² (4.30 % of its total area). Soibada has 715.1 km² (4.01 %). Larger areas, such as in Barique/Natarbora and Soibada, offer optimal potential for developing farming strategies based on two cropping seasons. Conversely, Laclubar Sub-District has the smallest area, indicating limited coverage suitable for agricultural use in Zone D.

Zone E includes the southern slopes at 100-500 m, also with a bimodal rainfall pattern and an 8-month rainy season (November-April and May-July). This zone occurs in Barique/Natarbora, Soibada, Laclubar, and Manatuto Sub-Districts. The largest area is in Barique/Natarbora at 1,764.4 km² (9.90 % of its total area). Laclubar has 981.4 km² (5.51 %). Soibada has 585.2 km² (3.28 %). Larger areas in Barique/Natarbora, Laclubar, and Soibada present greater opportunities to optimize land for more intensive agricultural production. Conversely, Manatuto Sub-District has a much smaller area at 0.09 km² (0.01 % of its total area), indicating constraints on land use for agriculture in Zone E due to topographic or ecological characteristics less favorable for productivity.

Zone F encompasses the southern lowlands below 100 m. It has a bimodal rainfall pattern with a rainy season of 7-8 months (November-March and May-July). This zone occurs in Barique/Natarbora Sub-District with 1,248.8 km² (7.01 % of its total area), indicating significant capacity for land management. Under a bimodal rainfall pattern, there is potential for two cropping seasons per year, enabling diversification of commodities that rely on more evenly distributed rainfall.

The division of agroclimatic zones provides a clear scientific framework for understanding land potential in Manatuto District, particularly for agricultural, livestock, and fisheries development. This overview forms the basis for subsequent land suitability evaluation by the research team, combining thematic maps such as soil type, rainfall, geology, land use, field observations, laboratory analyses, and matching with crop, horticulture, estate, industrial, forestry, and grazing requirements. This strategy supports integrated food security and sustainable resource management.

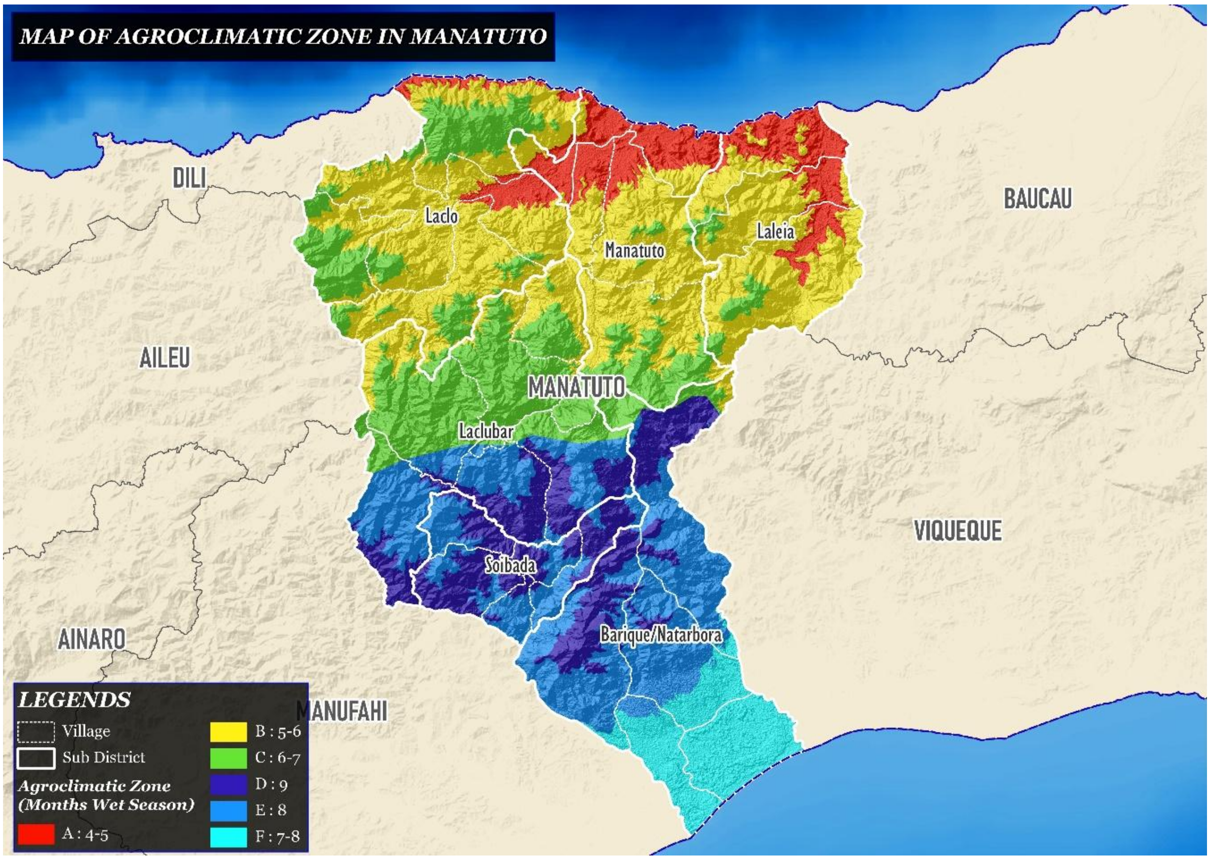


Figure 2.16 Agroclimatic Zone Map of Manatuto District

2.7 EXISTING CONDITIONS

Manatuto District faces significant challenges in agricultural management. The district experienced flooding in April 2021, causing widespread losses in rice fields with a total affected area of approximately 800 ha. This event informed development efforts, and Manatuto District designated irrigated rice as a primary focus in agricultural development **(Figure 2.17)**. The aim was to strengthen food security and improve production efficiency through better-controlled irrigation. Given the steep slope gradients in both agricultural and forest land, erosion risk is high. As a risk mitigation measure, the local government constructed embankments to protect agricultural land and maintain ecosystem stability.

Figure 2.17 Rice Fields in Manatuto District
(Source: Research Team Documentation, 2025)

Observations in Soibada Sub-District, particularly in Manufahi Village, indicated potential development of vanilla and coffee commodities, both robusta and arabica **(Figure 2.18).** However, coffee cultivation systems that still rely on shade trees such as mahogany limit productivity. In addition, supply chain and marketing issues are major constraints, requiring more targeted and efficient strategies.

Figure 2.18 Vanilla Plants in Manatuto
(Source: Research Team Documentation, 2025)

Meanwhile, Aubeon Village in Barique/Natarbora Sub-District demonstrated well-organized spatial planning and was awarded the best village at the national level in 2022. Successful implementation of horticulture programs showed community capacity in managing local resources. The area is also a site for restoration of marginal land through collaboration with AfoCO and MAPPF **(Figure 2.19)**, with key commodities such as *eucalyptus*, casuarina, and vetiver.

Figure 2.19 AfoCO and MAPPF Restoration Area
(Source: Research Team Documentation, 2025)

The topography of Manatuto District is dominated by steep slopes, increasing the risk of erosion and landslides, especially during periods of high rainfall **(Figure 2.20)**. The impacts of the 2021 flooding are still evident, particularly in affected areas. Flood scarring caused soil degradation, altered ecosystem structure, and reduced agricultural productivity.

Figure 2.20 Topographic Conditions in Manatuto District
(Source: Research Team Documentation, 2025)

Laclo Sub-District was one of the areas affected by flooding but still has potential to develop food crops such as rice; forestry species such as teak and sandalwood **(Figure 2.21)**; and horticultural crops such as citrus, papaya, and banana. Laleia and Manatuto Sub-Districts have also been designated as rice development areas in district agricultural planning.

Figure 2.21 Forestry Plants in Manatuto District
(Source: Research Team Documentation, 2025)

The agricultural potential in Laclo, Laleia, and Manatuto Sub-Districts indicates strategic opportunities to strengthen the food, forestry, and horticulture sectors **(Figure 2.22)**. These efforts need to be balanced with disaster risk management that affects land resilience. Soil and water resource management strategies are key factors in ensuring sustainable development.

Figure 2.22 Horticultural Crops in Manatuto District
(Source: Research Team Documentation, 2025)

In response to climate change, Manatuto District prioritized soil and water conservation through various initiatives. These measures aimed to maintain ecosystem balance, improve water infiltration, and ensure resource sustainability for agriculture and communities. The approach addressed disaster mitigation and long-term adaptive sustainable development.

2.8 *Chromolaena Odorata*

Chromolaena odorata (Siam weed) is a flowering weed in the family *Asteraceae* that thrives in tropical and subtropical regions. It is native to North America, Mexico, and the Caribbean, and spread to various parts of Asia, Africa, and Australia through human activities and natural phenomena (Day *et al*., 2013). Its spread, particularly in developing countries such as Timor-Leste, has significant impacts on ecosystems and local economies.

Figure 2.23 *C. odorata* Plant
(Source: Research Team Documentation, 2025)

In tropical Asia, *C. odorata* is commonly found from lowlands to elevations of 500 m asl, especially in open areas such as coconut and rubber plantations, house yards, and grazing lands (Peniwiratri & Arbiwati, 2021). It has distinctive morphology, with cylindrical hairy stems, simple serrated leaves, and compound inflorescences that are bluish when young and turn brown when mature **(Figure 2.23)**. Chemically, *C. odorata* contains active compounds such as flavonoids, tannins, alkaloids, saponins, and essential oils (Jamatia *et al.,* 2024). These constituents provide potential as raw materials for traditional medicine to treat conditions such as diabetes, burns, hypertension, and skin infections (Jamatia *et al.*, 2024).

In Timor-Leste, *C. odorata* was first recorded in the 1980s and spread rapidly due to slash-and-burn practices and a dry tropical climate that supports its growth (Day *et al.*, 2013). The plant can grow on various soil types, including marginal, less fertile lands, with an optimal elevation between 500 to 2,000 masl (Westaway *et al.,* 2018). Its rapid invasive growth reflects high adaptability to new environments and poses a serious threat to the sustainability of productive land.

Figure 2.24 Leaf Structure and Inflorescence of *Chromolaena odorata*
(Source: Ashasathees)

The threats posed by *Chromolaena odorata* to agriculture, livestock, and ecosystems are significant and require serious attention.

In agriculture, *C. odorata* forms dense thickets that inhibit the growth of crops such as corn, coffee, and various horticultural plants. It aggressively invades land newly opened for subsistence agriculture, a primary livelihood for rural communities. Its roots and extensive branching enable rapid uptake of soil nutrients, creating harmful nutrient competition with crops. As a result, agricultural productivity declines sharply, affecting local food security.

Negative impacts are also evident in the livestock sector. Leaves of *C. odorata* contain *hepatotoxic pyrrolizidine alkaloids* that can cause liver damage in cattle and goats if consumed in large amounts. The spread of this weed on grazing lands reduces forage availability, lowers carrying capacity, and adversely affects farmers' livelihoods, particularly in regions such as Timor-Leste.

Ecologically, *C. odorata* disrupts ecosystem balance by dominating native vegetation and impeding regeneration of trees and local plant species important for biodiversity. Its biomass dries easily, increasing fire risk during the dry season, a serious threat in tropical regions. Recurrent fires accelerate land degradation and reduce environmental quality, including declines in soil microbial communities that maintain soil fertility.

Although often considered a harmful weed, *C. odorata* has several potential uses, especially in agriculture, traditional medicine, and biomass management.

As an indicator of soil fertility, it can increase nutrient content, particularly Phospor, in sandy soils when its biomass is mixed with manure. Studies have shown that this combination can support the growth of cultivated plants such as shallot. In addition, the high organic matter content of *C. odorata* makes it a potential raw material for producing environmentally friendly organic fertilizers.

In traditional medicine, the plant has long been used to treat burns, diabetes, hypertension, and skin infections. Its flavonoid and phenolic contents provide strong antioxidant, anti-inflammatory, and antibacterial properties. Its uses vary across countries; in Vietnam, *C. odorata* leaves are used to treat soft tissue wounds and leech bites, whereas in Africa, the plant is used as a natural antiseptic.

Furthermore, *C. odorata* biomass can be processed into high-quality vermicompost through biodegradation using the earthworm *Eisenia fetida*. Studies have shown that the resulting vermicompost contains significant macronutrients such as N, P, and K. This makes *C. odorata* a promising alternative material to support sustainable agricultural practices through more efficient organic fertilizer production.

III. RESEARCH METHODS

This study was conducted in Manatuto District, Timor-Leste, with the primary objective of evaluating land suitability for agricultural development. Data were collected through field surveys, laboratory analyses, and the use of geospatial information systems. The study was implemented during May to June 2025 and consisted mainly of direct field observations, soil sampling, interviews with local farmers, and mapping based on a geographic information system. All research stages were organized systematically to produce accurate information that could serve as a basis for planning sustainable land management.

3.1 RESEARCH DESIGN

A. Methodological Approach

This study applied both quantitative and qualitative approaches. The quantitative approach aimed to obtain numerical data for statistical analysis, whereas the qualitative approach was used to explore farmers' experiences and perceptions related to agricultural practices in the study area (Trigunasih, 2016). The research methods comprised field observations and laboratory analyses, including soil sampling and interviews with local communities.

B. Sampling Point Determination

Sampling points were selected using a Village-based approach that considered land-use practices, agricultural traditions, and community dynamics. This approach was designed to represent homogeneous land units in the area and to produce results that were relevant and accurately reflected field conditions. Soil samples were collected as random composite samples using an auger method. Each land unit was represented by one composite soil sample, collected at a depth of 0-30 cm for annual crops and 30-60 cm for perennial crops. Each soil sample weighed 1 kg and was analyzed further in the laboratory.

C. Soil Morphological Observation

During soil sampling, environmental conditions were observed and recorded using a soil observation form. Parameters included soil color, soil texture, structure, consistency, and drainage class. For more detailed analyses, undisturbed soil cores were collected using ring samples to measure bulk density

(BD), permeability, and soil porosity, which inform land fertility and water-holding capacity (Sukarman *et al*., 2017).

D. Interviews and Questionnaires

In parallel with the field survey, structured interviews and questionnaires were administered to farming communities using purposive or judgmental sampling, taking into account respondents' experience and expertise in agriculture (Sekaran & Bougie, 2013). Data collected included cropping patterns, agricultural constraints, and prevailing land-use systems in the study area.

E. Land Suitability Evaluation

Field survey results, climate data, and laboratory analyses were tabulated and evaluated using an agro-ecosystem land suitability assessment based on the criteria of Ritung *et al.* (2011). The classification method followed the FAO system (1976) with a matching approach, which compares land characteristics with the growth requirements of the assessed crops. Agricultural commodities evaluated in this study included food crops, horticultural crops, spices and medicinal plants, forestry species, industrial crops, forage feed commodities, and grazing areas.

3.2 RESEARCH PROCEDURES

A. Literature Review

The literature review stage was conducted to compile relevant secondary data to support this study. Collected data included administrative maps of the study area, geographical conditions, agricultural land area, and agricultural commodity production. Climate data examined included temperature, rainfall, dry months, and relative humidity. In addition, previous studies relevant to land suitability evaluation were reviewed to strengthen the theoretical foundation of this research.

B. Land Unit Analysis

The land unit analysis aimed to determine land units as a basis for planning field observations. The resulting homogeneous land units served as references for soil sampling and the preparation of land suitability maps. The HLU analysis comprised:

a. Interpreting the Digital Elevation Model (DEM) to analyze landforms and slope gradients.

b. Analyzing satellite imagery to verify actual land use, particularly in areas that had undergone land conversion such as rice fields, settlements, and other infrastructure.
c. Using supporting data in the form of slope gradient, geology, and soil type maps to strengthen land unit delineation.
d. Overlaying thematic maps to produce homogeneous land units to be used as the basis for soil sampling.

C. Field Survey

Field surveys were conducted to verify the conformity of sampling points with actual field conditions. If discrepancies were found between the land-use analysis from satellite imagery and field conditions, adjustments were made by establishing new sampling points. Sampling point selection was based on satellite image analysis and the most recent field conditions.

In addition, interviews with local farmers were conducted to obtain supplementary information on agricultural practices and challenges in land management. Observations focused on environmental factors influencing agricultural productivity, including soil drainage, effective soil depth, erosion risk, flood risk, coarse fragments, surface rock outcrops, and surface rock fragment content (Ritung *et al.,* 2011).

Soil sampling was carried out by augering to a depth of 0-30 cm for annual crops and 30-60 cm for perennial crops. The collected soil samples were then analyzed in the laboratory to identify soil physical and chemical properties affecting soil fertility status. Climate data such as temperature, rainfall, and relative humidity were obtained from local climate observation stations and presented in tabular form. The results of the land suitability evaluation and the characteristics of each land unit were presented in **Table 3.1**, while the land suitability distribution map was shown in **Figure 3.1.**

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

No	Parameter	Data Acquisition		Data Source
		Primary	Secondary	
1	Temperature		√	Remote Sensing/ Climatology Timor-Leste
2	Rainfall		√	Remote Sensing/ Climatology Timor-Leste
3	Dry Months		√	Remote Sensing/ Climatology Timor-Leste
4	Humidity		√	Remote Sensing/ Climatology Timor-Leste
5	Drainage	√		Field Survey
6	Soil Texture	√		Laboratory Results
7	Coarse fragments	√		Field Survey
8	Effective Soil Depth	√		Field Survey
9	Cation exchange capacity (CEC)	√		Laboratory Results
10	Base saturation (BS)	√		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	√		Field Survey
20	Flood hazard	√		Field Survey
21	Surface rock cover	√		Field Survey
22	Rock outcrops	√		Field Survey

D. Laboratory Soil Analysis

Parameters used to determine soil properties or characteristics from laboratory-analyzed samples were:

a. Soil organic carbon (SOC) by the Walkley and Black method (%).
b. Total N by the Kjeldahl method (%).
c. Soil texture by the pipette method.
d. Soil pH by the potentiometric method (H2O 1:2,5).
e. Available P (ppm) and available K (ppm) by the Bray-1 method for soils with pH below 7 and the Olsen method for soils with pH above 7, with unit conversion (mg/100 g)
f. Salinity (dS/m) by the potentiometric method (H_2O 1:2,5).

g. CEC (cmol) and base saturation (%) using NH4OAc 1N 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 HNO^{3-}: $HClO_4$ digestion method.
j. Total Sulfur (ppm) and Available Sulfur (ppm) determined using the spectrophotometric method.
k. Determination of Soil Fertility Status Based (PPT, 1995)
l. Erosion hazard using the Universal Soil Loss Equation (USLE).

E. Land Suitability Analysis

Field observations and laboratory results were tabulated into agro-ecosystem land characteristics/qualities. Land suitability analysis for agro-ecosystems was conducted by matching land characteristics/qualities with the growth requirements of bamboo, teak, mahogany, pine, coffee, cocoa, and coconut to obtain land suitability classes based on the criteria of Ritung *et al.* (2011). Land suitability classification was analyzed to the land unit level.

Land suitability classes were established as actual suitability and potential suitability. Actual suitability for each homogeneous land unit was determined by matching land characteristics/qualities with crop growth requirements without improving limiting factors. Potential suitability was determined by considering inputs and management actions applied to each homogeneous land unit under the assumption that improvements were made to address the limiting factors.

F. Agricultural Commodity Development Planning

Commodity planning was based on potential land suitability for the agricultural commodities to be developed, using the highest land suitability class for each crop as the main parameter. Other parameters included primary land use in 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 suitability, the treatment of limiting factors, and improvement measures for each homogeneous land unit across the six Sub-Districts in Manatuto District. Preparing digital maps using a geographic information system greatly facilitated information interpretation. The information included agro-ecosystem land suitability, land-use recommendations, and agricultural commodity zoning. Land suitability maps were prepared based on homogeneous land units and the results of agro-ecosystem land suitability classification.

The classification results for each evaluated crop group were mapped. Land suitability for crop commodities was presented in agricultural commodity zoning maps, whereas land-use planning was presented in land-use recommendation maps. Systematically, the research flow diagram was presented in **Figure 3.1**.

H. Data Analysis Using Geographic Information System Technology

The land suitability information system consisted of spatial data (homogeneous land unit maps) and attribute data (land suitability classes). Integrating these two components produced an information system using QGIS 3.10, providing land suitability classes for food crops, horticultural crops, and estate crops based on the evaluation of their suitability. The compiled land suitability maps, along with the database and land resource information, were based on data and suitability criteria consistent with developments in use such as varieties, cultivation technologies, and land management.

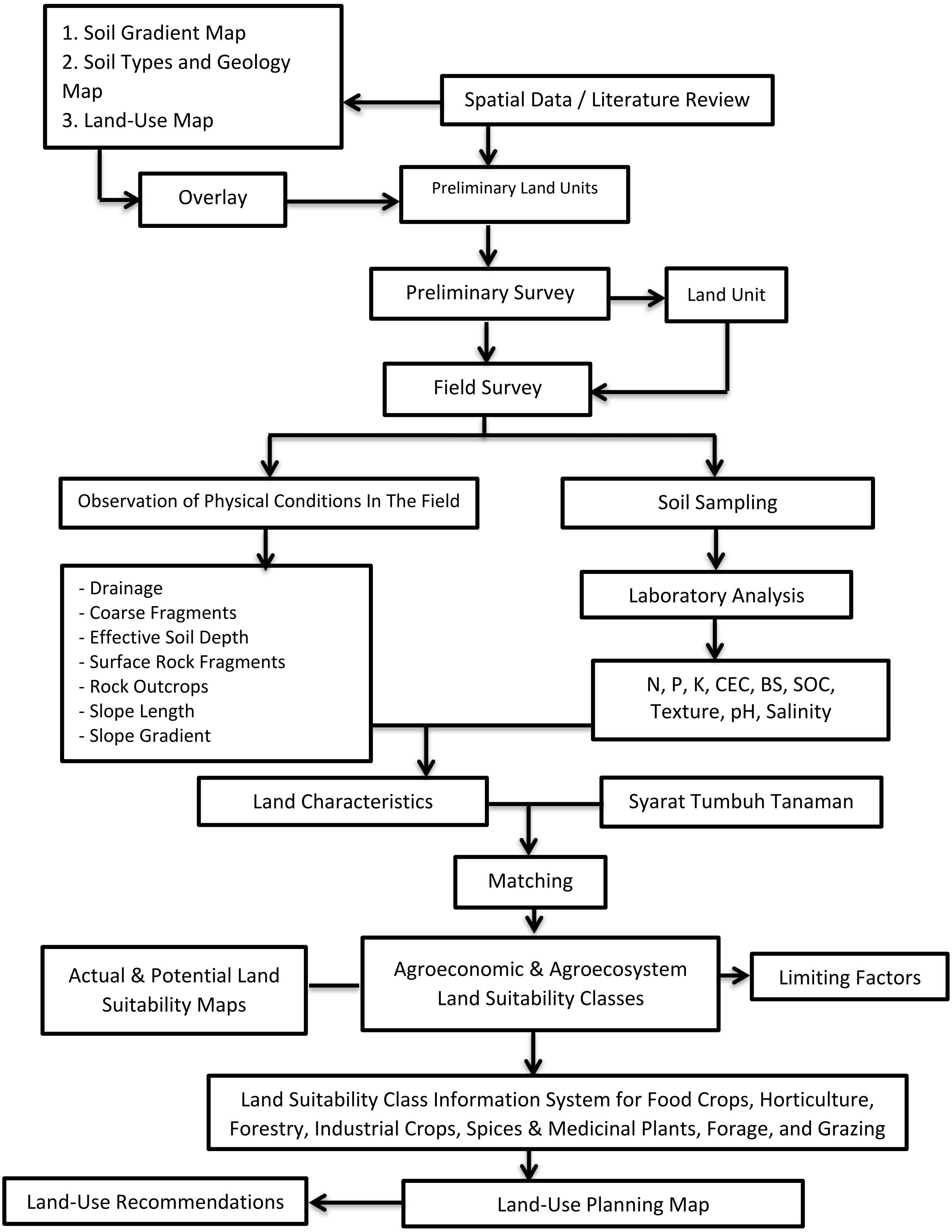


Figure 3.1 Research Process Flow Diagram

Land use planning maps were obtained based on land suitability classification and agricultural commodity zoning. The land use planning maps were thematic digital maps that provide guidance for land use for various food crops, horticultural crops, and estate crops. Digital maps were created by converting primary and secondary data and information from raster and analog forms into digital data. The advantages of digital maps include ease of editing errors, ease of copying, long-term storage, and the ability to measure distances and areas on-screen without field measurements, which require more time and costs (Nugroho and Yarianto SBS, 2010). The maps generated were in digital format or analog/hard copy in **.jpeg* format, printable, and digital maps in **.dbf or shapefile *.shp* in format, integrated, easy to copy, and informative. Map marginal information includes the map title, followed by the author's name, scale bar, and legend items (homogeneous land units, study area, soil type, slope gradient, and land use), sources, latitude and longitude coordinates, and the datum system used.

3.3 GEOGRAPHIC INFORMATION SYSTEM TECHNOLOGY

A Geographic Information System (GIS) is a system that contains spatially referenced data, which can be analyzed and transformed into information for specific purposes. The definition of GIS as a system includes the following capabilities:

1. To collect, store, and display information based on spatial location.
2. To identify locations within a specific area that meet pre-established criteria.
3. To explore the relationships between various data sets in a particular area.
4. To facilitate the selection and distribution of data for specific analytical applications that can predict the impacts of an alternative for a given area condition.
5. To present specific areas both graphically and numerically, both before and after analysis (Murai, 2006).

From the various definitions of GIS, some common keywords emerge: geographically referenced data, data analysis (spatial and attributes) to produce information, and specific objectives. Therefore, it can be concluded that, compared to other systems, GIS has the capability to handle data and information in a geographical context. This is particularly relevant in planning development, as development planning is conducted within the context of a specific region (area).

The term " Geographic " is a part of the spatial concept. These two terms are often used interchangeably, resulting in the third term, geospatial. All three terms carry the same meaning in the context of GIS. The use of the word "Geographic" refers to an issue concerning the Earth: the two or three dimensional surface (Prahasta, 2005).

The term "geographical information" refers to information about locations on the earth's surface, knowledge of the position where an object is located on the surface, and information about attributes present at a location, which are either provided or known (Prahasta, 2005).

GIS is a formal system consisting of various physical resources related to objects on the earth's surface. It is a type of software that can be used for input, storage, manipulation, display, and output of geographical information along with its attributes (Prahasta, 2005). **Figure 3.2** shows the components that make up a GIS.

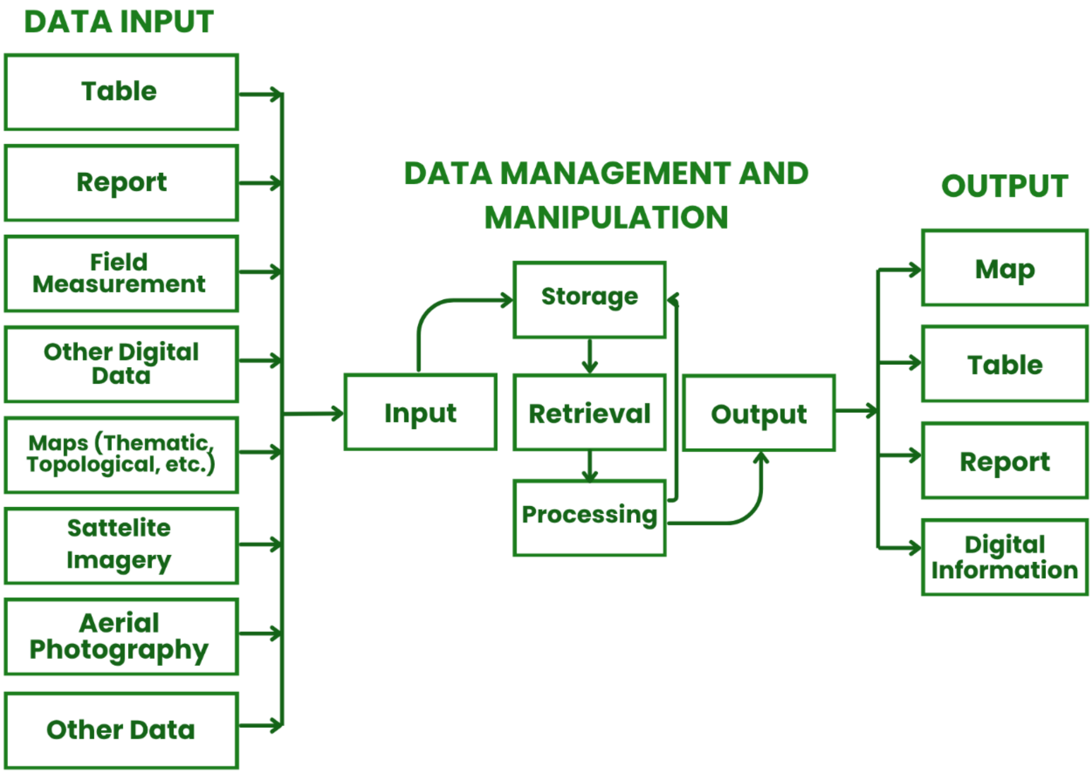


Figure 3.2 GIS Components
(Source: Prahasta, 2005)

GIS can be applied in various fields. Some of its capabilities include (Prahasta, 2005):

1. Cartographic Capability

   With this capability, GIS users can create maps and technical drawings effectively and efficiently. This cartographic capability includes digitization, graphic visualization, interactive line manipulation, and plotting.

2. Data Management Capability

   GIS has the ability to store, process, and manipulate geographically referenced data. This management capability also includes processing attribute data, which involves storing and displaying specific attributes associated with a given geographic feature.

3. Analytical Capability

   Analytical capability refers to the ability to interpret and study the data and information collected for specific purposes. This analysis includes engineering function analysis, prediction/forecasting ability, computational operations, demographic analysis, socio-cultural analysis, analysis of various regions and districts, graphic and tabular presentations, overlay analysis, logical analysis, and selection analysis.

4. GIS and Multimedia Integration

   The ability to integrate GIS and multimedia is one of the creative outcomes from the local innovators in Bali. Through the integration of multimedia with GIS, the final presentation of GIS analysis results becomes more engaging and easier to read and interpret.

A. GIS Process and Components

GIS essentially performs six processes, as follows (Prahasta, 2005):

1. Data Input

   Before geographic data can be used in GIS, it must be converted into a digital format. This process is called digitization. In this study, digitization was conducted on-screen, where data conversion was done using scanning technology.

2. Data Transformation

   Data types used in GIS may need to be transformed or manipulated in several ways to align with the system. For example, if there are scale differences, the data must be transformed into a common scale before being integrated. This transformation can be temporary for display purposes or permanent for analytical processes.

3. Editing

   The editing phase involves digital correction. Corrections may include adding or removing arcs or features by editing excess (overshoot) or missing (undershoot) arcs. Editing is also done to manually add arcs, such as creating polygons, lines, or points.

4. Data Management

   After spatial data has been entered, the next step is to process descriptive data, including annotation (adding text to coverage), labeling (providing information on the map), and attributing, which is the stage where each label ID from the labeling process is added with attributes providing information about the polygon or arc it represents.

5. Query and Analysis

   In GIS, queries are essentially analytical processes performed tabularly. Spatial analysis is the fundamental analysis type in GIS. GIS excels in spatial analysis, with two of the most important functions being:

   a) Proximity Analysis

      This geographic analysis is based on the distance between layers. Questions such as, how many houses are located within a watershed. Are answered by using buffering (creating support layers around a layer within a specific distance) to measure proximity between features.

   b) Overlay Analysis

      This is the process of integrating data from different layers, known as overlay. In simpler terms, overlay is a visual operation, but analytically, it requires more than one layer to be physically combined. For example, overlay could integrate soil, slope, and vegetation data or land ownership with property tax assessments.

6. Visualization

   For certain geographic operations, the best outcome is displayed in maps or graphs. Maps are highly effective for storing and presenting geographic information.

B. GIS Components

In general, GIS operates based on the integration of 5 components: hardware, software, data, people, and methods, which can be described as follows (Budianto, 2010):

1. Hardware

   Hardware refers to the computers where the GIS operates. Currently, GIS can operate on a wide range of hardware, from centralized server computers to desktop computers used as standalone or in network configurations.

2. Software

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

   a. Tools for data input and manipulation.

   b. A database management system (DBMS).

   c. Tools supporting query, analysis, and geographic visualization.

   d. Graphical User Interface (GUI) for accessing tools.

3. Data

   A critical component of GIS is data. Fundamentally, GIS works with two types of geographic data models: vector data model and raster data model. The vector data model represents, places, and stores spatial data using points, lines, or curves, or polygons with their associated attributes. The raster data model represents, places, and stores spatial data using a matrix or pixels forming a grid. Each pixel or cell has its own attribute, including unique coordinates (at the grid corner, center, or other locations). The accuracy of this data model depends on the resolution or pixel size (cell grid) on the Earth's surface.

4. Human

   GIS technology would not be useful without the human managing the system and designing plans applicable to real-world conditions. Like other information systems, GIS users have different levels, ranging from technical specialists who design and maintain the system to users who apply GIS to assist in their daily tasks.

5. Method

   A good GIS must balance well-designed planning with real-world rules. The methods used in modeling and implementation vary depending on the problem at hand.

C. Data Processing in GIS

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

1. Base Map Digitization

   Base map digitization is performed on the Indonesian Topographic Map at a scale of 1:25,000, which will later serve as the base for surveys and map digitization, including data updating. The conversion of data into digital format is done layer by layer with topological information.
2. Data Import

   Data import is performed for satellite images, which have formats different from their processing software. This format conversion is an initial step in image processing tasks.
3. Image Geometry Correction

   Image geometry correction is necessary for satellite images to have a reference or coordinate system. This correction can be done using 3 methods: image to image (pre-corrected), image to ground (using GPS for direct field measurements), and image to map.
4. Digital Image Processing

   Satellite images are processed digitally to enhance the spatial resolution from the standard 25 m multispectral band to 15 m in color. This is done using image data fusion with the Brovey Transformation method, which helps in visual interpretation of planimetric objects such as transportation networks and rivers.
5. Satellite Image Classification

   Another process performed is digital classification, supported by a knowledge base for extracting spatial information on land use. This classification process is done using supervised classification methods and filtering. Digital classification models, which offer higher grouping accuracy compared to human visual interpretation, are complemented by visual data interpretation from the Brovey Transform results. Digital classification groups recognizable objects in sample areas. The image processing software automatically searches for pixel patterns matching the sample areas, forming distinct classes. The classified images are then field-tested to check for deviations and identify uncertain pixels. Deviation from field testing must not exceed 3% of the test area. The clarified results are used for updating Indonesia's topographic maps using digital light table effect and raster-vector overlay methods.

6. Spatial Information Updating

   The update of spatial information on maps will be conducted using the raster-vector overlay method, complemented by the light table effect for interpreting and analyzing spatial information on land use. The update of planimetric spatial information will be carried out with raster-vector overlay. This integration model uses digital image classification and visual image interpretation to obtain accurate updated spatial data. Specific objects that are considered important for mapping but are not clearly visible on the image will be mapped using GPS tools during field surveys. The final result of this updating process will be digital land use spatial data in GIS.

7. Field Survey

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

8. Re-interpretation and Editing

   This work was carried out to correct inaccurate image interpretations based on field results. It was performed digitally in the laboratory to obtain final, updated spatial information.

9. Edge Matching

   Edge Matching was conducted to ensure consistency among adjoining map sheets. This process was performed digitally across all adjacent layers.

10. Digital Cartography and Map Production

    Cartographic processes were performed fully digitally to produce standard map layouts in accordance with prevailing cartographic conventions. The cartographic model for this work referred to the thematic map cartography standards issued by geospatial information agency.

11. Database Design and Modeling

    Database design and modeling were carried out for all GIS spatial data produced, consisting of land use spatial data, attribute data, and the thematic maps generated.

IV. LAND CHARACTERISTICS

4.1 TEMPERATURE

Air temperature is one of the principal factors in land suitability evaluation because it strongly influences the sustainability of natural resource management and the potential for regional development. In this study, the spatial distribution of temperature was analyzed by integrating field measurements with geospatial data derived from the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) using the Braak formula approach. This analysis provided a comprehensive depiction of temperature variability that reflects the complexity of topography, elevation, and microclimate. The results for Manatuto District showed that the area was dominated by warm to hot conditions **(Figure 4.1).**

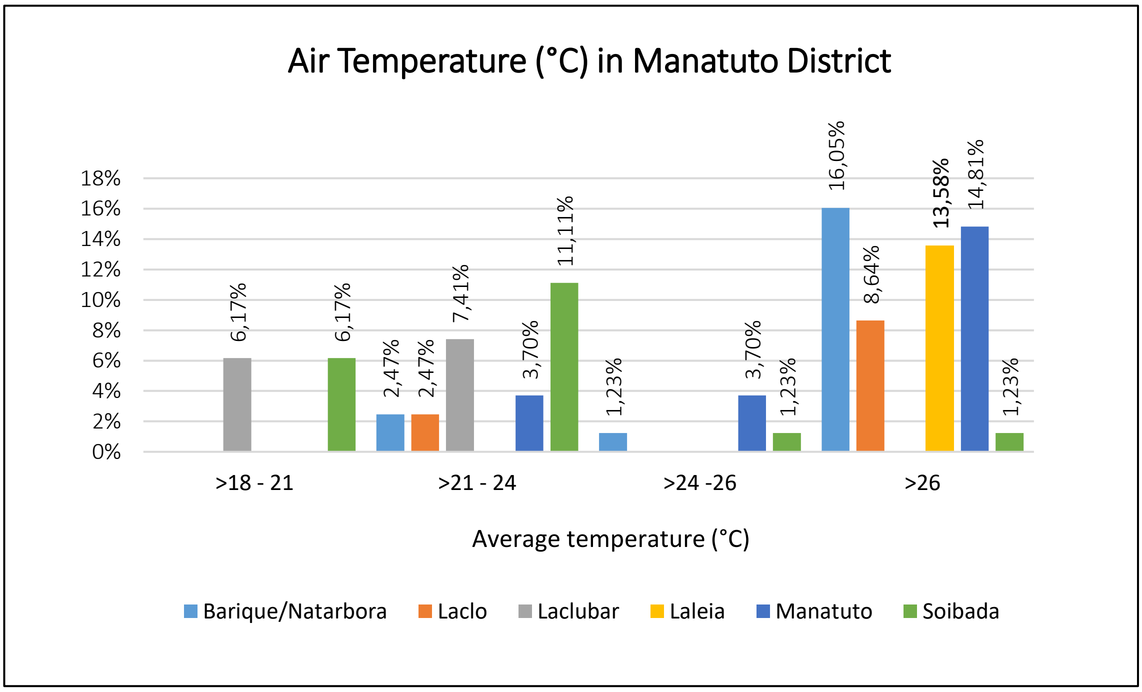


Figure 4.1 Air Temperature Data (°C) in Manatuto District

The >26 °C category was the most dominant temperature range in Manatuto District, particularly in Barique/Natarbora Sub-District. This area is often associated with low rainfall and poor soil drainage. Barique/Natarbora Sub-District is located on the low-lying southern coast of Timor-Leste, which generally experiences higher temperatures. Lowland areas, such as coastal zones, tend to have higher air temperatures than mountainous regions because atmospheric cooling diminishes with decreasing elevation (Rangwala *et al.,* 2012). Proximity to the sea can cause higher daytime temperatures due to strong solar radiation and high humidity; when the sea breeze is not sufficiently strong, the cooling effect is reduced.

The dominance of high temperatures reflects an environmental thermal regime that tends to be extreme and directly affects hydrologic balance and plant physiology. Based on abiotic stress theory, temperatures above the optimal threshold (>26 °C) can increase the rate of evapotranspiration and reduce photosynthetic efficiency, thereby triggering a significant risk of soil drought during the dry season. Rising air temperature can also reduce agricultural production and increase pest and disease incidence in crops (Sukarman *et al*., 2018). Maintaining productivity and water-use efficiency in high-temperature zones requires optimizing conservation technologies. Strategies such as applying organic mulch, implementing drip irrigation systems, and using rainwater harvesting and storage techniques support sustainable water resource management. The implementation of these technologies is consistent with the principles of integrated ecotechnology, which combines technical efficiency with ecological sustainability.

The next most dominant temperature range was >21-24 °C, especially in Soibada Sub-District, indicating a relatively stable thermal climate favorable for multi-season agriculture. This zone exhibits a moderate thermal regime that allows flexibility in crop selection with lower risk of temperature stress. Moderately high temperatures also reduce the risk of excessive evapotranspiration, enabling plant root systems to make more effective use of available soil water.

Overall temperature variability in Manatuto District requires adaptive approaches responsive to local thermal conditions. Water management strategies, soil conservation, and the selection of stress-tolerant varieties are important instruments for maintaining the resilience of agricultural systems under complex agroclimatic dynamics.

4.2 RAINFALL

Rainfall is a principal climatological factor in land suitability analysis because it determines a region’s capacity to support agricultural activities, soil conservation, and water management. This evaluation assessed the distribution pattern of rainfall by accumulation category and spatial variation among Sub-Districts. Data were drawn from field observations and integrated with geospatial analysis using CHIRPS satellite imagery, producing climate mapping suitable for agroclimatic zoning.

The rainfall distribution across the analysis area exhibited diverse patterns **(Figure 4.2).** The most dominant rainfall level in Manatuto District was 2,000-2,500 mm/year, occurring in Soibada Sub-District. This is because the area lies in mountainous terrain at higher elevations than coastal areas such as Barique/Natarbora. Mountain regions tend to receive more rainfall due to orographic processes (Barry & Chorley, 2010). This level of rainfall indicates high agroclimatic potential for rainfed agricultural systems, particularly for horticultural commodities that require stable soil moisture and a consistent water supply throughout the growth cycle. These conditions support plant physiological efficiency and reduce the risk of water stress during critical vegetative and reproductive stages.

The next dominant rainfall range was 1,000-1,500 mm/year in Laleia Sub-District. This zone requires conservative approaches to water management, including water-saving irrigation technologies such as drip irrigation, rainwater harvesting, and the use of micro-reservoirs to maintain continuity of water supply to crops. These strategies align with principles of input efficiency in agriculture under tropical climate variability (Rayalu, 2024). The subsequent dominant rainfall range was 500-1,000 mm/year in Manatuto Sub-District. Coastal lowlands tend to receive less rainfall than mountain regions because significant orographic uplift of moist air does not occur to trigger precipitation (Houze, R. A., 2012).

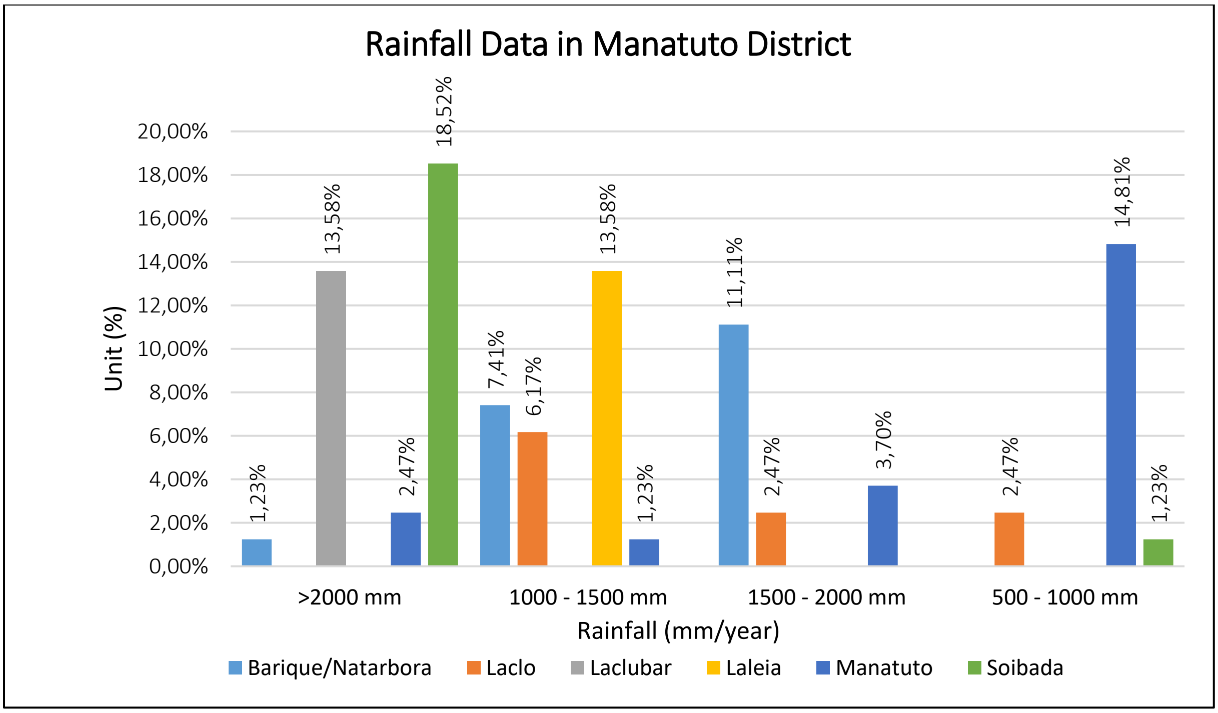


Figure 4.2 Rainfall Data in Manatuto District

This rainfall heterogeneity accords with the concept of agroclimatic zoning (Oldeman, 1975), which emphasizes that rainfall distribution determines cropping patterns, commodity types, and technologies required to support farm success. Each area therefore needs to apply context-appropriate adaptive strategies, such as rainwater harvesting, construction of small reservoirs, and selection of drought-tolerant varieties, to optimize productivity and the resilience of agriculture under local climatic conditions.

4.3 DRY MONTH

The distribution of dry-month duration in Manatuto District showed significant interregional variation, reflecting differences in microclimatic conditions that directly affect water availability and agricultural cropping patterns (**Figure 4.3**). The most dominant dry-month duration was >6 months, occurring in Manatuto Sub-District, which is situated in lowland areas as described **in Subsection 4.2**. This indicates heightened vulnerability to drought risk and water deficit for agricultural activities. A prolonged dry season limits crop choices and can lead to drought, crop failure, and increased fire hazard, particularly in peatland (Sukarman *et al.,* 2018). In response, mitigation-oriented technological interventions are required, including rainwater harvesting systems, water-saving irrigation technologies (e.g., drip and low-pressure sprinkler), and soil moisture conservation through mulching and vegetative ground cover. These interventions are intended to maintain production, reduce the rate of land degradation, and strengthen farmers' adaptive capacity to climatological stress.

The next dominant dry-month duration was 3-4 months in Soibada Sub-District. This duration provides opportunities to optimize two cropping seasons per year. More stable hydrologic conditions enable efficient planning of cropping patterns, agricultural input management, and commodity diversification based on market demand. In the humid tropics, zones with limited dry months allow more flexible crop rotations and higher cropping index (IP), which directly affects land productivity and resource-use efficiency (Rejekiningrum *et al.*, 2022).

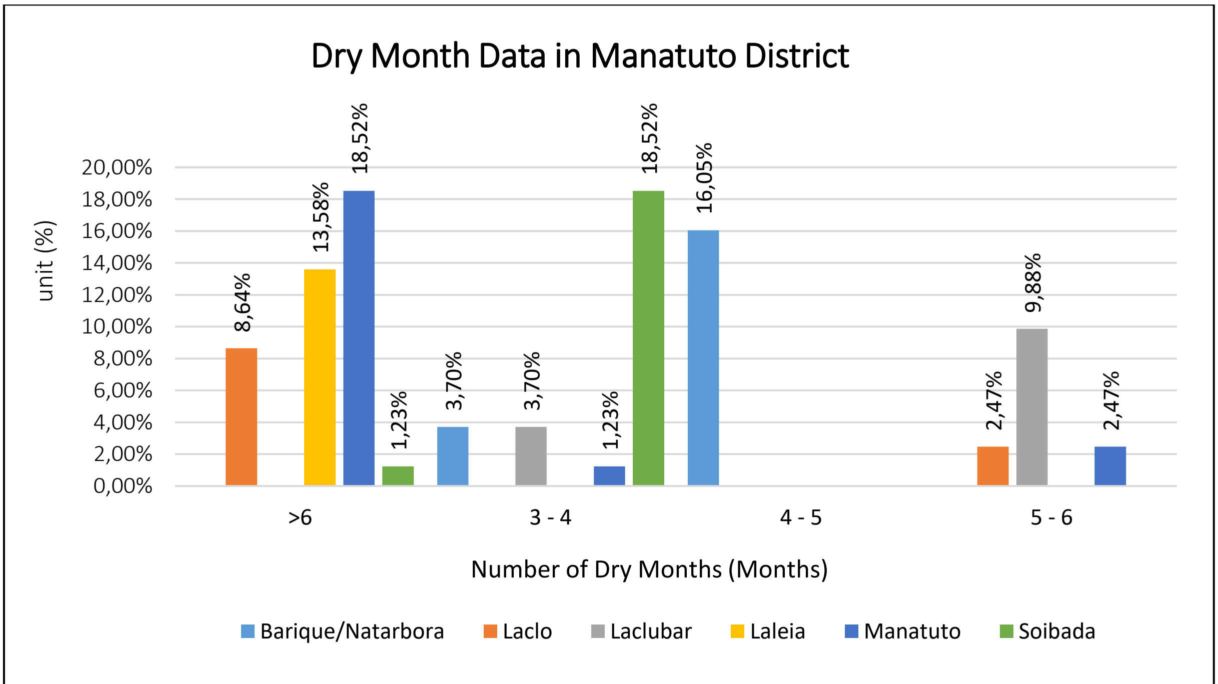


Figure 4.3 Dry Month Chart in Manatuto District

The length of the dry period is an important indicator in evaluating land suitability because it influences water availability for agrarian activities, soil productivity, and water resource management. Overall, variation in dry-month duration in Manatuto District requires area-based adaptive strategies that consider microclimate dynamics, local agronomic potential, and the efficiency of resource conservation. This evaluation provides a basis for decisions on land use and the planning of sustainable agricultural production systems responsive to climate variability.

4.4 ELEVATION

The distribution of elevation in Manatuto District showed a varied pattern, with dominance in the 0-400 masl class **(Figure 4.4).** This class occurred primarily in Barique/Natarbora Sub-District, followed by Manatuto Sub-District, indicating that most administrative areas lay in lowlands to foothills. Ecologically, this elevation zone is associated with relatively high air temperatures, easier accessibility, and higher intensity of human activities, including settlements and agriculture. These conditions are consistent with Molyneux *et al.* (2012), who reported that lowland areas in Timor-Leste commonly serve as centers of population concentration and are prone to land degradation if not managed with conservation practices.

In contrast, the 400-700 masl category, found in Soibada, Manatuto, and Barique/Natarbora Sub-Districts, had the smallest coverage but played a vital role for soil and water resources. This elevation functions as a hydrologic transition zone where rainfall infiltration occurs optimally, helping to recharge groundwater reserves. In addition, the morphological characteristics in this elevation class support slope stability and erosion control, directly contributing to soil conservation. Although limited in area, these zones often act as ecological buffers between lowlands and mountain regions and support biodiversity that is sensitive to changes in elevation and moisture. Protection and sustainable management of this zone are therefore important in land-use planning and natural resource conservation.

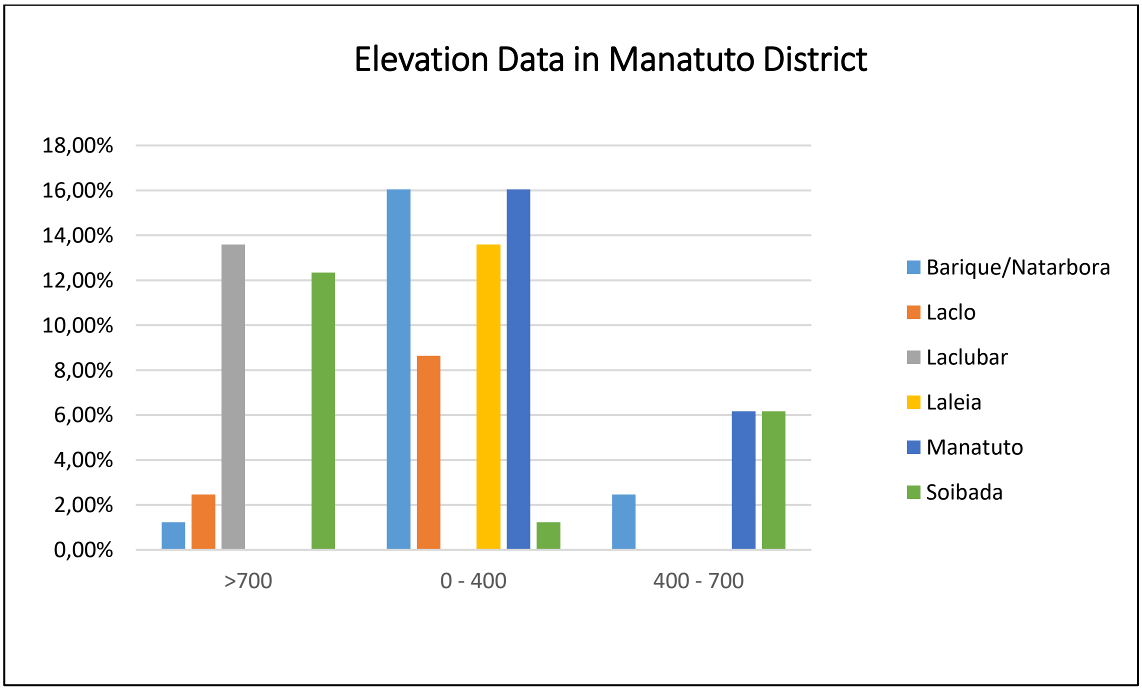


Figure 4.4 Elevation Data in Manatuto District

4.5 DRAINAGE

Drainage is an important indicator in land suitability evaluation because it directly influences water infiltration capacity, waterlogging potential, and the efficiency of nutrient uptake by plants. This analysis is crucial for determining commodity types, cultivation intensity, and landscape-based water management. Drainage conditions in Manatuto District were identified from field observations **(Figure 4.5).**

Based on observations, Manatuto District was dominated by well drained conditions, particularly in Soibada Sub-District. As described **in Chapter 2**, this area is dominated by Mollisols. Mollisols are fertile soils formed by the accumulation of organic matter under grassland, producing soil structure and texture conducive to good drainage and nutrient retention. These conditions reflect soil with high porosity and textures that facilitate efficient water movement. They allow optimal water infiltration without stagnation or excess moisture, thereby supporting root growth and sustained soil microbiological activity. Good drainage is known to enhance soil aeration, nutrient uptake efficiency, and crop productivity (Holilullah & Novpriansyah, 2015).

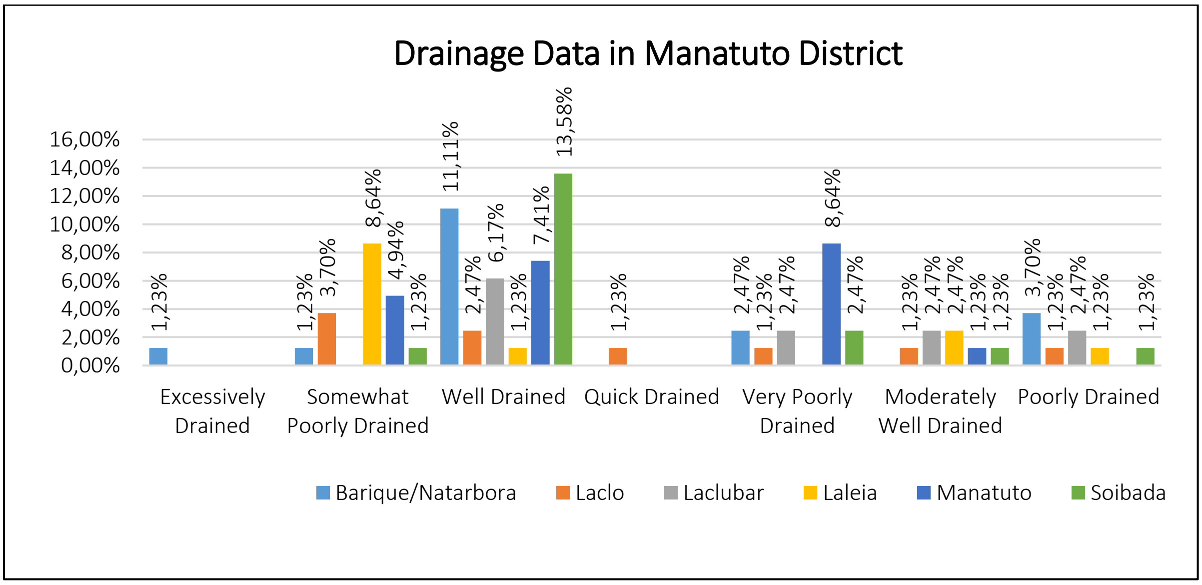


Figure 4.5 Drainage Conditions (%) in Manatuto District

The next most common drainage class was somewhat poorly drained, occurring in Laleia Sub-District. This condition indicates limitations in subsurface water movement due to clayey soil texture and relatively flat topography. It can cause waterlogging, reduce soil aeration, and hinder root system development. Soils with restricted drainage are at higher risk of oxygen stress and reduced nutrient uptake efficiency. Therefore, this area requires technical interventions such as constructing open drainage channels, managing slope gradients, and selecting commodities adapted to high moisture and shallow root systems.

Overall, the drainage assessment in Manatuto District provides an essential basis for land-use decision-making and for planning agricultural systems aligned with local biophysical capacities. Differentiating cultivation strategies among Sub-Districts should be based on drainage quality to ensure production efficiency and the sustainability of land resources.

4.6 COARSE FRAGMENT

The characteristics of coarse fragments are an important factor in determining land suitability for agriculture because they affect the soil's capacity to store water, regulate infiltration, and support plant roots. The analysis of coarse fragment percentages in Manatuto District showed diverse distributions (Figure 4.6).

The most dominant coarse fragment category in Manatuto District was <3 %, particularly in Manatuto Sub-District. This reflects soil physical conditions that are highly favorable for intensive cultivation. Low coarse fragment content enables efficient tillage, increases water-holding capacity, and strengthens interactions between plant roots and nutrients. These characteristics are important for improving agricultural efficiency and land productivity in tropical regions (Mahfut *et al*., 2015).

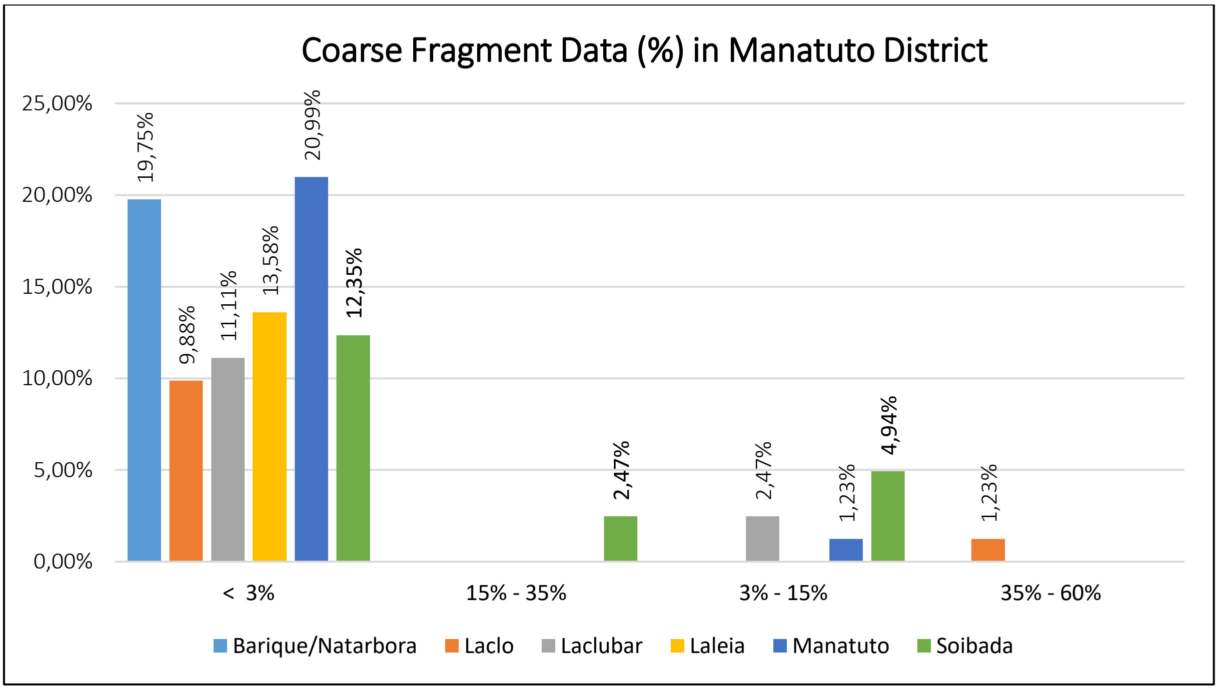


Figure 4.6 Coarse Fragment Data (%) in Manatuto District

The least extensive coarse fragment category in Manatuto District was 35-60 %, occurring only in Laclo Sub-District. This indicates significant physical limitations of the land. High coarse fragment content can reduce effective soil volume, hinder root penetration, and increase the risk of erosion and soil moisture deficit. Such characteristics are common on marginal land, where coarse fractions such as gravel and small stones dominate the soil profile, resulting in low water-holding capacity and suboptimal aeration. Research by Mansyur *et al.* (2023) showed that marginal soils dominated by coarse fractions have low permeability, limited porosity, and high bulk density, which directly affect the growth efficiency of horticultural crops in tropical areas such as Tarakan.

Variation in coarse fragment content in Manatuto District shows a significant influence on land suitability levels. Zones with low proportions of coarse fragments have optimal potential for intensive cultivation, whereas areas with high coarse fragment content present technical challenges in tillage and production efficiency. Understanding the distribution of coarse fragments is therefore a crucial aspect of land-use planning based on local biophysical characteristics.

4.7 EFFECTIVE SOIL DEPTH

Effective soil depth is a principal parameter in land suitability evaluation because it directly affects root system development, water retention, and the efficiency of nutrient uptake by plants. Soils with deep effective depth (90-120 cm) are generally categorized as highly suitable for cultivation because they lack restrictive layers such as hard rock, plinthite, or massive clay layers that can obstruct root penetration (Aditiyas *et al.,* 2014).

Based on field observations **(Figure 4.7)**, Manatuto District had effective soil depth predominantly in the deep category, namely 90-120 cm, with the widest distribution in Manatuto Sub-District. This phenomenon can be explained from a soil morphogenetic perspective, in which soil formation proceeded stably without disruption by geomorphological limiting factors such as severe erosion, shallow sedimentation, or tectonic activity. In addition, relatively gentle topography and soil textures conducive to water infiltration supported the development of deep, uniform soil profiles.

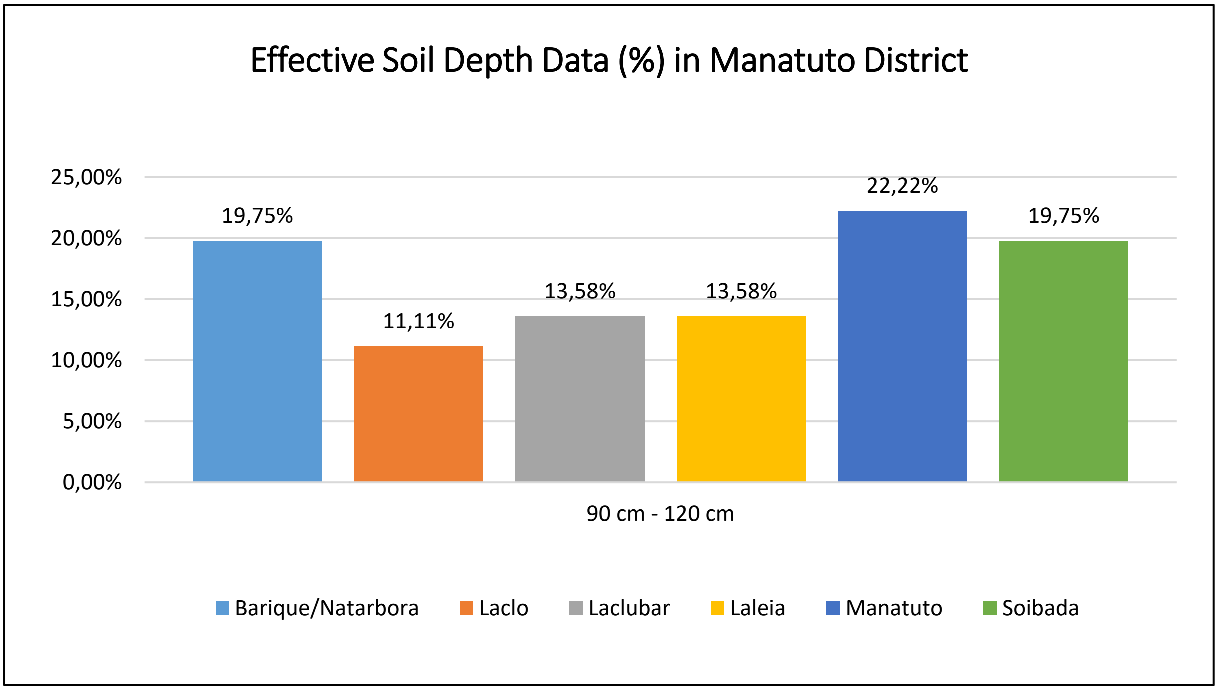


Figure 4.7 Effective Soil Depth Data (%) in Manatuto District

These conditions indicate high agronomic potential and support for intensive cultivation systems. Uniform soil depth also facilitates land suitability zoning and the application of mechanized agriculture because special treatments for restrictive layers are not required.

4.8 SURFACE ROCKS

The presence of surface rocks is an important biophysical indicator in land suitability evaluation because it directly affects tillage ease, water-holding capacity, and the development of plant root systems. A high proportion of surface rocks can reduce effective soil volume and increase the risk of erosion as well as management costs. According to Armanto *et al.* (2024), rock characteristics as soil parent material contribute significantly to soil productivity through pedogenetic and geomorphological processes, so land use must comprehensively consider agrogeological aspects.

Based on field observations **(Figure 4.8)**, Manatuto District was dominated by the <5 % surface rock category, particularly in Barique/Natarbora Sub-District. This proportion indicates that land in this zone had high potential for intensive agricultural development because physical impediments to tillage and plant growth were minimal. This condition aligns with principles of soil productivity that emphasize the importance of stable soil structure with minimal coarse fractions to support deep-rooted cropping systems and agricultural mechanization (Armanto *et al*., 2024).

The next most dominant category of surface rocks was 15-40 %, found in Soibada Sub-District. This proportion poses challenges for cultivation because abundant rocks can hinder root growth, reduce the effective capacity for nutrient uptake, and increase land preparation costs. Land-use strategies in this zone therefore need to adopt conservative approaches such as zero tillage, use of cover crops, and the selection of shallow-rooted commodities that are adaptive to limited physical conditions.

The distribution of surface rocks in Manatuto District has significant implications for land-use planning. Areas with high rock content are more suitable for plantation systems or vegetative conservation, whereas zones with low rock content can be optimized for intensive agriculture. Land management strategies based on surface rock characteristics are key to improving the efficiency and sustainability of land use in the district.

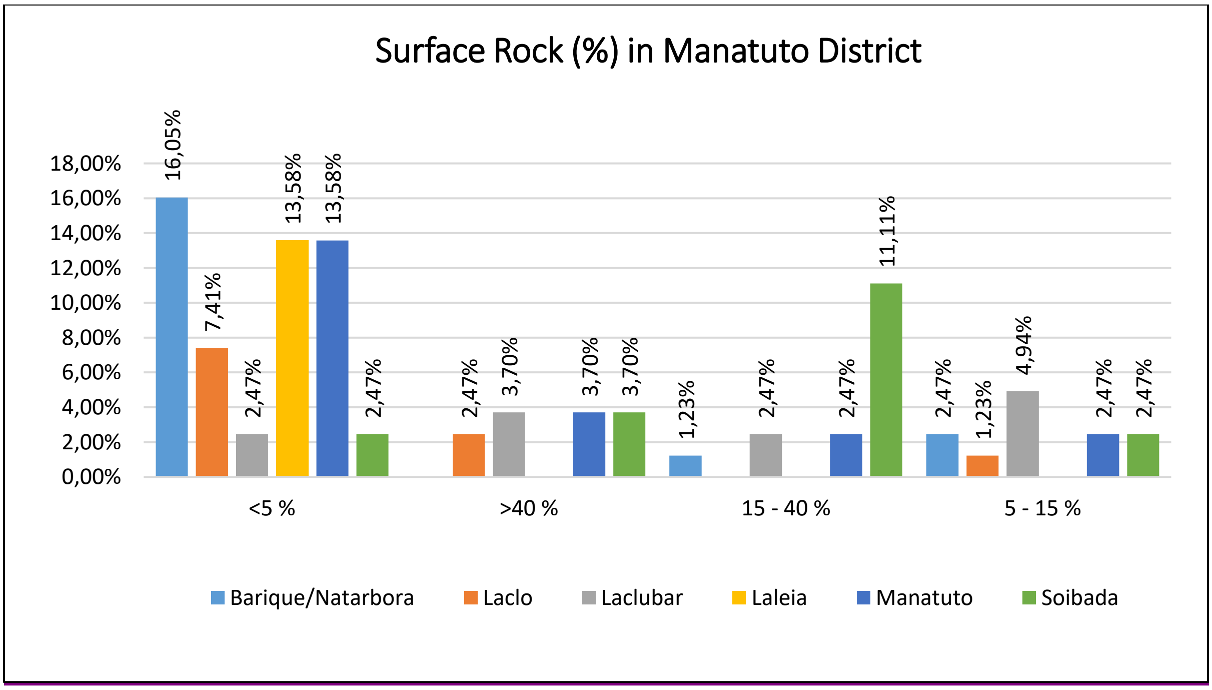


Figure 4.8 Surface Rock Data (%) in Manatuto District

4.9 ROCK OUTCROPS

Rock outcrops are a critical geological indicator in land suitability assessment because their presence can influence soil physical characteristics, infiltration and water-storage capacity, and the level of erosion risk. In land management, exposed rock has direct implications for the difficulty of tillage, crop selection, and the efficiency of applying agricultural technologies.

Spatial analysis of rock outcrop percentages in Manatuto District showed dominance of the <5 % category, especially in Barique/Natarbora Sub-District **(Figure 4.9).** This indicates that most of the district had soil surfaces relatively free from exposed rock, which strongly supports agricultural activities and infrastructure development by allowing optimal tillage, enhanced water infiltration, and efficient application of cultivation technologies.

The next most dominant outcrop category was 15-25 %, occurring in Soibada Sub-District. This condition creates technical challenges for land preparation, particularly for intensive systems that require soil surfaces free of physical barriers. Land-use strategies in this zone should therefore consider conservative and adaptive approaches, such as selecting shallow-rooted commodities, applying minimum tillage, or implementing landscape engineering with cover vegetation to reduce erosion risk and improve land hydrologic function.

Overall, variation in rock outcrop levels in Manatuto District provided an initial basis for classifying land suitability and served as a reference for designing land management strategies based on local geological characteristics.

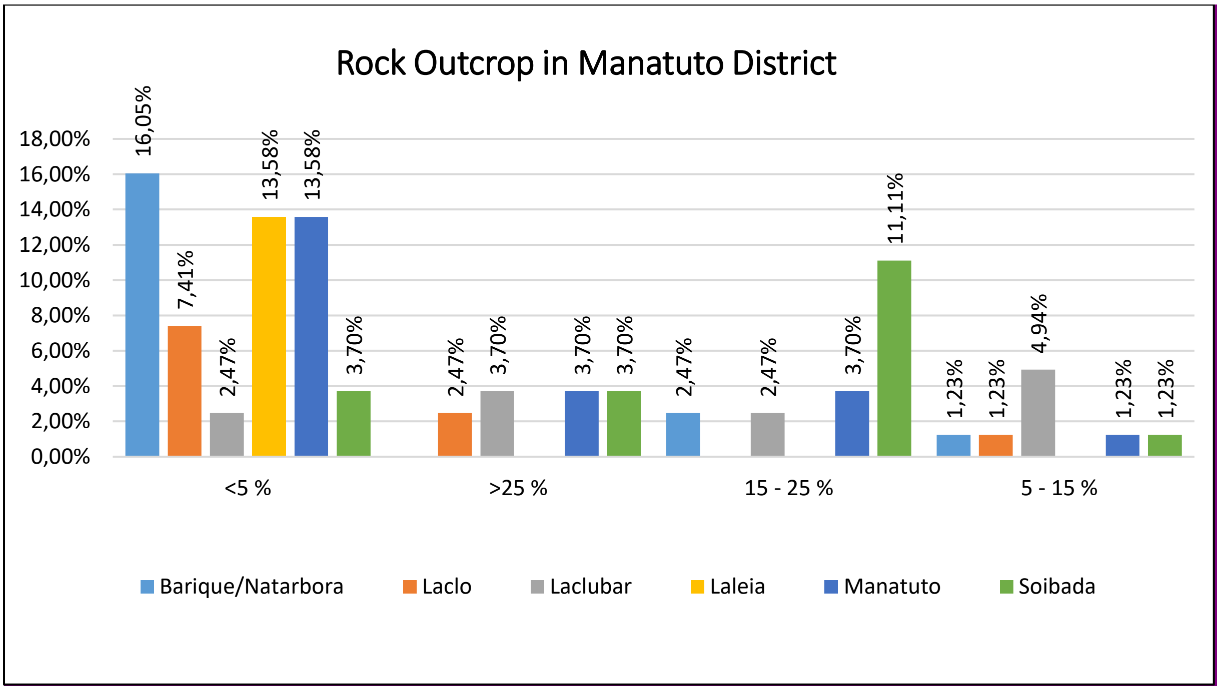


Figure 4.9 Rock Outcrop Data (%) in Manatuto District

4.10 FLOOD HAZARD

Flood hazard represents a potential threat arising from extreme hydrometeorological events to people, infrastructure, and ecological systems in a given area. Spatial assessment of flood hazard in Manatuto District showed variation in vulnerability levels based on local biophysical and topographic conditions **(Figure 4.10).**

Laleia Sub-District had the largest area in the very high flood hazard category. This indicates the need for priority interventions, both structural and non-structural. Relevant mitigation strategies include embankment construction, rehabilitation of recharge areas, and strengthening community-based early warning systems. Irawan *et al.* (2018) stated that mitigation approaches based on the topographic wetness index (MTWI) and land use are effective for identifying priority flood-management zones in basins with flat morphology and high rainfall intensity.

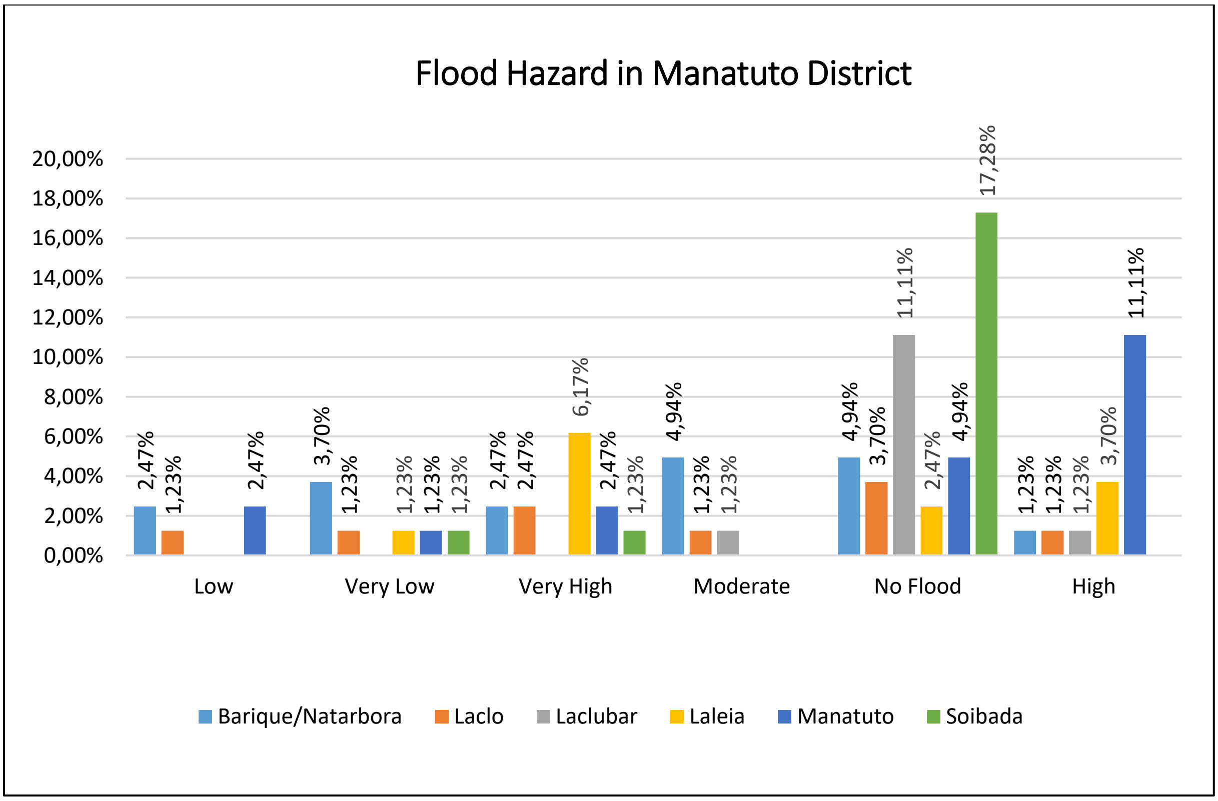


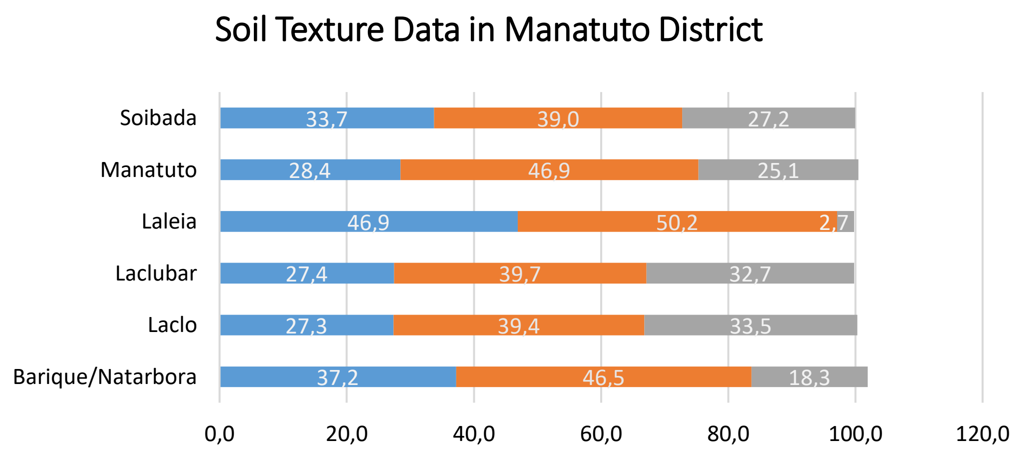
Figure 4.10 Flood Hazard Data in Manatuto District

However, Manatuto District in general was dominated by areas classified as no flood hazard or not prone to flooding. This indicates that most areas had relatively higher topography, efficient drainage systems, and vegetative cover functioning to reduce surface runoff. This condition is consistent with findings by Laswanto *et al.* (2025), which showed that areas with low TWI values and natural vegetation cover have minimal flood potential and can serve as references in planning disaster-resilient landscapes.

4.11 SOIL TEXTURE

Soil texture characteristics in each area of Manatuto District varied among texture classes **(Figure 4.11)**. In the Sub-Districts of Barique/Natarbora, Laclo, Laclubar, Manatuto, and Soibada, textures were dominated by silt and clay fractions, so the soils were classified as clay loam with good water and nutrient holding capacity. These conditions require appropriate drainage management to maintain optimal aeration and support root development. In Laleia Sub-District, the texture was classified as silty clay loam with a very high silt fraction, indicating finer soil with high water-retention capacity that still requires careful drainage management.

The inter-sub-district variation in texture reflects differences in soil physical properties that directly affect fertility and crop growth potential. Land management strategies should therefore be tailored to the texture characteristics of each sub-district to support productivity and maintain soil sustainability. Finer textures tend to increase soil organic matter availability and water storage, whereas coarser textures promote better soil aeration.



	Barique/Natarbora	Laclo	Laclubar	Laleia	Manatuto	Soibada
Clay (%)	37,2	27,3	27,4	46,9	28,4	33,7
Silt (%)	46,5	39,4	39,7	50,2	46,9	39,0
Sand (%)	18,3	33,5	32,7	2,7	25,1	27,2

Figure 4.11 Soil Texture Data in Manatuto District

4.12 pH

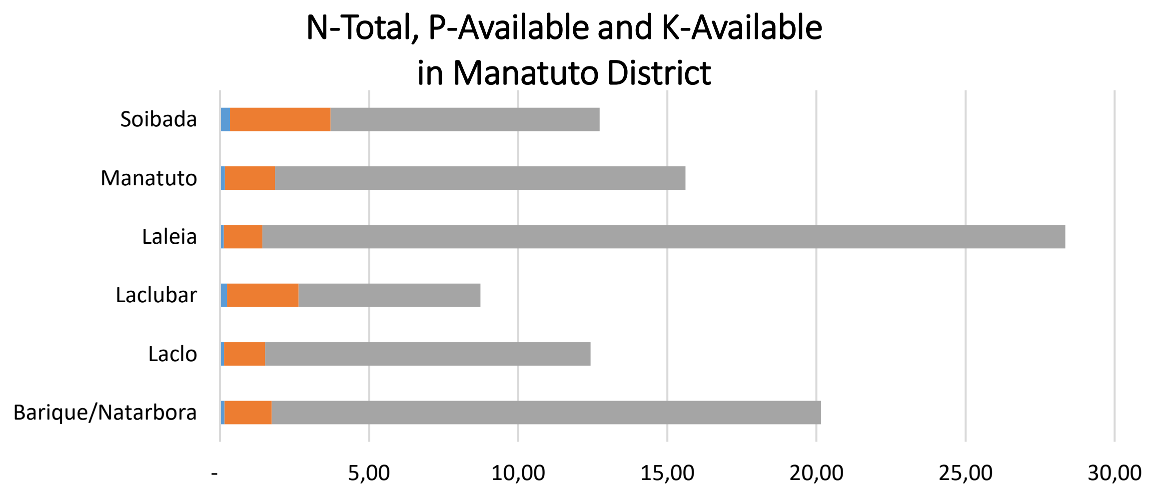
Soil pH is a key chemical parameter in land suitability evaluation because it directly affects nutrient availability, microbiological activity, and the growth of plant root systems. Soil pH values reflect the acidity or alkalinity of the soil, which is classified into several categories. According to laboratory analysis, the pH in Manatuto District ranges from neutral to slightly alkaline, with values between 6.17 and 7.67 **(Figure 5.1 in Chapter 5).**

Soils with high pH (alkaline) can lead to deficiencies in micronutrients such as zinc, copper, and boron, as well as disrupt ion balance in the soil solution. Moreover, high pH soils are often associated with alkaline conditions that hinder nutrient absorption and degrade soil structure. Neutral pH soils are generally considered the most suitable for most agricultural commodities, as they support soil microorganism activity, improve fertilizer efficiency, and enhance root interactions with nutrients.

4.13 TOTAL NITROGEN

The total nitrogen (N-Total) content in Manatuto District is considered low, ranging from 0.13 to 0.34 **(Figure 4.12),** with the highest values found in Soibada Sub-District and the lowest in Laleia Sub-District. The low nitrogen content in the study area is related to the moderate soil texture. Soils with this texture tend to support nitrogen leaching. Total nitrogen content is an important chemical parameter in land suitability evaluation because nitrogen is an essential nutrient that supports plant vegetative growth, protein formation, and enzymatic activity. N-Total represents the total nitrogen available in both organic and inorganic forms, although not all of it is immediately available to plants.

Soils with low to very low N-Total indicate limited nitrogen availability, which can inhibit plant growth, reduce leaf area, and slow biomass formation. Conversely, soils with high N-Total show good agronomic potential because they support optimal plant growth without the need for intensive fertilization. However, excessive nitrogen content can cause nutrient imbalances and increase environmental pollution risks through leaching or denitrification, especially in soils with poor drainage.



	Barique/Natarbora	Laclo	Laclubar	Laleia	Manatuto	Soibada
N-total	0,16	0,14	0,24	0,13	0,17	0,34
P-Available	1,58	1,38	2,40	1,29	1,68	3,37
K-Available	18,43	10,91	6,10	26,92	13,76	9,02

Figure 4.12 N-Total, Available P, and Available K Content Data in Manatuto District

4.14 AVAILABLE PHOSPHORUS

Available phosphorus (P-available) is the fraction of phosphate in the soil that can be directly absorbed by plants, especially in the form of orthophosphate ions ($H_2PO_4^-$ and HPO_4^{2-}). This element plays a crucial role in plant metabolism, such as energy formation (ATP), nucleic acid synthesis, and root system development. In land suitability evaluation, P-available is categorized as a key chemical parameter that determines fertility levels and both actual and potential suitability classifications. According to laboratory analysis, the P-available content in Manatuto District is considered very low, ranging from 1.29-3.37 ppm **(Figure 4.12).**

Soils with low P-available generally show limited phosphorus availability for plants, especially in acidic soils or calcareous soils with high calcium content. In these conditions, phosphorus tends to be fixed by Al^{3+} or Ca^{2+} ions, making it biologically unavailable. Soils with high P-available content show good agronomic potential because they support optimal plant growth without the need for additional phosphorus fertilization. However, excessive phosphorus levels can cause nutrient imbalances, particularly with micronutrients such as zinc (Zn) and iron (Fe), and increase environmental pollution risks through surface runoff in poorly drained soils.

4.15 AVAILABLE POTASSIUM

Laboratory analysis showed that the available potassium (K-available) content in Manatuto District is categorized as very low to moderate (**Figure 4.12**). Laclubar Sub-District had low K-available content, at 6,10 me/100 g, while Laleia Sub-District had moderate K-available content, at 26,92 me/100 g. Available potassium (K-available) is an essential macronutrient that plays a significant role in physiological processes such as protein formation, enzyme activation, osmotic pressure regulation, and transport of photosynthetic products. In land suitability evaluation, K-available serves as a chemical soil indicator to assess the soil's capacity to support optimal plant growth.

Soils with low to very low K-available content indicate limited potassium uptake by plants, which can lead to deficiencies, such as yellowing of leaf margins, stunted growth, and reduced crop quality. Soils with high to very high K-available content indicate good agronomic potential because they support optimal plant growth without the need for intensive potassium fertilization. However, excessively high potassium levels can cause antagonism with the uptake of other nutrients such as magnesium and calcium and increase environmental pollution risks through leaching in coarse-textured soils with fast drainage.

4.16 ELECTRICAL CONDUCTIVITY (EC) / TOXICITY

Electrical conductivity (EC), or soil electrical conductivity, is an important chemical indicator in land suitability evaluation. This parameter is used to assess soil salinity, which directly influences root-zone toxicity, water availability, and nutrient uptake efficiency by plants. According to laboratory analysis, EC in Manatuto District ranged from low to high, with values between 1,52 and 3,75 dS/m (**Figure 5.1 in Chapter 5**). The high EC values in this region are due to the location of the study area near rivers that drain into the sea and close to the coastline. This is consistent with Indahwati (2012), who stated that the closer an area is to the coastline or to river mouths, the higher the salinity levels. Conversely, according to Marwanto *et al*. (2009), salinity decreases with distance from the coast.

Soils with low EC generally do not induce osmotic stress on plants and support optimal nutrient uptake. These conditions are ideal for horticultural commodities, food crops, and intensive farming systems. Soils with high EC show significant toxicity levels, which can lead to physiological disturbances in plants, such as osmotic stress, cell membrane damage, and reduced enzymatic activity. According to Da Costa *et al.* (2015), EC is one of the chemical parameters used in land suitability evaluation in Timor-Leste, especially for annual crops. Their study emphasized that high salinity can inhibit root growth and disrupt ion balance in the soil solution, requiring conservative management practices such as leaching, the use of tolerant varieties, and amendments.

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 an important chemical characteristic of soil related to soil fertility. The CEC value is also closely related to base saturation. Laboratory analysis results show that CEC in Manatuto District ranges from low to high **(Figure 5.1).** Soibada Sub-District has a high CEC value of 25.09 me/100 g, followed by Barique/Natarbora Sub-District with a moderate CEC of 22.64 me/100 g, while Laclo Sub-District has a low CEC of 13.77 me/100 g. Factors affecting CEC include organic matter content, soil texture, and soil development. Soils with higher organic matter content and clay texture tend to have higher CEC, assuming other factors are constant (Suryani, I., 2014).

Soils with clay texture and high organic matter tend to have high CEC due to the availability of numerous ion exchange sites. While a high CEC is generally beneficial, in some cases, excessively high CEC may indicate extreme base saturation. This condition can cause soil structure degradation, poor drainage, and impaired root growth. Sandy soils or soils with low organic matter content generally exhibit low CEC and require special management practices to improve their cation exchange capacity. Low CEC can be improved by adding organic materials such as compost or manure. The addition of zeolite rock powder can also enhance soil CEC (Novizan, 2005).

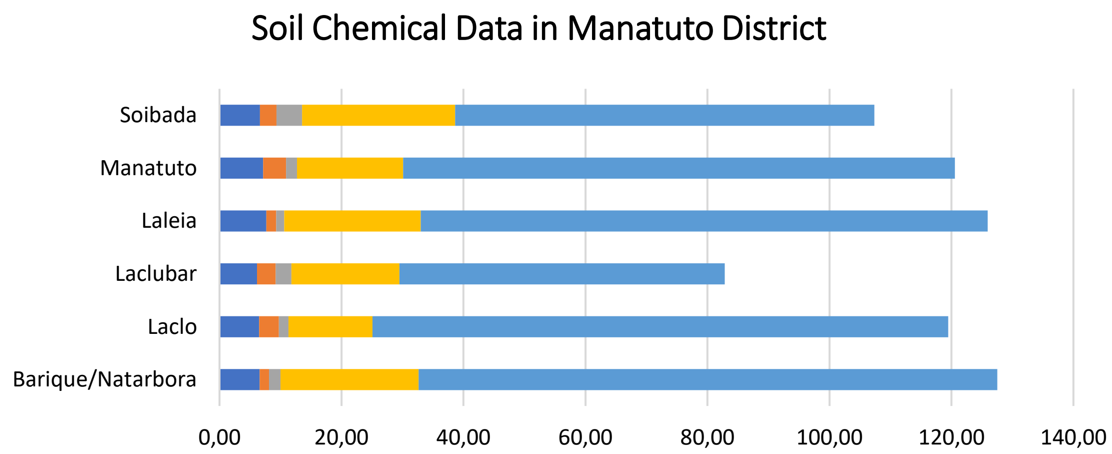
5.2 BASE SATURATION (BS)

Base Saturation (BS) represents the percentage of base cations in the soil's cation exchange complex relative to the total cation exchange capacity. The higher the BS value, the greater the proportion of base cations available to plants, which positively impacts soil fertility. The base saturation analysis results for Manatuto District range from moderate to very high **(Figure 5.1).** Barique/Natarbora Sub-District has a very high BS of 94.88%, followed by Laclo with Sub-District 94.40%, while Laclubar Sub-District has a moderate BS of 53.34%. The high BS values observed in the study area indicate that the cation exchange complex is predominantly filled with base cations. Cation exchange capacity provides information on the availability of nutrients, resulting in a pH in the neutral range. High BS indicates that most of the cation exchange sites are filled with essential plant nutrients. Soils with high BS generally have a neutral to slightly alkaline pH, which supports the optimal availability of macro and micronutrients.

5.3 C-ORGANIC

The analysis of organic carbon (C-Organic) in Manatuto District shows values ranging from low to high **(Figure 5.1).** Soibada Sub-District has a very high C-Organic content of 4.16%, followed by Laclubar Sub-District with a moderate value of 2.58%, while several other Sub-District in the region have low C-Organic content, ranging from 1.32% to 1.89%. C-Organic is a major component of organic matter, and organic matter acts as a soil colloid, so lower organic matter results in lower CEC, soil pH, and nutrient absorption, particularly N, P, and K (Mukhlis, 2011).

C-Organic reflects the status of organic material in the soil. Organic matter plays a crucial role in determining the soil's capacity to support plant growth. A decrease in organic matter content in the soil will reduce its ability to sustain plant productivity. This is in line with the statement by Risma *et al.* (2023), which highlights that C-Organic regulates the amount of carbon in the soil to enhance plant productivity, extend plant lifespan, and improve nutrient use efficiency.



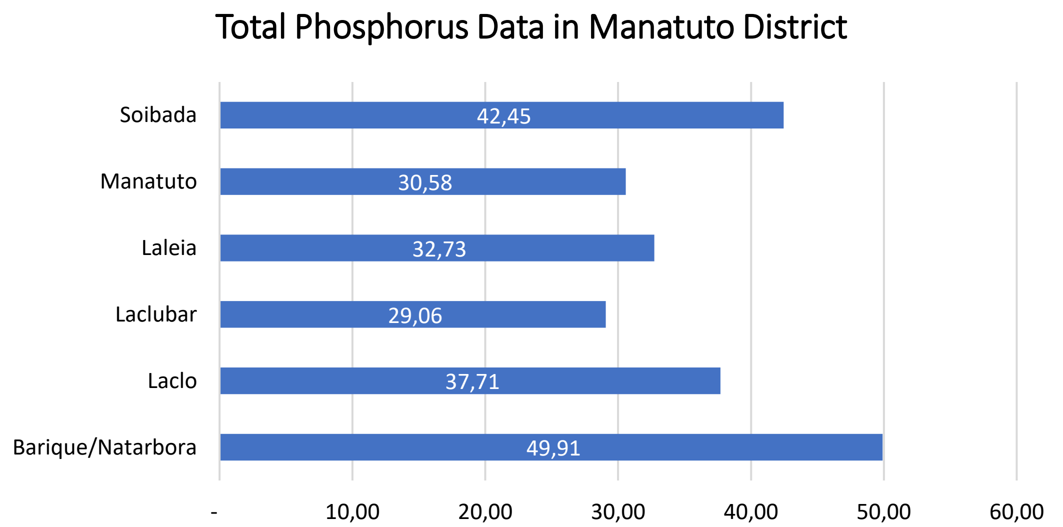
	Barique/Natarbora	Laclo	Laclubar	Laleia	Manatuto	Soibada
pH	6,59	6,49	6,17	7,67	7,15	6,63
Salinity	1,52	3,24	3,04	1,63	3,75	2,73
C-Organic (%)	1,89	1,56	2,58	1,32	1,83	4,16
CEC	22,64	13,77	17,74	22,36	17,38	25,09
BS	94,88	94,40	53,34	92,97	90,47	68,73

Figure 5.1 Soil Chemical Data in Manatuto District

5.4 TOTAL PHOSPHORUS

Laboratory analysis results indicate that the P-Total content in District Manatuto ranges from moderate to high **(Figure 5.2).** Sub- District Barique/Natarbora has a high P-Total value of 49.91 mg/100 g, followed by Soibada Sub-District at 42.45 mg/100 g, while Laclubar Sub-District has a moderate P-Total value of 29.06 mg/100 g. P-Total includes both inorganic and organic phosphorus bound in soil particles and organic matter. According to Foth (1990), P-Total represents the total amount of phosphorus in the soil, consisting of phosphorus available to plants and that which is unavailable due to strong binding with soil minerals or organic matter.

P-Total values ranging from moderate to high indicate that the soil has sufficient phosphorus reserves to support plant growth over the medium to long term, especially when managed properly. Low P-Total may occur in sandy soils with low adsorption capacity, continuous phosphorus uptake by plants without replenishment, and low organic matter content.



	Barique/Natarbora	Laclo	Laclubar	Laleia	Manatuto	Soibada
Total	49,91	37,71	29,06	32,73	30,58	42,45

Figure 5.2 P-Total Data in Manatuto District

5.5 TOTAL POTASSIUM

K-Total represents the total amount of potassium present in the soil, including both available and unavailable forms for plants. Laboratory analysis results show that K-Total levels in Manatuto District range from moderate to very high **(Figure 5.3)**. Laleia Sub-District has a very high K-Total value of 134.91 mg/100 g, followed by Barique/Natarbora Sub-District with 112.99 mg/100 g, while Laclubar Sub-District has a moderate K-Total value of 22.38 mg/100 g. The K-Total content in soil is strongly influenced by soil type and parent material. Soils derived from potassium-rich rocks, such as granite, typically have high K-Total.

Soils with K-Total values ranging from moderate to high have sufficient potassium reserves to support medium- to long-term crop cultivation, especially when properly managed to ensure optimal availability. Although high K-Total is generally beneficial, if it is not balanced with other nutrients or if potassium dominates excessively, it may interfere with the absorption of other nutrients. Reducing the application of potassium fertilizers, particularly excessive KCl, can help address excessively high K-Total.

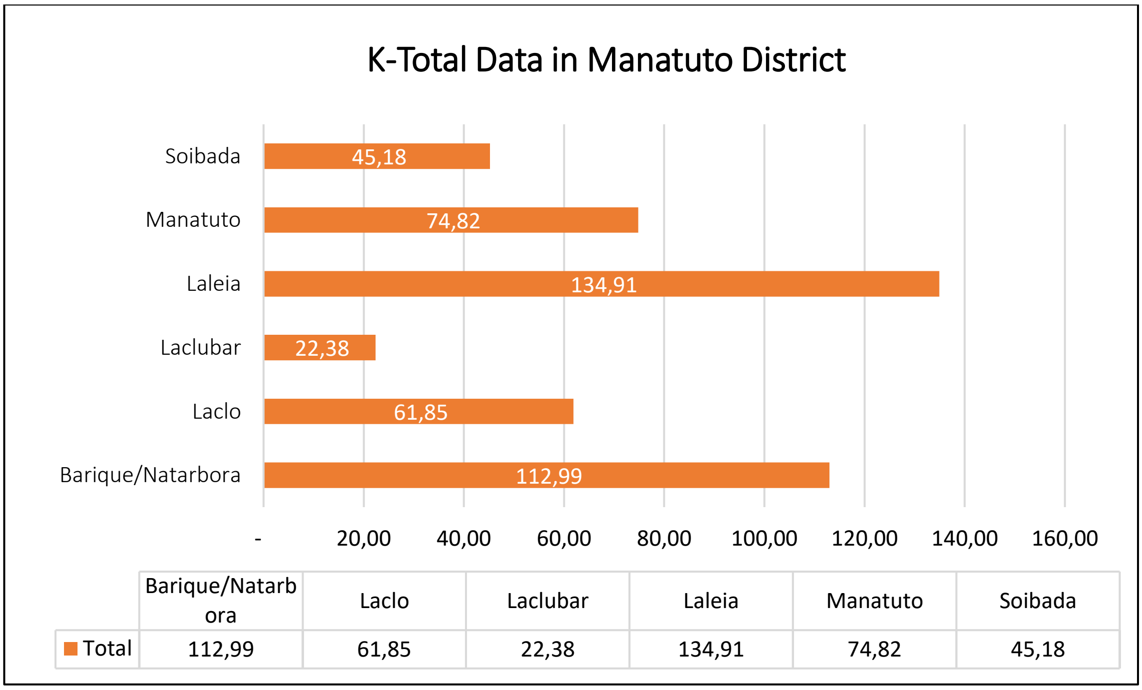


Figure 5.3 K-Total Data in Manatuto District

5.6 TOTAL ZINC

Zn-Total represents the total amount of zinc (Zn) stored in the soil, including both available forms for plants and those bound in mineral or organic forms within the soil. Laboratory analysis results indicate that Zn-Total levels in Manatuto District vary **(Figure 5.4)**. Laclubar Sub-District shows the highest Zn-Total value at 100.93 ppm, followed by Barique/Natarbora Sub-District with 90.20 ppm, while Manatuto Sub-District has the lowest Zn-Total value at 79.11 ppm. A good Zn-Total content in soil should not only be sufficiently high in total quantity but also have adequate available Zn for effective plant absorption.

Excessively high Zn-Total content may be associated with contamination or excessive fertilizer use. To manage high Zn-Total levels, reducing the use of fertilizers containing Zn and adjusting soil pH to prevent excessive availability of Zn in toxic forms for plants can be effective. Low Zn-Total can lead to deficiencies and reduced agricultural yields, while excessively high values may pose a risk of toxicity.

5.7 AVAILABLE ZINC

Zn-Available refers to the fraction of zinc in the soil that is water-soluble or exchangeable, thus directly available for plant absorption. Generally, Zn in the soil comes from dissolved mineral sources. Zinc is adsorbed by the soil in the form of Zn^{2+} ions through clay content, organic material, and oxidation of Al and Fe via adsorption processes, and is then absorbed by plants (Riwandi *et al.,* 2017). Laboratory analysis results show that Zn-Available levels in Manatuto District vary **(Figure 5.4)**. Soibada Sub-District has the highest Zn-Available value at 1.78 ppm, followed by Manatuto Sub-District with 1.76 ppm, while Laleia Sub-District has the lowest Zn-Total value at 0.59 ppm. Zn-Available in soil can be low even when Zn-Total is high. This is because zinc bound in clay minerals or organic material is not easily dissolved and thus unavailable to plants. Soil pH, organic matter content, soil texture, and microbial activity heavily influence this availability.

Low Zn-Available levels in plants can result in low-quality products and reduced yields (Alloway, 2008). To increase low Zn-Available levels, applying Zn-containing fertilizers and adjusting soil pH can be effective. Zn-Available may increase with excessive Zn fertilization, particularly in the long term, in heavy metal-contaminated environments, or in extremely acidic soils, which promote the dissolution of metals including Zn. To reduce excess Zn-Available, lime can be added to raise soil pH, thus decreasing Zn solubility.

5.8 TOTAL SULFUR

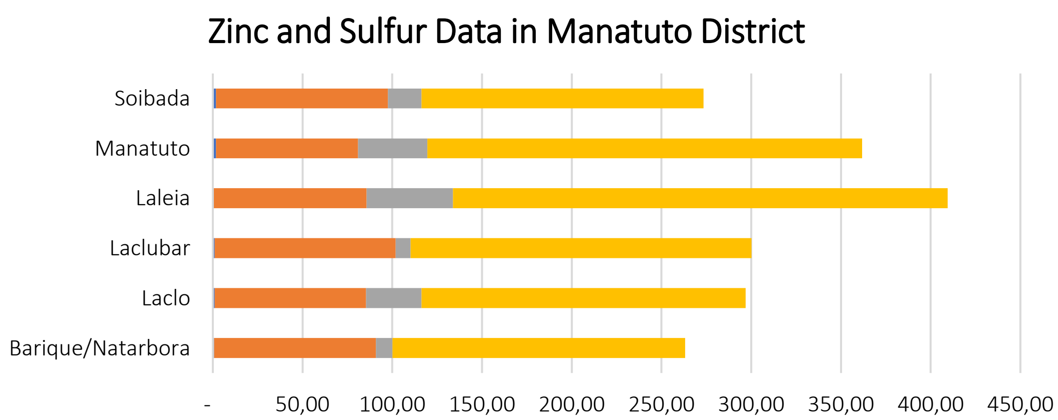
Sulfur is an essential secondary macronutrient for plant growth, playing a role in the formation of amino acids. Sulfur in soil exists in two main forms: organic sulfur and inorganic sulfur, with the majority being organic. S-Total refers to the total amount of sulfur in all these forms (Brady & Weil, 2008). Laboratory analysis results show that S-Total levels in Manatuto District vary **(Figure 5.4)**. Laleia Sub-District has the highest S-Total value at 275.63 ppm, followed by Manatuto Sub-District with 242.25 ppm, while Soibada Sub-District has the lowest S-Total value at 157.15 ppm.

Several factors contribute to low sulfur levels in soil, including low organic matter content and continuous use of chemical fertilizers without the addition of organic materials, which can deplete sulfur. S-Total levels can be improved by adding organic materials such as manure or compost. High S-Total levels may occur due to the accumulation of organic material, particularly in peat soils or soils with poor drainage. High sulfur levels can cause plant issues, such as interference with the uptake of other nutrients or soil acidification if excessive sulfate is present. To reduce high S-Total levels, improving soil drainage can help leach excess sulfur from the root zone.

5.9 AVAILABLE SULFUR

S-Available represents the fraction of total sulfur that has undergone mineralization from organic materials and is ready for absorption by plants. This content is crucial as it directly indicates soil fertility in relation to sulfur. Laboratory analysis results show that S-Available levels in Manatuto District vary **(Figure 5.4)**. Laleia Sub-District has the highest S-Available value at 48.06 ppm, followed by Manatuto Sub-District with 38.66 ppm, while Laclubar Sub-District has the lowest S-Total value at 8.36 ppm. Low S-Available content in soil may be caused by low organic matter, which provides limited sulfur from organic sources. To increase S-Available content in soil, sulfur-containing fertilizers and organic materials can be applied.

High S-Available levels may result from continuous sulfur fertilization without proper soil analysis, especially in the long term, in heavy metal-contaminated environments, or in extremely acidic soils. To reduce high S-Available levels, improving soil drainage can naturally leach excess sulfur from the root zone, and rotating crops that are tolerant to or require high levels of sulfur can also help.



	Barique/Natarbora	Laclo	Laclubar	Laleia	Manatuto	Soibada
Zn tersedia	0,75	1,07	0,98	0,59	1,76	1,78
Zn total	90,20	84,27	100,93	85,13	79,11	95,73
S-tersedia	9,16	30,95	8,36	48,06	38,66	18,80
S-total	163,03	180,61	189,97	275,63	242,25	157,15

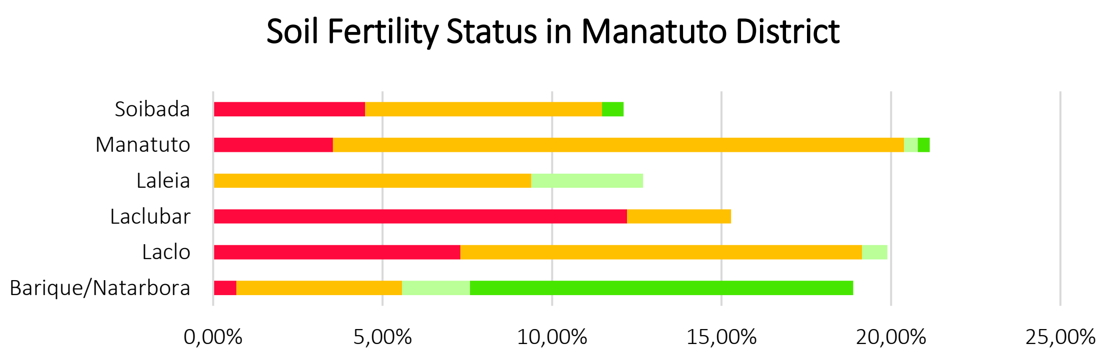
Figure 5.4 Zn and S Data in Manatuto District

5.10 SOIL FERTILITY STATUS

The analysis of soil fertility status in Manatuto District shows that the majority of the area falls under the low fertility category, covering 53.06% (951.07

km²) of the total area. The very low fertility category covers 28.21% (505.66 km²), followed by high fertility at 12.29% (220.24 km²). The area with medium fertility is the smallest, covering only 6.45% (115.59 km²). These data indicate that more than half of the land in Manatuto District is considered less fertile and requires efforts to improve soil quality to support agricultural productivity. On the other hand, areas with high fertility are relatively limited, and therefore, they must be used optimally to support sustainable agricultural production in the region.

Based on the soil fertility status data **(Figure 5.5)**, Barique/Natarbora Sub-District is dominated by high fertility, covering an area of 202.64 km², followed by low fertility with 87.65 km². The medium and very low fertility categories cover 35.93 km² and 12.26 km², respectively. In Laclo Sub-District, the largest area is categorized as low fertility, covering 212.46 km², followed by very low fertility at 130.81 km². The medium and high fertility categories are relatively small, covering 13.30 km² and having no high fertility areas, respectively. In Laclubar Sub-District, the area is dominated by very low fertility, covering 218.88 km², followed by low fertility at 55.12 km². No areas with medium or high fertility were found in this sub-district. In Laleia Sub-District, low fertility is the most dominant, covering 168.27 km², followed by medium fertility with 59.19 km². This sub-district has no areas with high or very low fertility. Manatuto Sub-District is dominated by low fertility, covering 302.21 km², followed by very low fertility at 63.34 km². The medium and high fertility categories are relatively small, covering 7.16 km² and 6.25 km², respectively. In Soibada Sub-District, low fertility is also the most prevalent, covering 125.35 km², followed by very low fertility at 80.37 km², and high fertility at 11.35 km². No areas with medium fertility were found in this sub-district.



	Barique/Natarbora	Laclo	Laclubar	Laleia	Manatuto	Soibada
Very Low	0,68%	7,30%	12,21%	0,00%	3,53%	4,48%
Low	4,89%	11,85%	3,08%	9,39%	16,86%	6,99%
Moderate	2,00%	0,74%	0,00%	3,30%	0,40%	0,00%
High	11,30%	0,00%	0,00%	0,00%	0,35%	0,63%

Very Low Low Moderate High

Figure 5.5 Soil Fertility Status in Manatuto District

In general, the low fertility category is the most dominant in the majority of sub-districts, followed by the very low fertility category. Meanwhile, the high and medium fertility categories cover only relatively limited areas. This highlights the need for special attention in land management to improve fertility, particularly in areas with low and very low fertility, to support sustainable agricultural productivity. Given the dominance of low fertility land, the implementation of effective management strategies is essential, such as the use of organic fertilizers, soil conservation techniques, and optimal irrigation management. Additionally, optimizing the use of land with medium and high fertility can be a strategic step in improving agricultural yields to support food security and the well-being of local communities. Close collaboration between farmers, academics, and the government is key to formulating sustainable solutions to enhance agricultural productivity in this District. The Soil Fertility Status Map can be seen in **Figure 5.6.**

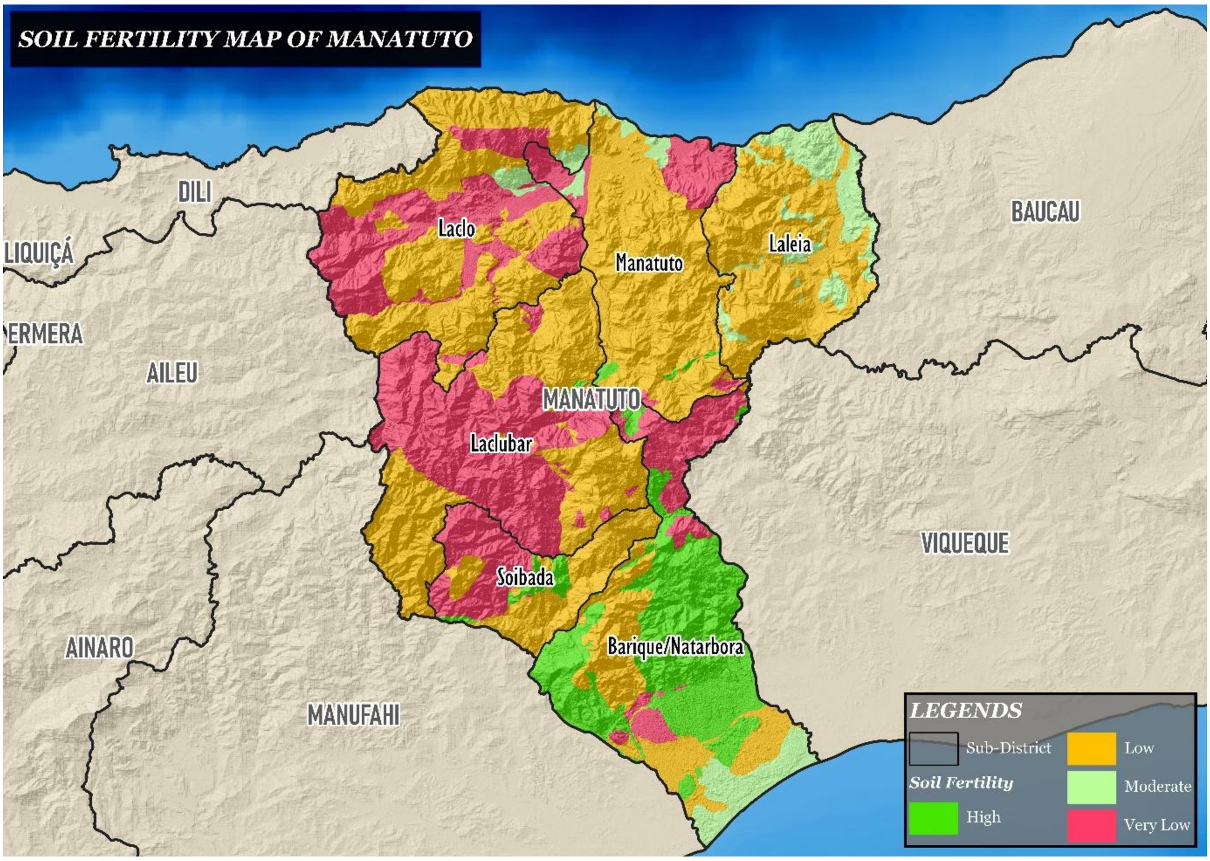


Figure 5.6 Soil Fertility Status Map of Manatuto District

VI. EROSION AND CONSERVATION

6.1 SOIL EROSION

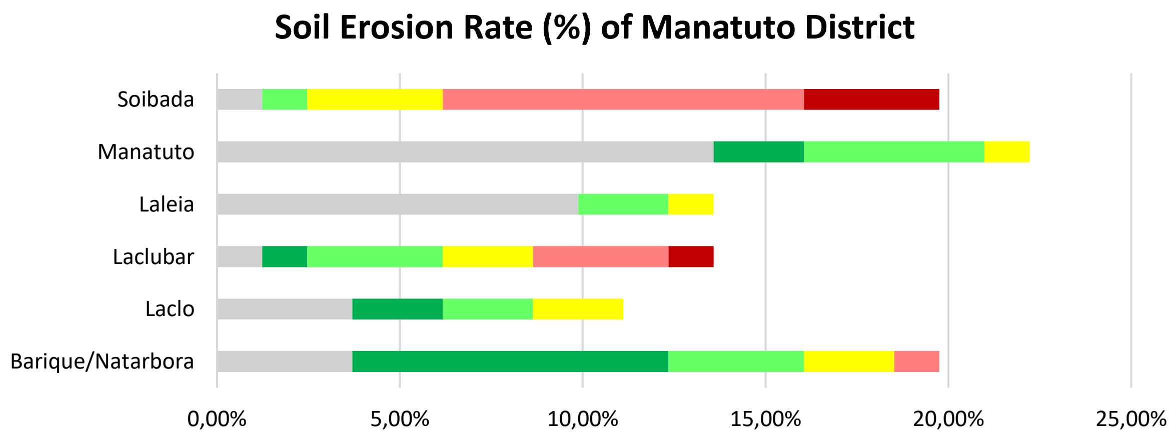
Soil erosion analysis plays an important role in land suitability evaluation, particularly for agricultural commodity development. Soil erosion not only affects land productivity but also impacts ecosystem sustainability, environmental degradation, and the soil's capacity to store nutrients and water. In agricultural land management, erosion analysis serves as the basis for designing soil conservation strategies to mitigate negative impacts and maintain sustainable land use.

According to the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1978), soil erosion is influenced by several main factors, namely rainfall erosivity, soil erodibility, slope length and slope gradient, vegetation cover, and land management practices. Topography dominated by steep slopes, low levels of land conservation, unstable soil structure due to geological influences, and minimal vegetation cover are key factors that accelerate erosion rates. As noted by Morgan (2005), uncontrolled soil erosion can result in the loss of topsoil, the most fertile component of the soil, thereby limiting its productive capacity.

The analysis showed that soil erosion levels in Manatuto District were grouped into six categories: no erosion (33.33 %), very slight (14.81 %), slight (18.52 %), moderate (13.58 %), severe (14.81 %), and very severe (4.94 %). This distribution indicates that most of the area falls within the no erosion to slight categories, totaling 66.66 %. Meanwhile, areas with moderate to very severe erosion account for 33.33 % of the total area.

Erosion hazard levels in Manatuto District vary from very slight to very severe. Soibada Sub-District falls into the severe to very severe hazard categories. This condition is caused by high rainfall, **as described in Chapter 4**, which can reduce soil infiltration capacity and accelerate the breakdown of soil aggregates, thereby increasing the risk of erosion. High-intensity and high-volume rainfall increases surface runoff that transports soil particles, especially in clayey soils with limited vegetation cover (Zhang *et al.,* 2025; Mendrofa and Hulu, 2024). Dominant soil orders such as Inceptisols and Vertisols presented in **Chapter 2 of this book** have clayey textures, making them more susceptible to erosion. In addition, the presence of steep to very steep slopes further exacerbates erosion. The steeper the slope, the greater the potential for erosion; longer slope lengths may reduce the number of overland flow interruptions but increase the volume of soil eroded (Arsyad, 2020).

Slope gradient and slope length are closely related to soil erodibility, namely the soil's capacity to resist the erosion process. Steep slopes tend to be associated with higher erodibility, making soils more easily eroded (Yulina *et al*., 2015). By contrast, Barique/Natarbora Sub-District has a very slight erosion hazard. This condition is due to relatively flat slope characteristics, as described in Chapter 2 of this book. Flat slopes are generally more stable and more resistant to erosion processes (Anthony, 2001). In addition, a well-functioning drainage system, as presented in Chapter 4, helps reduce erosion risk by conveying water efficiently and preventing ponding that can damage soil structure. The erosion data for Manatuto District are presented in **Figure 6.1**. The spatial distribution of soil erosion in Manatuto District is presented in **Figure 6.2**.



	Barique/Natarbora	Laclo	Laclubar	Laleia	Manatuto	Soibada
No Erosion	3,70%	3,70%	1,23%	9,88%	13,58%	1,23%
Very Light	8,64%	2,47%	1,23%	0,00%	2,47%	0,00%
Light	3,70%	2,47%	3,70%	2,47%	4,94%	1,23%
Moderate	2,47%	2,47%	2,47%	1,23%	1,23%	3,70%
Heavy	1,23%	0,00%	3,70%	0,00%	0,00%	9,88%
Very Heavy	0,00%	0,00%	1,23%	0,00%	0,00%	3,70%

Figure 6.1 Soil Erosion Severity in Manatuto District

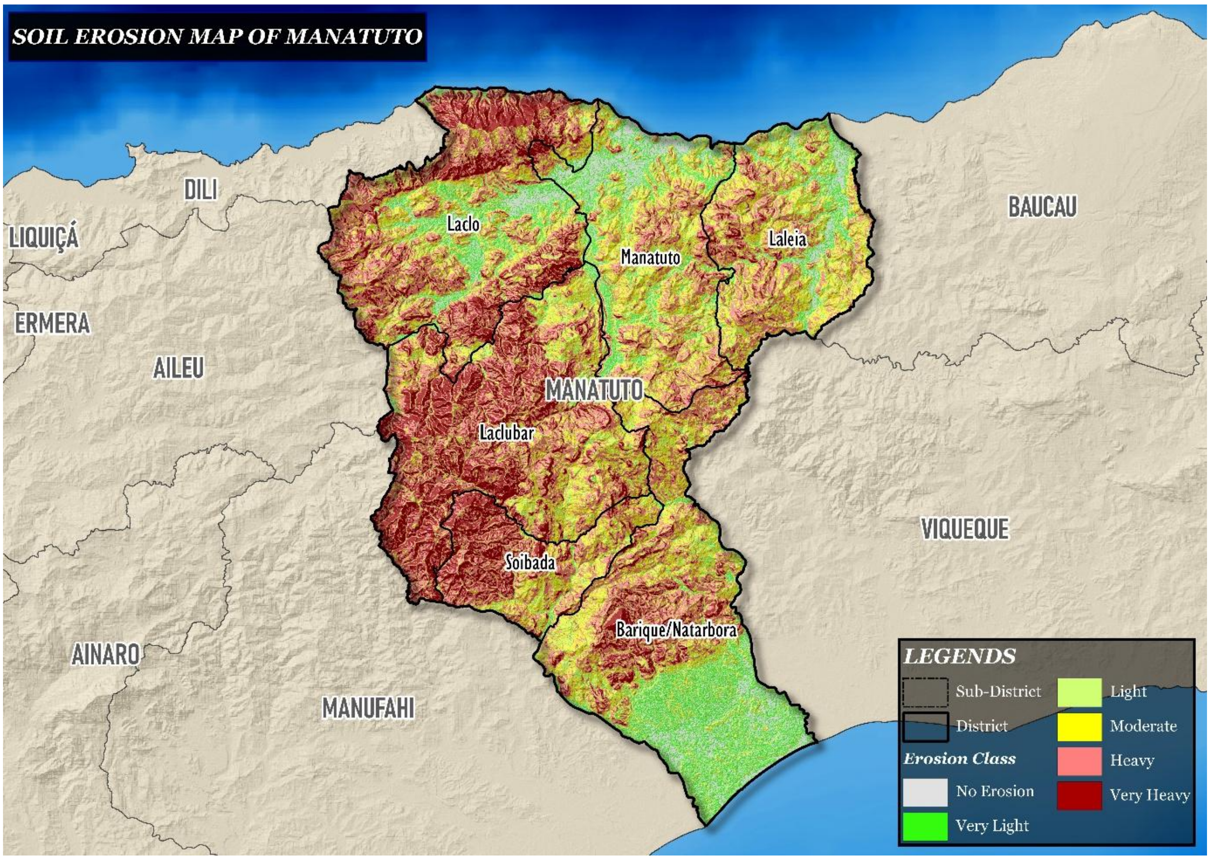


Figure 6.2 Spatial Distribution of Soil Erosion in Manatuto District

6.2 SOIL AND WATER CONSERVATION

Conservation is a long-term natural resource management effort aimed at maintaining land quality and productivity. Conservation measures play an important role in protecting soil from degradation, rehabilitating degraded soils, and increasing infiltration while maintaining soil fertility. Conservation practices comprise mechanical, vegetative, and chemical methods.

Conservation in Manatuto District is based on slope gradients ranging from flat to very steep (0 to >45%). On flat to gentle slopes (0 to 8%), food crops, secondary crops, and horticulture are recommended. These commodities can also be cultivated on land with slope gradients up to 40%, provided terraces are constructed to increase rainfall infiltration into the soil, thereby reducing erosion and surface runoff. Where slopes exceed 45%, the land should be used for perennial crops (timber species such as banyan, mahogany, albizia, teak, gamal, *lamtoro*, and others), because if terraces are constructed the planting area becomes very narrow and the soil is prone to erosion and even landslides during heavy rainfall. Slope gradient data for Manatuto District are presented in **Table 6.1**, and the slope gradient map is presented in **Figure 6.3**.

Table 6.1 Slope Gradient Data in Manatuto District

Sub-District	Slope Gradient (%)	Potential Class	Area (ha)	Area (%)
Barique/Natarbora	>45	Agroforestry	3.362,57	1,89
Barique/Natarbora	0-8	Highly Potential	11.387,17	6,39
Barique/Natarbora	15-25	Moderately Potential	8.329,92	4,68
Barique/Natarbora	25-45	Agroforestry	10.489,79	5,89
Barique/Natarbora	8-15	Potensial	6.056,41	3,40
Laclo	>45	Agroforestry	8.352,14	4,69
Laclo	0-8	Potensial	4.713,71	2,65
Laclo	15-25	Moderately Potential	6.795,52	3,82
Laclo	25-45	Agroforestry	13.276,39	7,45
Laclo	8-15	Potensial	3.637,66	2,04
Laclubar	>45	Agroforestry	12.790,60	7,18
Laclubar	0-8	Highly Potential	1.133,73	0,64
Laclubar	15-25	Moderately Potential	7.336,04	4,12
Laclubar	25-45	Agroforestry	14.802,94	8,31
Laclubar	8-15	Potensial	3.031,69	1,70
Laleia	>45	Agroforestry	1.060,61	0,60
Laleia	0-8	Potensial	3.635,30	2,04
Laleia	15-25	Moderately Potential	7.205,66	4,05
Laleia	25-45	Agroforestry	7.360,69	4,13
Laleia	8-15	Potensial	3.284,75	1,84
Manatuto	>45	Agroforestry	1.281,44	0,72
Manatuto	0-8	Potensial	6.506,88	3,65
Manatuto	15-25	Moderately Potential	7.602,10	4,27
Manatuto	25-45	Agroforestry	7.365,21	4,14
Manatuto	8-15	Potensial	4.317,73	2,42
Soibada	>45	Agroforestry	3.649,71	2,05
Soibada	0-8	Potensial	335,01	0,19
Soibada	15-25	Moderately Potential	2.907,62	1,63
Soibada	25-45	Agroforestry	5.128,32	2,88
Soibada	8-15	Potensial	978,34	0,55

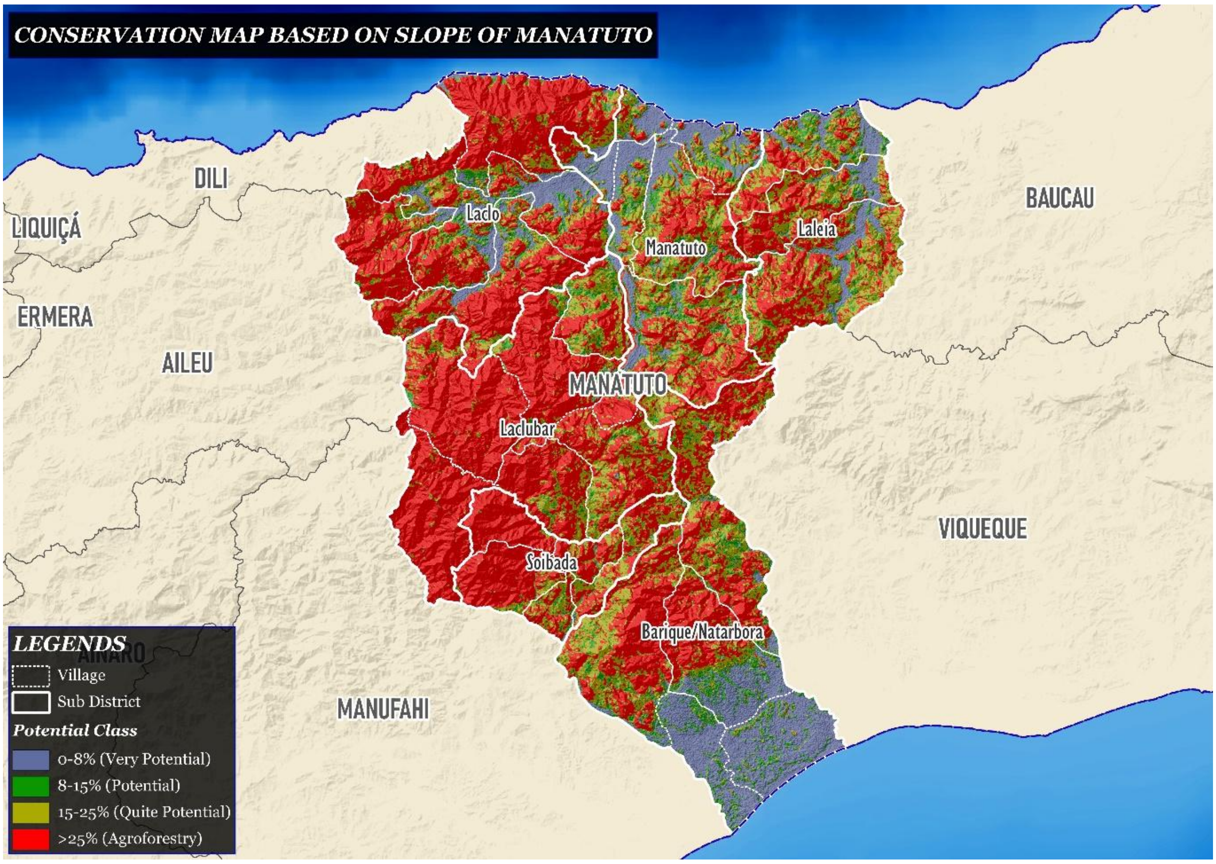


Figure 6.3 Conservation Map Based on Slope Gradient in Manatuto District

Manatuto District has similar slope gradient classes in all sub-districts, with different areal extents. The sub-district with the largest area of slopes of 25-45 % is Laclubar Sub-District, namely 14,802.94 ha or 8.31 %, which means land with very steep slopes can only be used for perennial crops or agroforestry. Gentle slopes (0-8 %) are most extensive in Barique/Natarbora Sub-District at 11,387.17 ha or 6.39 %. Barique/Natarbora Sub-District has potential for the development of food crops, horticulture, and plantation crops. Land with highly potential use at gentle slopes (0-8 %) covers 27,711.78 ha (15.56 %), land with potential use at slopes of 8-15 % covers 21,306.57 ha (11.96 %), land with moderately potential use at slopes of 15-25 % covers 40,176.85 ha (22.56 %), and the area above 25 % slope totals 88,920.41 ha (49.92 %).

Based on the Manatuto slope gradient map in **Figure 6.3**, coastal or central areas with flat (0-8 %), gentle, and somewhat steep slopes (8-25 %) are suitable for food crops, secondary crops, plantation crops, and horticulture. To improve growth, land with moderate to somewhat steep slopes requires terracing to reduce erosion. Areas shown in red gradients in the upper parts are classified as very steep (>45 %), where only perennial or timber species should be developed and managed under agroforestry.

Agroforestry is a land management system that integrates trees, agricultural crops, and/or livestock on the same land to provide diverse ecological interactions and ecosystem functions. Integration among agroforestry components (trees, agricultural crops, and livestock) can increase fertility and improve soil physical, biological, and chemical properties, provide specific habitats, enhance biodiversity, reduce runoff, dissipate the kinetic energy of raindrops, bind soil particles, increase soil water-holding capacity, and control erosion.

Based on its components, agroforestry is classified into several systems:

1. Agrisilvicultural system: integration of trees and specific food crops on the same land.
2. Silvopastoral system: combination of tree cultivation and forage grasses to support livestock husbandry.
3. Agrosilvopastoral system: cultivation of trees, food crops, pasture, and livestock on the same land. This system aims to optimize land production functions but requires intensive management at the subsystem level.
4. Home garden: characterized by intensive cultivation of perennial and seasonal crops, generally comprising vegetables, cereals, fruit trees, grasses, and livestock.
5. Other systems: including multipurpose tree planting, beekeeping, as well as aquaculture and forestry, all of which can be utilized for various agricultural and non-agricultural purposes. The agroforestry conservation model is presented in **Figure 6.4**.

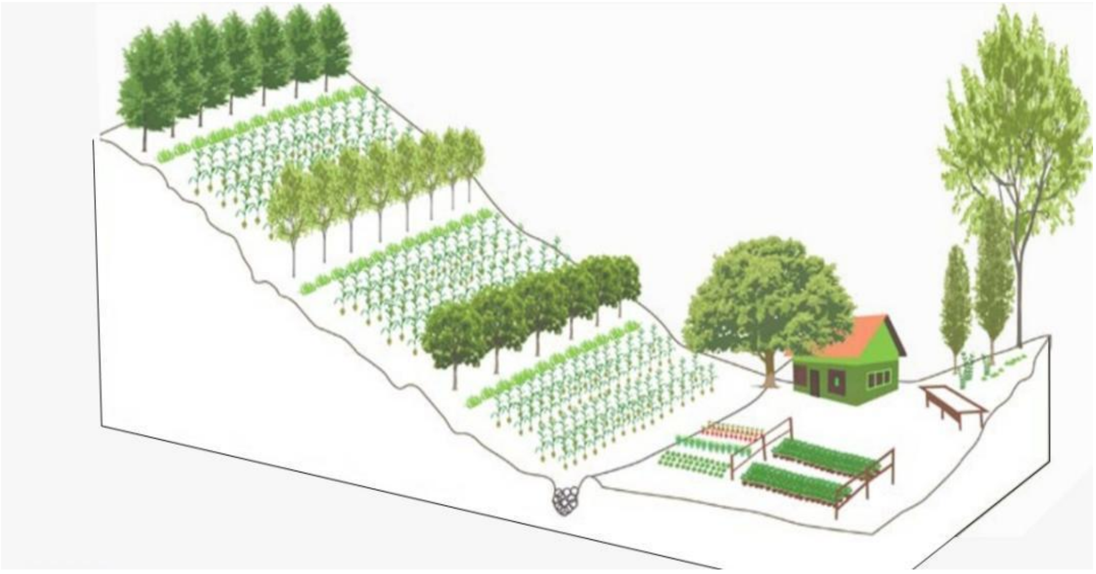


Figure 6.4 Agroforestry Conservation Model
(Source: La *et al*., 2016)

A. Importance of the Agroforestry Concept

Agroforestry plays a significant role in the production of both local commodities (firewood, timber, fruits, and animal feed) and global commodities (coffee, tea, cocoa, rubber, and sap). Agroforestry also plays a strategic role in assisting countries through poverty alleviation, food security, and environmental sustainability. It helps improve farmer resilience and increase household income by providing diverse harvests at different times of 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 beneficial to plants and pasture. Agroforestry provides various benefits, including:

1. Improving Food Security and Nutritional Enrichment

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

2. Resilient Livelihoods

The integration of trees, food crops, and livestock reduces the vulnerability of production to climate disasters and market shocks. Moreover, agroforestry can reduce pest outbreaks in monoculture systems by creating a better microclimate. Agroforestry mitigates climate impacts on agricultural systems, creating resilient livelihoods.

3. Mitigating and Adapting to Climate Change

Integrating various agricultural crops helps mitigate the impacts of climate change on the agricultural sector. The use of trees in agroforestry contributes to carbon sequestration, regulates the microclimate, and helps reduce the pace of climate change, positively influencing plant growth.

4. Protecting the Environment

Agroforestry systems help regulate climate and environmental services. Perennial crops improve air and water quality. Tree litter can be used as organic material to reduce the use of chemical fertilizers. The deep root systems support the nutrient cycle. Agroforestry components also support biodiversity by providing suitable habitats for flora and fauna in agricultural landscapes.

5. Poverty Alleviation

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

B. Agroforestry and Agroecology in Manatuto District

The most successful agroforestry systems in Manatuto District typically involve mixed cultivation of fruit trees and timber-producing trees with spices. Main fruit crops chosen include jackfruit, banana, mango, pineapple, and orange. Timber-producing trees commonly planted alongside fruit crops include mahogany, sandalwood, moringa, and albizia. Agroforestry has adopted modern approaches focusing on crop rotation, intercropping, and agro-silvopasture techniques.

Paudel *et al.* (2022) describe the common agroforestry model applied in Timor-Leste, including Manatuto District.

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

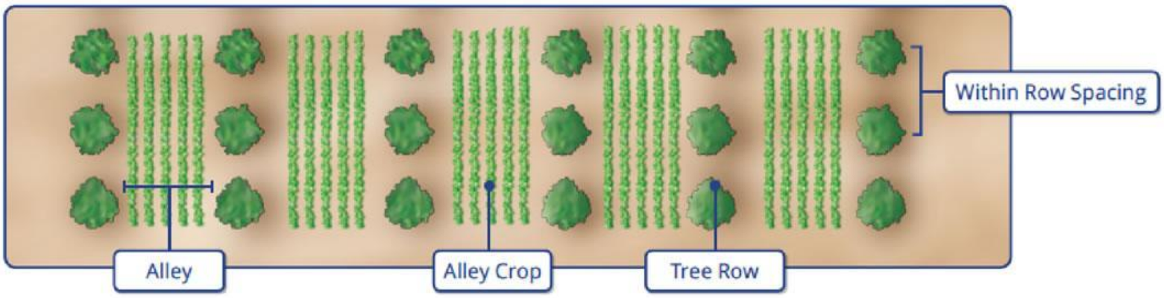


Figure 6.5 Alley Cropping Planting System Concept
(Source: https://www.fs.usda.gov/nac/practices/alley-cropping.php)

2. Hedgerow Planting involves creating boundaries or fences using trees/shrubs. This is mainly applied in steep hill areas for soil conservation. The concept is presented in **Figure 6.6.**

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

3. Random Planting of both woody and seasonal plants with irregular planting distances on flat lands. The random planting concept is presented in **Figure 6.7.**

Figure 6.7 Random Planting System Concept
(Source: https://ppid.menlhk.go.id/berita_foto/browse/264)

4. Alternating Row Planting with seasonal planting between rows on flat, wide areas. An example of an agroforestry model that can be implemented in Manatuto District is Casuarina (wood + fruit), with Casuarina as the main plant and supporting plants like pineapple, orange, guava, mango, and jackfruit. This agroforestry model can be applied at altitudes of 500-1,500 m with average rainfall ranging from 1,500-3,000 mm/year.

Cogné & Lescuyer (2024) combine agroecological and socio-technical data to identify types of Agroforestry Systems (AFS) in Manatuto District, which include home gardens combining perennial crops, spices, and small livestock; integration of crops and barren land with a defined planting distance for food crops and trees; planting perennial crops (papaya, banana, chili, etc.) combined with timber plants (palms); forest gardens, usually near water sources; and silvopastoral systems that combine trees, shrubs, and grazing livestock on the same land.

Manatuto District has three agroecological zones (AEZs) based on agroclimatic zones. These zones have biophysical parameters such as elevation, average rainfall, and soil type, which are essential in selecting the appropriate crops and agroforestry models to apply in Manatuto District. Agroecological zone data and main crop types are presented in **Table 6.2**. The agroclimatic zone map of Manatuto District is presented in **Figure 6.8**.

Table 6.2 Agroecological Zone Data and Main Crops

Zone	Altitudes (m)	Rainfall (mm/year)	Main Crops
Zone A	<100	500-1500	Corn, Cassava, Rice, Sweet Potato, Peanut
Zone B	100-500	500-1500	Corn, Cassava, Rice, Sweet Potato, Peanut
Zone C	>500	1500-3500	Rice, Corn, Cassava, Cocont
Zone D	>500	500-1500	Corn, Cassava, Rice, Sweet Potato, Peanut
Zone E	100-500	500-1500	Corn, Cassava, Rice, Peanut
Zone F	<100	1500-3500	Rice, Corn,Cassva, Coconut

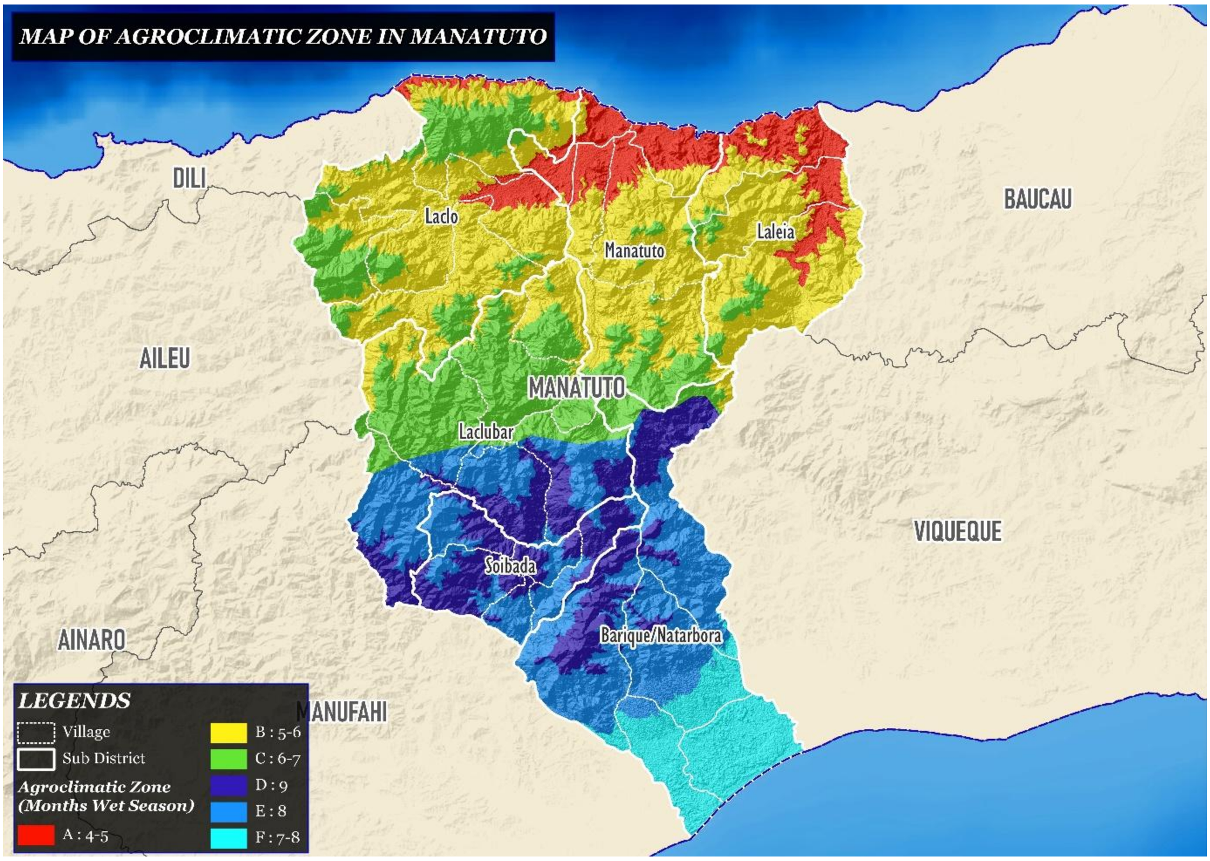


Figure 6.8 Agroclimatic Zone Map of Manatuto District

The following are recommendations for implementing agroforestry according to the agroecological zones based on agroclimatic zones.

1. Zone A

Suitable conservation techniques include check dam gabion dams, ridge terraces, biopore holes, riverbank protection, rainwater reservoirs, and drainage systems. Suitable crops include mahogany, sandalwood, teak, and high-value timber species.

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 crops include mahogany, sandalwood, cinnamon, coffee, cocoa, and vanilla.

3. Zone C

Suitable conservation techniques include terraces with channels, bench terraces, rainwater reservoirs, drainage systems, grass planting, and check dams. Suitable timber species include mahogany and sandalwood, while suitable food crops include corn, cassava, and sweet potatoes.

4. Zone D

Suitable conservation techniques include terraces with channels, bench terraces, rainwater reservoirs, drainage systems, grass planting, and check dams. Suitable timber species include mahogany and sandalwood, while suitable food crops include corn, cassava, and sweet potatoes.

5. Zone E

Conservation techniques include channel terraces, bench terraces, rainwater reservoirs, drainage systems, grasslands, and check dams.

6. Zone F

Suitable conservation techniques include check dam gabion dams, ridge terraces, biopore holes, riverbank protection, rainwater reservoirs, and drainage systems. Suitable crops include mahogany, teak, sandalwood, corn, and cassava.

C. Conservation Techniques in Manatuto District

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

1. Check Dam

A check dam is a small, low dam constructed in a streambed or other water channels to reduce water flow speed, reduce erosion, and promote the deposition of eroded materials through the spillway. Check dams are useful for preserving agricultural land and strengthening the structures of dams in hilly and disaster-prone areas. Several types of dams include:

a. **Brushwood**, which is made from wood or branches, suitable for small streams. Typically, it has an effective height of about 1 m above ground level, with a foundation depth of 0.75-1 m for the posts. The brushwood conservation model is presented in Figure 6.9. The steps for constructing a brushwood dam are:

   1) Dig a trench approximately 5 cm wide, insert wooden posts (150-200 cm) with a depth of about one-third to half the length of the post, with a spacing of 30-50 cm between posts
   2) The center should be lower than the sides to form a gap for maximum water flow retention
   3) Branches from trees (mahogany, rosewood, sesbania) and shrubs are woven between the posts to the desired height
   4) The ends of the interwoven materials should extend at least 30 cm into the channel
   5) The back of the dam should be filled with soil
   6) The sides of the brushwood, about 1.5-2 times the height of the dam, should be protected with galvanized wire
   7) Sidewalls should be built to direct water flow toward the dam
   8) Adjust the steepness of the stream's headwater to prevent erosion

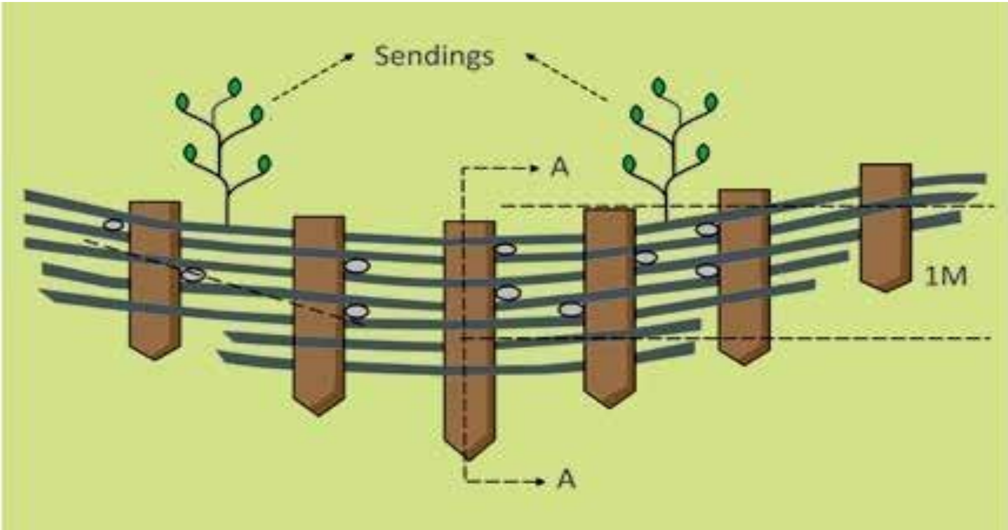


Figure 6.9 Brushwood Check Dam
(Source: Godinho *et al.,* 2023)

b. **Loose Stone**, dams are made from loose stones to block small to medium-sized river channels. A boulder dam follows the same principle but uses large rocks as barriers. Typically, these dams have a maximum effective height between 1 and 2 meters, with the foundation depth being at least half of the effective height, and the dam thickness at the spillway ranging from 0.5-1 meter. The loose stone conservation model is shown in **Figure 6.10.** The steps to construct a loose stone or boulder dam are as follows:
   1) Clear the site and mark the construction line with string
   2) Cut the riverbank at a 1:1 slope. The foundation of the wing wall must be >0.5 m, and the height of the wing wall should match the depth of the spillway
   3) The dam foundation should extend beyond the spillway
   4) For larger dams, build two wing walls with appropriate foundations to direct water into the spillway or gap and prevent damage to the riverbank
   5) Use boulders for the gaps and downstream side of the spillway. The center should remain low for the water channel
   6) In cases of high waterflow, concrete may be required for the gaps and top of the dam, or the entire structure may be covered with wire mesh
   7) Build a stone apron beneath the dam
   8) Place large stones at the base of the dam, and use stones about 50 x 30 cm throughout the dam.

9) On the upstream side, fill the dam with soil to enhance its stability

Figure 6.10 Loose Stone Check Dam
(Source: https://www.flickr.com/photos/mocobio/27742059100)

c. **Gabion**, dam is made using hexagonal or square wire baskets filled with stones. General specifications for gabions include a maximum effective height of <5 m, with the foundation depth being half of the effective height, and a dam thickness at the spillway of <1 m. The gabion conservation concept is shown in **Figure 6.11**. The steps to construct a gabion dam are as follows:
   1) The structure must extend at least 0.5 m into the riverbank and be protected from floodwaters with wing walls
   2) Wing walls with suitable foundations should be built on top to direct water into the spillway or gap and prevent riverbank damage. The space between the dam and the wing walls must be filled with soil
   3) The foundation of the dam must extend beyond the spillway
   4) Place large stones along the sides of the gabion box, while smaller stones are used to fill the center. The stones used for construction should be larger than the wire mesh size (mesh size 10 x 10 cm and 15 x 15 cm)
   5) If debris is present, a concrete layer should be applied at the front of the dam to protect the gabion wire from damage
   6) The dimensions of the spillway are calculated based on the maximum flow from the river catchment area
   7) Build an apron beneath the dam
   8) Fill the back of the dam with soil to increase its 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 directly controls water flow and reduces soil loss. It alters the continuity of topography and reduces slope length by intercepting 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, reduce nutrient loss, and improve crop productivity. Terracing is not suitable for shallow soils. The concept of conservation using terracing systems is presented in **Figure 6.12**, and terracing implementation is shown in **Figure 6.14.**

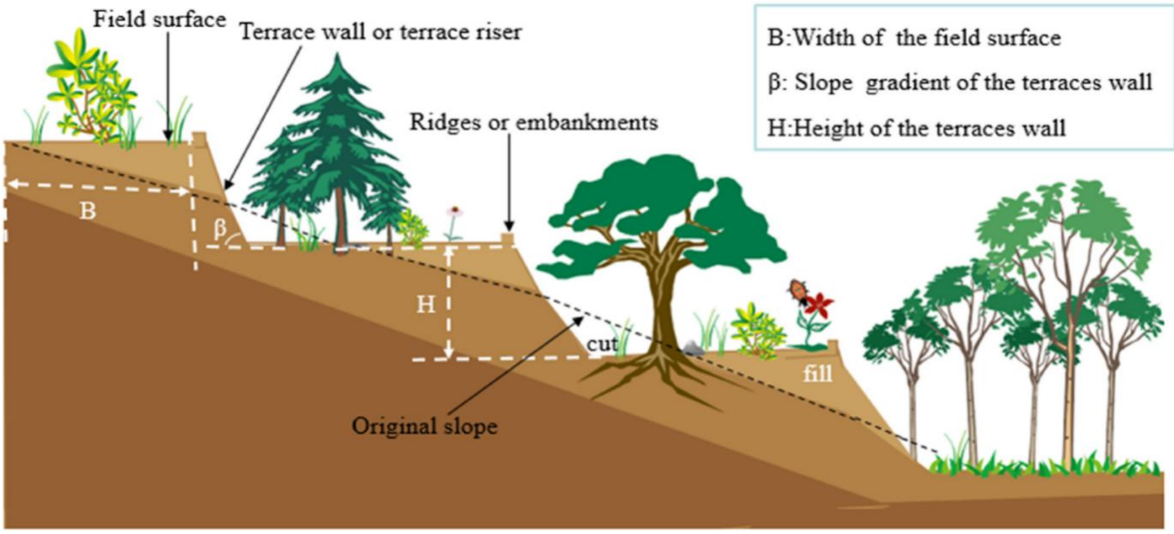
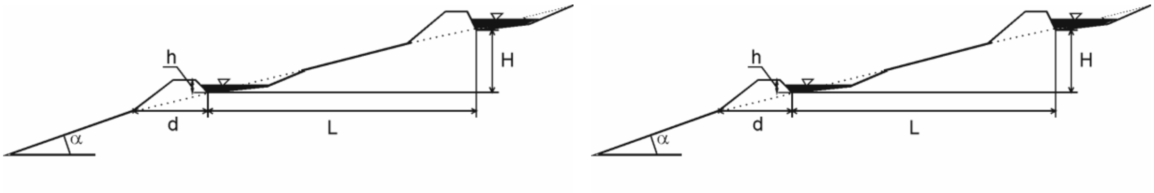


Figure 6.12 Terracing Conservation Concept
(Source: Deng *et al*., 2021)

Several types of terraces based on their suitability for slopes include:

a. **Broad Channel Terraces**, typically built to capture and channel excess water in fields. These terraces are suitable for wet areas with slopes not exceeding 20%

b. **Ridge Terraces**, built to capture and hold excess water by spreading it across the land between hilltops. These terraces are mostly applied on gentle slopes (<3%) because the water spreads more widely without needing high ridgelines. Ridge terraces have water channels at the back of the ridge (hill) to drain surface water into spillways and increase water absorption into the soil. Ridge terraces divide the slope into smaller hydrological units, reducing water flow paths and affecting water circulation on the slope and throughout the watershed. 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 are parallel to the contours and are built on permeable soil in areas with relatively low rainfall. Water flowing through them is retained on the embankment and absorbed into the soil. Ridge terraces with water outflow, these terraces have either surface or subsurface drainage. Subsurface drainage releases water through wells or pumps into ditches, rivers, or reservoirs. These terraces are used in areas with high rainfall and on soils with low permeability. The concept of ridge terrace division is presented 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 Ridge Terraces Concept; 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 lined with stones or vegetation for protection. Step terraces can be built flat, inward (axis), or outward and are typically used in rainfed rice fields, dry fields, and various agroforestry systems.

d. **Individual Terraces**, built around each individual plant, particularly for perennial crops. This type of terrace is typically constructed in plantation areas or fruit orchards.

e. **Garden Terraces**, for perennial crops, particularly for plantation crops and fruit orchards. Terraces are built at varying intervals depending on planting distance. Terraces are constructed manually using the cut-and-fill method, where soil from a higher level is cut and moved to a lower level. The specifications for terrace design include:
    1) The length of terraces is generally a maximum of 100 meters in one direction of the drainage channel for humid tropical climates. The length of the terrace is limited by the land's size and shape, cutting degree, and soil type
    2) The width of the terrace: optimal width ranges from 2.5-5 meters (manual construction), and 3.5-8 meters (machine or tractor construction). The width is adjusted based on soil depth, tilling equipment, plant type, and other needs
    3) Terrace grade, horizontal gradient ranges from 0.5-1% depending on climate and soil type.
    4) Height and slope of the sub-terraces: sub-terraces are made of compacted soil and protected with grass or stones. The height of the

sub-terraces should not exceed 2 meters. The vertical interval (VI) between consecutive terraces can be calculated using the formula:

VI = (S x Wb) / 100 - (S x U)

Where:

S = Slope (%)

Wb = Width of the bench (m)

U = Slope of the sub-terrace (m)

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

3. Biopore Infiltration Holes

Biopore holes are cylindrical holes drilled into the ground to increase water infiltration, reduce flooding, convert organic waste into compost, reduce greenhouse gas emissions (CO^2 and methane), and leverage the role of soil and plant roots. Biopore holes can increase water infiltration up to 40 times, thereby enhancing soil moisture and maximizing groundwater reserves. Additionally, biopores can improve soil fertility by converting kitchen waste into compost.

Biopore construction can be done by digging or using a drill to make holes with depths ranging from 30-100 cm. The distance between holes is approximately 0.5-1 meter. 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 pipe sections to prevent erosion. Only organic waste (kitchen waste and/or garden waste) should be used. The waste should not be too compacted, as it will disrupt the water infiltration process. The compost produced is typically ready within 2-8 weeks. The concept of biopore infiltration hole application is shown in **Figure 6.15.**

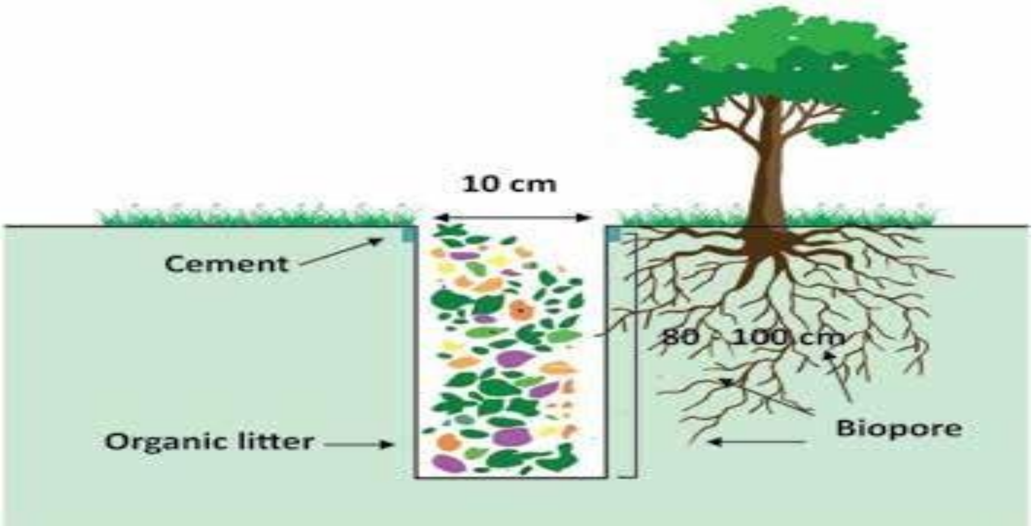


Figure 6.15 Biopore Infiltration Holes
(Source: Godinho *et al.,* 2023)

4. Riverbank

Riverbank protection is a soil and water conservation technique applied along riverbanks to prevent landslides, reduce soil erosion, improve river water quality, and prevent sedimentation. Riverbank protection can be implemented in open areas along riverbanks that are vulnerable to erosion and landslides, on steep riverbanks, barren river borders, 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 using vegetation is presented in Figure 6.16.

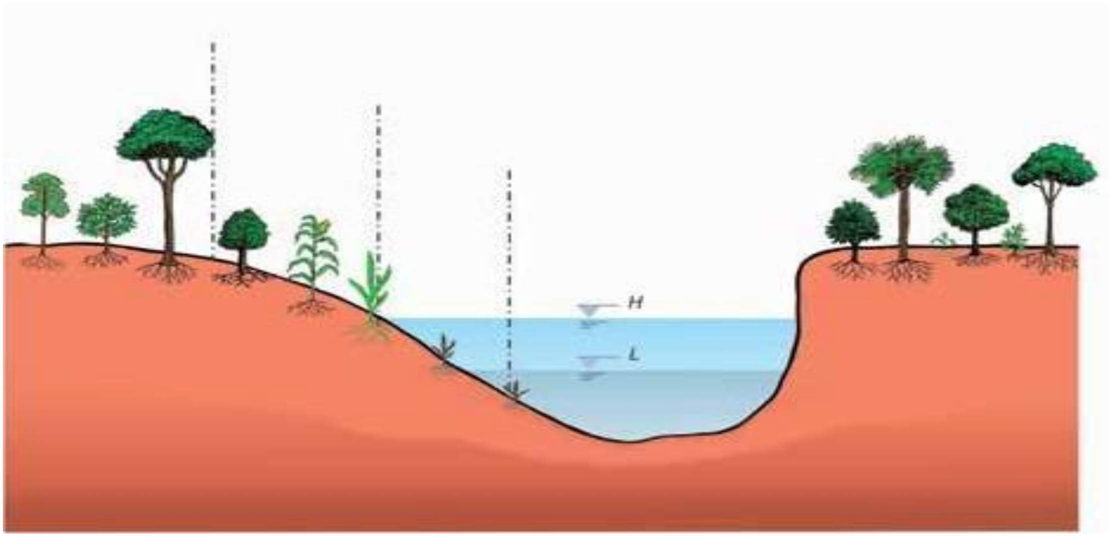


Figure 6.16 Riverbank Protection with Various Layers of Trees, Shrubs, and Grasses
(Source: Godinho *et al.,* 2023)

5. Grass Planting

Grass planting is used to control soil erosion. The fibrous root system can form a dense mass of interconnected lateral roots, which helps stabilize, trap, and reinforce the soil. Grasses with deep, strong, and fibrous root systems are capable of penetrating and binding soil particles, effectively controlling sedimentation. Grass can also be a component of functional systems and promote the formation of terraces, even on steep slopes (Do *et al.,* 2023).

Grass planting can be carried out in three methods:

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

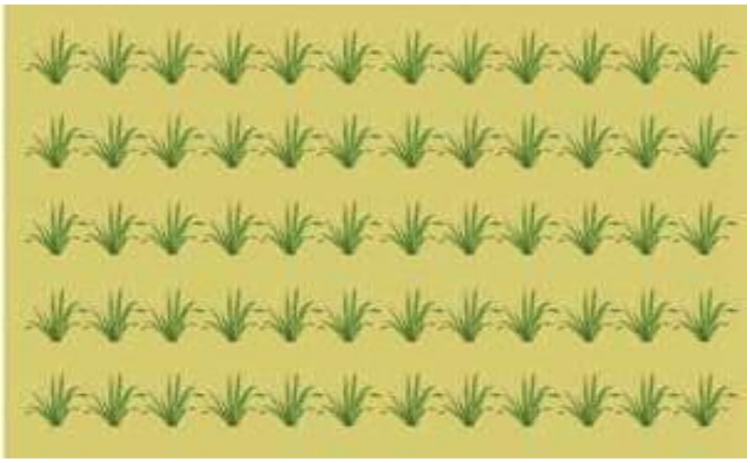


Figure 6.17 Horizontal Grass Planting
(Source: Godinho *et al*., 2023)

b. Vertical and Downward Grass Planting, suitable for slopes <65 degrees in moist locations. 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.**

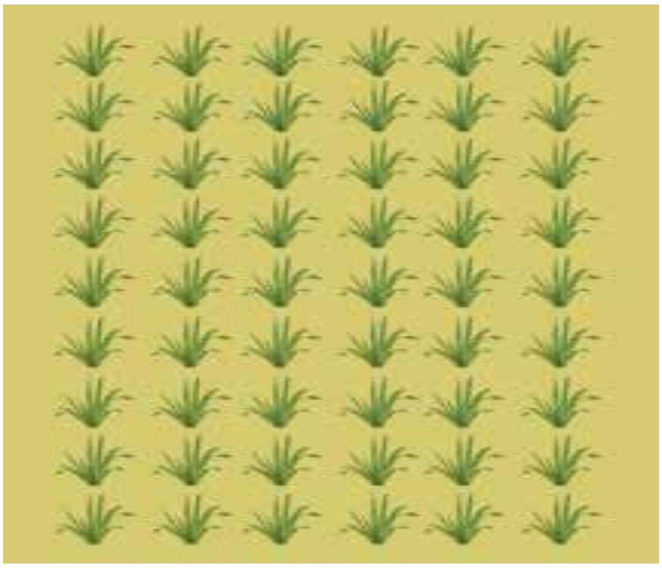


Figure 6.18 Vertical Grass Planting
(Source: Godinho *et al.,* 2023)

c. Diagonal Grass Planting, 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.**

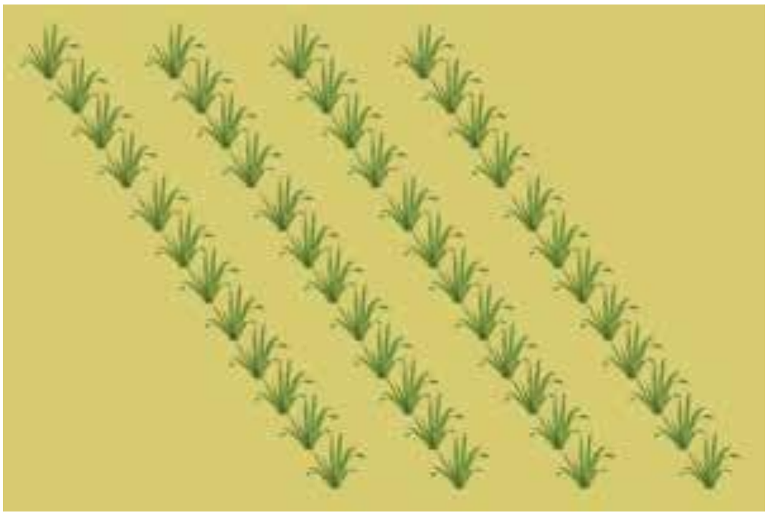


Figure 6.19 Diagonal Grass Planting
(Source: Godinho *et al.,* 2023)

6. Rainwater Reservoirs

A rainwater reservoir is a water collection pond used for irrigation during the dry season, preventing or reducing floods during the rainy season, enhancing water infiltration, improving soil productivity, extending the planting period, and increasing farmers' income. This conservation technique can be applied in areas with high rainfall and high surface runoff on slopes of 8-30%.

The construction of rainwater reservoirs involves excavating soil, clay lining, and constructing a spillway. When excavating, the embankment or edge of the reservoir should be higher than the ground surface to prevent soil from entering the reservoir. A drainage channel should be constructed to prevent overflow of the water in the reservoir. The distance between the drainage channel and the reservoir surface should be between 25-50 cm. Furthermore, the clay lining serves to reinforce the reservoir walls, typically made 25 cm thick. The reservoir wall cover should be constructed with a 70-80 degree slope or in steps to prevent landslides. On sandy soils, the dam wall needs to be lined with plastic, cement, or a mixture of lime and clay (1:1) to prevent rapid water absorption. Finally, the spillway should be constructed facing the area to be irrigated, with a width of 15-25 cm and a depth of 10-15 cm. Additionally, rainwater reservoirs need regular maintenance by cleaning the spillway, reservoir edges, and dam walls, as well as removing sediment buildup. The concept of constructing a rainwater reservoir is shown in Figure 6.20.

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

7. Drainage Channels

Drainage channels are used to direct water to areas where it can infiltrate into the soil or be stored. The construction of drainage channels typically includes small waterfalls to prevent erosion and landslides. Drainage channel construction starts with digging the soil to a depth of at least 50 cm from the cultivation area, with a base width of 50 cm. The base of the channel in bench terraces is made with a slope of 0.1 - 0.5% outward. Grass is planted across the drainage channel every 1 meter, with a height of 20 cm. Small bamboo poles are placed horizontally across the waterfall with a depth of 0.5 m. Bamboo should be placed outside. Maintenance includes cleaning the channel from sediment, trimming weeds, and repairing damaged bamboo constructions. The drainage channel concept is presented in **Figure 6.21.**

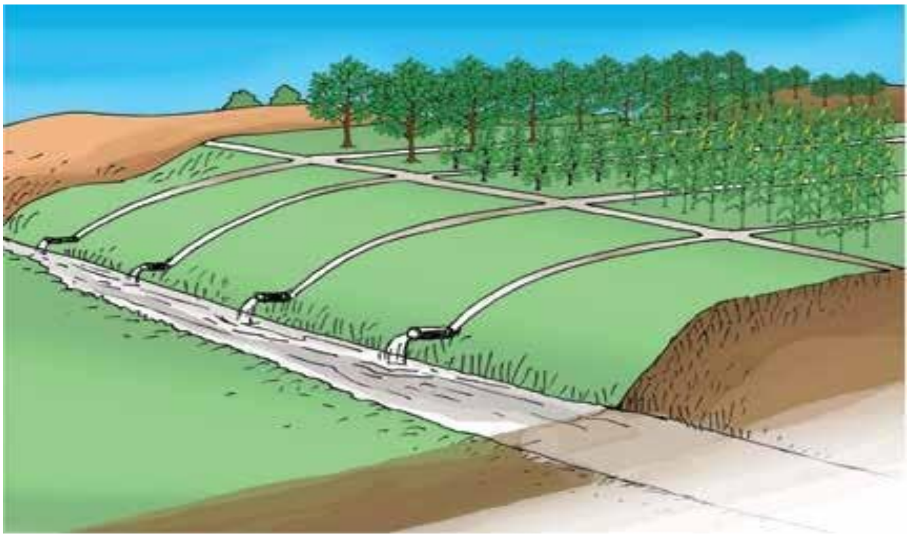


Figure 6.21 Drainage Channel
(Source: Godinho *et al.,* 2023)

8. Wattle Fence / Live Check Dam

A wattle fence is a short vegetative fence or wall built along the contour to capture debris moving down the slope, reinforce, and modify the slope. This conservation technique creates a microhabitat for various plant species.

A wattle fence is constructed by clearing vegetation (wood or branches) to use as posts. The posts, 100 cm long, are spaced 100 cm apart along the fence line. Two 50 cm long posts are placed between the main posts, protruding 20-30 cm from the soil surface. A trench (at least 15 cm deep) is made along the contour between the installed posts. The lower ends of plant cuttings are placed in the trench, and the cuttings are woven between the posts and the soil is compacted back into the trench. The wattle fence concept is presented in **Figure 6.22.**

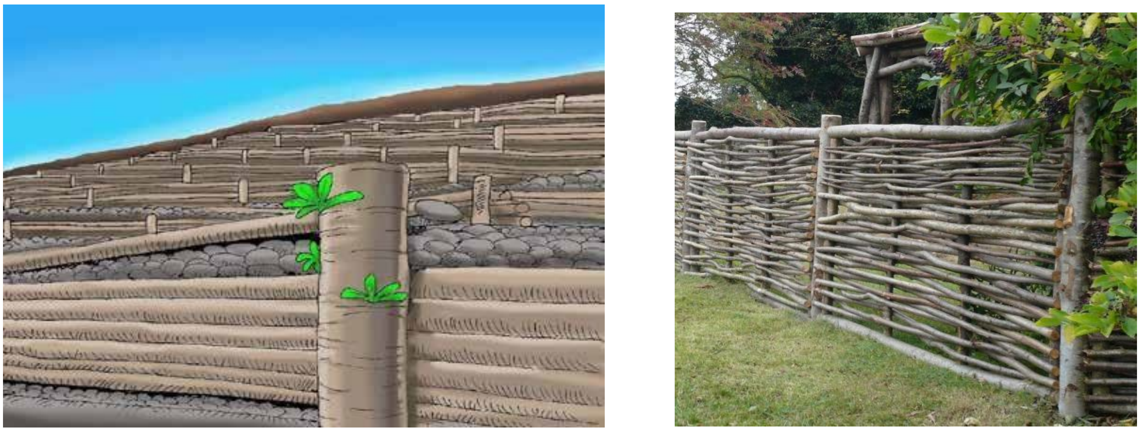


Figure 6.22 Wattle Fence

9. Vegetative Actions

Vegetative actions aim to achieve better soil and water conservation efficiency through the alternating planting of fruit trees, spices, and food crops. Conservation practices should minimize soil disturbance (minimum tillage), improve ground cover, and use crop rotation to increase the sustainability of agriculture (Huang *et al*., 2022).

a. **Conservation Forests,** in soil and water conservation, they help reduce surface runoff erosion and maintain or restore soil fertility. Tree species and stand structure are key factors determining conservation effectiveness. Native tree species and layered vegetation (e.g., trees + shrubs + spices) are prioritized for greening efforts.
b. **Hedge Planting**, the use of hedgerows is also effective in controlling slope soil erosion, holding runoff, and improving soil fertility. Hedgerow plants 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 in areas prone to erosion, mountains, near rivers, and reservoirs
    2) Half cover, applied only during certain seasons
    3) Rotating cover, conducted in areas with light erosion, divided into sub-zones for rotation
    4) Cover combined with planting, for areas with moderate erosion and very low vegetation cover

Additionally, increasing vegetation cover can use mulch, consisting of leaves, compost, and manure to cover the soil surface. Mulching prevents soil moisture loss due to evaporation, prevents soil erosion, and controls weeds. Materials used 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 yield higher results than those produced continuously. Rotation benefits also depend on seasonal weather conditions and long-term practices. Long-term crop diversification improves agroecosystem productivity compared to monoculture systems and leads to reduced input use. The combination of legume and brassica crops tends to benefit the soil due to the combination of taproot and fibrous roots, which make 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 water with a specific small volume capacity, smaller than a reservoir or dam. Water reservoirs are usually built by damming small rivers or can be built outside rivers. The water reservoir stores water during the rainy season and provides it during the dry season to meet the needs of the local population, livestock, and gardens or fields, following a priority sequence. The water reservoir's body height and storage capacity are determined by the amount of need. The concept of water reservoir construction is presented in **Figure 6.23.**

Figure 6.23 Implementation of Water Reservoirs

VII. AGRICULTURAL LAND SUITABILITY EVALUATION

Land suitability refers to how appropriate an area of land is for a specific use. For example, land can be rated as highly suitable for rice fields, moderately suitable for coffee, or marginally suitable for oranges. Land suitability can be evaluated based on two conditions: current conditions and conditions after improvements.

7.1 AGRICULTURAL LAND SUITABILITY

Land suitability evaluation based on current conditions uses field survey data. This assessment reflects the capacity of the land as it exists without additional interventions. The actual land suitability or current suitability (current suitability) refers to land in its natural state, not considering potential improvements or management practices that could address constraints or limiting factors at each land unit or map unit. To determine the actual land suitability class, the evaluation is first based on the land's worst characteristic/most limiting factor, and then the suitability class is determined based on this worst quality.

Potential land suitability refers to the suitability of land after improvements. For example, land that is marginally suitable (S3) due to nutrient deficiencies could change to moderately suitable (S2) or even highly suitable (S1) after fertilization. The potential land suitability evaluation is carried out after making improvements to the limiting factors that affect soil quality, with the aim of increasing its suitability. With technology, land that naturally has a low suitability class (actual suitability) can be improved to a higher suitability class (potential suitability). However, not all land characteristics can be improved with current technology, and some may require high levels of management to be addressed. In land-use planning, the primary focus is on potential land suitability, as this evaluation provides an overview of the maximum potential of land for various uses after improvements are made. Therefore, potential land suitability helps in planning for effective and sustainable land use, as well as determining the necessary improvement actions to achieve optimal outcomes.

7.2 LAND SUITABILITY CLASSIFICATION STRUCTURE

The land suitability classification system, as outlined in the Framework of Land Evaluation (FAO, 1976), is widely used in Indonesia and other developing countries. The system classifies land into four categories: order, class, subclass, and unit (Hardjowigeno, 2015). The system is systematically presented **Table in 7.1**.

Table 7.1 Land Suitability Classification System (FAO, 1976)

Order	:	indicates whether the land is suitable or not suitable for a specific use.
Class	:	indicates the degree of land suitability
Subclass	:	indicates the type of limitations or improvements required within each class
Unit	:	indicates variations in the severity of limiting factors affecting the management of the subclass.

Order and class are typically used in land surveys, while subclasses are used in semi-detailed land mapping and units in detailed land mapping. Order is also used in coarse-scale land mapping (exploratory):

Suitability Order

The suitability order describes the general suitability of land, meaning whether the land is suitable or not suitable for a particular planned land use. At the order level, land is divided into suitable (S) and unsuitable (N) land.

Suitable Order (S)

Land in this order can be used over a long period for a considered land use purpose. The benefits derived from the management of such land will be satisfactory when calculated against the inputs applied, with no or only a minimal risk of damage to land resources.

Order Not Suitable (N)

Land in this order has various limitations, either physical (e.g., very steep slopes, rocky terrain, etc.), or economic (e.g., input costs are not balanced by output, preventing its use for the planned purpose).

Suitability Class

The suitability class indicates the level of suitability within the order. In the suitable order (S), land is divided into very suitable (S1), moderately suitable (S2), and marginally suitable (S3). Land in the not suitable order (N) is not further categorized.

Highly Suitable Class (S1)

Land that has no significant or evident limiting factors for sustainable land use or only minor limiting factors that do not substantially reduce land productivity.

Moderately Suitable Class (S2)

Land that has moderate limitations requiring increased management input. These limitations reduce productivity or profit and increase the required inputs.

Marginally Suitable Class (S3)

Land with severe limitations requiring intensive management efforts. These limitations significantly reduce productivity and profits and require considerable additional inputs to achieve expected output.

Not Suitable Class (N1)

Land with severe limitations that are difficult to overcome, preventing its sustainable use over the long term.

Class N2: permanently not suitable. Land with permanent limitations that prevent any sustainable use over the long term.

7.3 LAND SUITABILITY ASSESSMENT RESULTS

Land suitability analysis is a critical step in designing strategies for sustainable land resource management. This evaluation process uses an integrated approach, including geospatial data utilization, field observations, and laboratory physical and chemical soil analysis. This approach enables the identification of both the potential and limitations of land resources for the development of various agricultural commodities, livestock feed, and grazing areas.

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

The data collected is then analyzed based on the growth requirements of each plant species for both actual and potential suitability, considering various land improvement efforts, such as fertilization, adding organic matter, or implementing soil conservation techniques. This process provides comprehensive information to determine commodity development priorities, identify limiting factors, and design relevant technical solutions.

The placement of different plants in the same column in **Table 7.2** shows that these plants share similar growth requirements and limiting factors. This means that the commodities need similar environmental conditions for optimal growth and face similar challenges in cultivation. On the other hand, plants placed in different columns have different growth requirements and limiting factors, requiring a management approach tailored to their specific needs.

This scientific approach forms the basis of land suitability evaluation in Manatuto District. The results of this analysis provide strategic guidance for maximizing land productivity while maintaining the sustainability of natural resources in each region.

A. Land Suitability Evaluation of Barique/Natarbora Sub-District

Barique/Natarbora Sub-District has very suitable potential for irrigated rice cultivation and moderately suitable potential for various agricultural commodities, such as food crops (upland rice, peanut, sorghum, corn, cassava, soybean, wheat, etc.), horticultural vegetables (shallot, chili, bell pepper, caisim, broccoli, vegetable tomato, etc.), horticultural fruits (rambutan, mango, watermelon, melon, avocado, durian, strawberry, grape, etc.), horticultural flowers (rose, aster, sunflower), spices and medicinal plants (vetiver root, lemongrass, vanilla), and industrial crops (rubber, robusta coffee, tea, kapok). livestock forage plants, such as elephant grass, setaria, legumes, and grazing areas, can also be developed in this region.

However, the development of agricultural commodities in Barique/Natarbora faces several biophysical and chemical soil limitations. These include temperature, rainfall, the length of the dry season, steep slopes, erosion levels, rock outcrops, surface rocks, shallow effective soil depth, drainage systems, flood risks, and chemical parameters such as texture, cation exchange capacity (CEC), base saturation (BS), and the levels of macronutrients such as nitrogen (N), phosphorus (P), and potassium (K).

Several of these limiting factors can still be addressed through various technical interventions, such as optimizing the irrigation system, planting slope-strengthening vegetation, building terraces, land clearing, digging planting holes, developing water recharge zones, adding organic matter, and applying appropriate fertilization. However, temperature remains a permanent limiting factor that cannot be improved. Therefore, adaptation strategies and the selection of commodities that are suited to the specific environmental conditions of this region are needed.

Commodities such as **wheat, potato, carrot, garlic, snow pea, and arabica coffee** are generally not recommended for development due to permanent temperature limitations. Besides the mentioned commodities, **Table 7.5** presents alternative crops deemed suitable for agricultural development in Barique/Natarbora Sub-District.

B. Land Suitability Evaluation of Laclo Sub-District

Laclo Sub-District has very suitable potential for irrigated rice cultivation and moderately suitable potential for various agricultural commodities, such as food crops (upland rice, sorghum, corn, soybean, green bean, cowpea, taro, etc.), horticultural vegetables (shallot, chili, bell pepper, caisim, bean, cucumber, cabbage, etc.), horticultural fruits (guava, jackfruit, watermelon, melon, avocado, durian, custard apple, pineapple, etc.), holticultura flowers (rose, aster, sunflower), spices and medicinal plants (ginger, candlenut, pepper, nutmeg, etc.), and industrial crops (tobacco, quinine, cotton, oil palm). Livestock forage plants such as elephant grass, setaria, legumes, and grazing areas can also be developed in this region.

Laclo has promising biophysical potential for agricultural commodity development, but its use is still limited by several factors. These include climatic characteristics (temperature, rainfall intensity, and dry season duration), land morphology (steep slopes, erosion levels, rock outcrops, and surface rocks), and soil characteristics (shallow effective soil depth, suboptimal drainage system, and flood risk potential). Additionally, soil chemical constraints such as texture, cation exchange capacity (CEC), base saturation (BS), and the levels of macronutrients nitrogen (N), phosphorus (P), and potassium (K) also affect land suitability for various agricultural commodities.

Most of these limiting factors can be addressed through technical interventions and land conservation management approaches, including: optimizing the irrigation system, planting slope-strengthening vegetation, constructing terraces, land clearing, digging planting holes, building water recharge zones, adding organic matter, and applying fertilization based on specific nutrient needs. However, temperature remains a permanent factor that cannot be technically improved. Therefore, adaptation strategies involving the selection of agricultural commodities compatible with local environmental conditions are needed.

Commodities such as **wheat, potatoes, carrots, garlic, snow pea, and arabica coffee** are not generally recommended for development due to temperature limitations. In addition to these commodities, **Table 7.5** presents alternative crops suitable for agricultural development in Laclo Sub-District.

C. Land Suitability Evaluation of Laclubar Sub-District

Laclubar Sub-District has moderately suitable potential for the development of various agricultural commodities, including food crops (rainfed rice, upland rice, sorghum, corn, sweet potato, mung bean, cowpea, taro, etc.), horticultural vegetables (shallot, chili, bell pepper, caisim, green bean, cucumber, cabbage, etc.), horticultural fruits (orange, breadfruit, snakefruit , pineapple, etc.), holticultural flowers (rose, aster, sunflower), spices and medicinal plants (cinnamon, jatropha, aromatic ginger etc.), and industrial crops (robusta coffee, *melinjo*, cashew, etc.). Livestock forage plants such as elephant grass, setaria, legumes, and grazing areas can also be developed in this region.

However, the development of agricultural commodities in this area faces several limiting factors, both biophysical and chemical. Biophysical constraints include low temperature, rainfall distribution and intensity, the length of the dry season, steep slopes, high erosion levels, the presence of rock outcrops and surface stones, limited effective soil depth, suboptimal drainage systems, and flood risks. From the chemical perspective, limiting factors include soil texture, cation exchange capacity (CEC), base saturation (BS), and low levels of essential nutrients such as nitrogen (N), phosphorus (P), and potassium (K).

Most of these limitations can still be addressed through appropriate technical interventions, such as improving irrigation efficiency, reinforcing slopes with vegetation and constructing terraces, land clearing and treatment, selective planting hole excavation, development of water recharge zones, adding organic matter, and applying appropriate fertilization. However, temperature remains a permanent limiting factor that cannot be technically modified. Therefore, ecological adaptation strategies are essential, particularly through the selection of agricultural commodities that are ecologically compatible with the specific agro-climatic conditions of the region.

Commodities such as **wheat, potatoes, carrots, garlic, snow pea, and arabica coffee** are generally not recommended for development due to permanent temperature limitations. In addition to these commodities, **Table 7.5** presents alternative crops that are deemed suitable for agricultural development in Laclubar Sub-District.

D. Land Suitability Evaluation of Laleia Sub-District

Laleia Sub-District has very suitable potential for irrigated rice cultivation and moderately suitable potential for various agricultural commodities, such as food crops (upland rice, peanut, sorghum, corn, cassava, mung bean, cowpea, etc.), horticultural vegetables (caisim, cucumber, green bean, broccoli, etc.), horticultural fruits (rambutan, melon, papaya, longan, custard apple, strawberry, grape, etc.), spices and medicinal plants (turmeric, aromatic ginger, galangal), industrial crops (clove, tobacco, coconut, etc.). Livestock forage plants such as elephant grass, setaria, legumes, and grazing areas can also be developed in this region.

Although Laleia has biophysical potential that supports agricultural development, the utilization of this resource is still constrained by various limiting factors, both biophysical and chemical. Biophysical constraints include less than ideal temperature, rainfall intensity, the length of the dry season, steep slopes, high erosion levels, the presence of rock outcrops and surface stones, shallow effective soil depth, suboptimal drainage systems, and seasonal flood risks. Additionally, chemical soil constraints contribute to reduced productivity, with factors such as soil texture that does not support root systems, low cation exchange capacity (CEC), limited base saturation (BS), and deficiencies in essential nutrients such as nitrogen (N), phosphorus (P), and potassium (K).

Most of these constraints can be mitigated through technical interventions and land engineering approaches, including optimizing irrigation systems, planting erosion-controlling vegetation, constructing terraces, intensive land treatment and cleaning, efficient planting hole excavation, development of water recharge zones, increasing organic matter content, and applying fertilization based on specific soil needs. However, temperature is a permanent limiting factor that cannot be technically modified. Therefore, ecological adaptation strategies are essential, including the selection of agricultural commodities that are adaptive to the specific environmental conditions of Laleia Sub-District.

Commodities such as **wheat, potatoes, carrots, garlic, mung bean, and arabica coffee** are not generally recommended for development due to temperature limitations. In addition to these commodities, **Table 7.5** presents alternative crops suitable for agricultural development in Laleia Sub-District.

E. Land Suitability Evaluation of Manatuto Sub-District

Manatuto Sub-District has very suitable potential for irrigated rice cultivation and moderately suitable potential for various agricultural commodities, such as food crops (rainfed rice, upland rice, peanut, sorghum, corn, cassava, mung bean, cowpea, etc.), horticultural vegetables (bell pepper, eggplant, bitter melon, vegetable tomato, etc.), horticultural fruits (passion fruit, watermelon, melon, banana, strawberry, grape, etc.), horticultural flowers (rose, aster, sunflower), spices and medicinal plants (galangal, cardamom, sesame, etc.), and industrial crops (rubber, cotton, kapok, etc.). Livestock forage plants such as elephant grass, setaria, legumes, and grazing areas can also be developed in this region.

Manatuto Sub-District has significant biophysical potential to support agricultural development. However, this potential is still limited by various factors derived from both biophysical and chemical soil characteristics. Major biophysical constraints include suboptimal temperature, uneven rainfall distribution, long dry periods, steep slopes, high erosion levels, the presence of rock outcrops and surface stones, shallow effective soil depth, inadequate drainage systems, and seasonal flood risks. From the chemical aspect, several parameters restrict the land's production capacity, including soil texture that is not conducive to root development, low cation exchange capacity (CEC), limited base saturation (BS), and deficiencies in essential nutrients such as nitrogen (N), phosphorus (P), and potassium (K).

Most of these limiting factors can be mitigated through integrated technical and land conservation approaches. Strategic actions may include optimizing irrigation systems, rehabilitating land through the planting of erosion-controlling vegetation, building terraces, intensive land treatment, creating structured planting holes, developing water recharge zones, increasing organic matter content, and applying fertilization based on specific soil needs. However, temperature remains a permanent limiting factor that cannot be technically altered. Therefore, adaptation strategies involving the selection of agricultural commodities tolerant to the specific agro-climatic conditions of Manatuto Sub-

District are essential to optimize productivity and the sustainability of agricultural systems in the region.

Commodities such as **wheat, potatoes, carrots, garlic, mung bean, and arabica coffee** are generally not recommended for development due to Temperature limitations. In addition to these commodities, **Table 7.5** presents alternative crops suitable for agricultural development in Manatuto Sub-District.

F. Land Suitability Evaluation of Soibada Sub-District

Soibada Sub-District has very suitable potential for irrigated rice cultivation and moderately suitable potential for various agricultural commodities, such as food crops (upland rice, peanut, sorghum, corn, cassava, mung bean, cowpea, etc.), horticultural vegetables (shallot, chili, caisim, etc.), horticultural fruits (jackfruit, breadfruit, durian, strawberry, grape, etc.), holticultural flowers (rose, aster, sunflower), spices and medicinal plants (pepper, candlenut, cinnamon, etc.), and industrial crops (robusta coffee, tea, tobacco, etc.). Livestock forage plants such as elephant grass, setaria, legumes, and grazing areas can also be developed in this region.

Soibada Sub-District has biophysical characteristics that support agricultural sector development; however, land use in the region is still constrained by various limiting factors. Biophysical constraints include suboptimal temperature, inconsistent rainfall distribution, long dry periods, steep slopes, high erosion levels, rock outcrops, and surface stones, limited effective soil depth, inadequate drainage systems, and seasonal flood risks. From the chemical aspect, factors such as soil texture unsuitable for root systems, low cation exchange capacity (CEC), limited base saturation (BS), and low levels of essential macro-nutrients such as nitrogen (N), phosphorus (P), and potassium (K) further limit productivity.

Most of these constraints can be addressed through integrated conservation approaches and technical interventions, such as optimizing irrigation, planting vegetation to control erosion, constructing terraces, intensive land treatment, creating structured planting holes, developing water recharge zones, and applying fertilization tailored to specific soil needs. However, Temperature remains a permanent limiting factor that cannot be modified technically. Therefore, ecological adaptation strategies, including selecting agricultural commodities tolerant to local agro-climatic conditions, are crucial to ensure the sustainability and efficiency of agricultural production systems in Soibada.

Commodities such as **wheat, potato, carrot, garlic, mung bean, and arabica coffee** are not recommended for development due to permanent temperature constraints. In addition to these commodities, **Table 7.5** presents alternative crops suitable for agricultural development in Soibada Sub-District.

Table 7.2 Land Suitability Evaluation Analysis Matrix in Manatuto District

Commodities	Sub-District	Limiting Factors	Potential Land Suitability / Land Improvement Efforts
FOOD COMMODITIES			
Irrigated Rice	• Barique/Natarbora • Laclo • Laleia • Manatuto • Soibada	N : Flood	S1
Rainfed rice	• Laclubar • Laleia • Manatuto	N : Slope, Flood	S2 : Slope, Flood
Dryland Food Commodities			
Upland Rice	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	S3 : Drainage, Erosion, Rock Outcrops S2 : Slope, Surface rocks	S3 : Rock Outcrops S2 : Surface rocks
Peanut	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	N : Flood S3 : Rock Outcrops S2 : Slope, Surface rocks	S3 : Rock Outcrops S2 : Surface rocks, Flood
Sorghum	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	N : Rainfall, Flood S3 : Rock Outcrops S2 : Slope, Surface rocks	S3 : Rock Outcrops S2 : Rainfall, Surface rocks, Flood
Corn	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	N : Erosion, Slope, Flood S3 : Rainfall, Drainage, Rock Outcrops S2 : Surface rocks	S3 : Rock Outcrops S2 : Slope, Erosion, Surface rocks, Flood
Cassava	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto	N : Flood S3 : Drainage, Erosion, Rock Outcrops	S3 : Rock Outcrops S2 : Effective Depth, Surface rocks, Flood

	• Soibada	S2 : Rainfall, Effective Depth, Slope, Surface rocks	
Soybean Green Bean Cowpeas	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	N : Flood S3 : Rainfall, Rock Outcrops S2 : Temperature, Drainage, Slope, Surface rocks	S3 : Rock Outcrops S2 : Temperature, Surface rocks, Flood
Taro	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	N : Flood S3 : Temperature, Rainfall, Rock Outcrops S2 : Drainage, Slope, Surface rocks	S3 : Temperature, Rock Outcrops S2 : Surface rocks, Flood
Wheat	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	N : Temperature, Flood S3 : Rock Outcrops S2 : Rainfall, Drainage, Slope, Surface rocks	N : Temperature S3 : Rock Outcrops S2 : Surface rocks, Flood
Sweet potato	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	N : Dry Month, Flood S3 : Rock Outcrops S2 : Effective Depth, Slope, Surface rocks	S3 : Dry Month, Rock Outcrops S2 : Effective Depth, Surface rocks, Flood
VEGETABLE HORTICULTURAL COMMODITIES			
Potato Carrot	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	N : Temperature, Flood S3 : Rainfall, Drainage, Slope, Rock Outcrops S2 : Erosion, Surface rocks, Texture, N-total, P-Available , K-Available, CEC, BS	N : Temperature S2 : Slope, Rock Outcrops, Surface rocks, Texture
Garlic	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	N : Temperature, Flood S3 : Rainfall, Drainage, Slope, Rock Outcrops	N : Temperature S2 : Slope, Rock Outcrops, Surface rocks

		S2 : Erosion, Surface rocks, N-total, P-Available, K-Available, CEC, BS	
Shallot	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	**N :** Flood **S3 :** Drainage, Rock Outcrops **S2 :** Temperature, Rainfall, Slope, Erosion, Surface rocks, Texture, N-total, P-Available, K-Available, CEC, BS	**S2 :** Rock Outcrops, Temperature, Slope, Surface rocks, Texture
Chili	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	**N :** Rainfall, Flood **S3 :** Drainage, Rock Outcrops **S2 :** Slope, Erosion, Surface rocks, N-total, P-Available, K-Available, CEC, BS	**S2 :** Rock Outcrops, Slope, Surface rocks, Rainfall
Bell Pepper	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	**N :** Flood **S3 :** Rainfall, Drainage, Rock Outcrops **S2 :** Temperature, Erosion, Surface rocks, N-total, P-Available, K-Available, CEC, BS	**S2 :** Rock Outcrops, Temperature, Surface rocks
Caisim	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	**N :** Flood **S3 :** Rainfall, Drainage, Dry Month, Rock Outcrops **S2 :** Temperature, Slope, Erosion, Surface rocks, Texture, N-total, P-Available, K-Available, CEC, BS	**S2 :** Dry Month, Rock Outcrops, Temperature, Slope, Surface rocks, Texture
Mung Bean Broccoli	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	**N :** Flood **S3 :** Rainfall, Drainage, Rock Outcrops	**S2 :** Rock Outcrops, Temperature, Slope, Surface rocks

		S2 : Temperature, Slope, Erosion, Surface rocks, N-total, P-Available, K-Available, CEC, BS	
Snow Pea	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	**N :** Temperature, Flood **S3 :** Drainage, Slope, Rock Outcrops **S2 :** Rainfall, Erosion, Surface rocks, N-total, P-Available, K-Available, CEC, BS	**N :** Temperature **S2 :** Slope, Rock Outcrops, Surface rocks
Cucumber	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	**S3 :** Rainfall, Drainage, Slope, Rock Outcrops, Flood **S2 :** Erosion, Surface rocks, N-total, P-Available, K-Available, CEC, BS	**S2 :** Slope, Rock Outcrops, Surface rocks
Cabbage	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	**N :** Flood **S3 :** Rainfall, Drainage, Slope, Rock Outcrops **S2 :** Temperature, Erosion, Surface rocks, Texture, N-total, P-Available, K-Available, CEC, BS	**S2 :** Slope, Rock Outcrops, Temperature, Surface rocks, Texture
Eggplant **Bitter Melon** **Tomato Vegetable** **Long Bean**	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	**N :** Flood **S3 :** Rainfall, Drainage, Slope, Rock Outcrops **S2 :** Temperature, Erosion, Surface rocks, N, P, K, CEC, BS	**S2 :** Slope, Rock Outcrops, Temperature, Surface rocks
FRUIT HORTICULTURAL COMMODITIES			
Rambutan **Mango**	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	**S3 :** Rainfall, Rock Outcrops, N-total, P-Available **S2 :** Erosion, Effective Depth, Slope, Surface rocks, K-Available	**S2** : Rock Outcrops, Surface rocks, Effective Depth
Guava **Jackfruit**	• Barique/Natarbora • Laclo • Laclubar	**S3 :** Rock Outcrops, N-total, P-Available	**S2** : Rock Outcrops, Surface rocks, Effective Depth

	• Laleia • Manatuto • Soibada	**S2 :** Rainfall, Erosion, Effective Depth, Slope, Surface rocks, K-Available	
Watermelon Melon	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	**N :** Slope, Flood **S3 :** Rainfall, Rock Outcrops, N-total, P-Available **S2 :** Drainage, Erosion, Surface rocks, K-Available	**S2** : Slope, Flood, Rock Outcrops, Surface rocks
Banana	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	**N :** Dry Month **S3 :** Rock Outcrops, N-total, P-Available **S2 :** Drainage, Erosion, Slope, Surface rocks, Texture, K-Available	**S3** : Dry Month **S2** : Rock Outcrops, Surface rocks, Texture
Papaya	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	**S3 :** Rainfall, Rock Outcrops, N-total, P-Available **S2 :** Erosion, Slope, Surface rocks, K-Available	**S2** : Rock Outcrops, Surface rocks
Orange	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	**S3 :** Rock Outcrops, N-total, P-Available **S2 :** Erosion, Effective Depth, Slope, Surface rocks, K-Available	**S2** : Rock Outcrops, Surface rocks, Effective Depth
Avocado	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	**N :** Dry Month **S3 :** Rock Outcrops, N-total, P-Available **S2 :** Rainfall, Erosion, Effective Depth, Slope, Surface rocks, K-Available	**S3** : Dry Month **S2** : Rock Outcrops, Surface rocks, Effective Depth
Soursop	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	**S3 :** Rock Outcrops, N-total, P-Available **S2 :** Temperature, Erosion, Effective Depth, Slope, Surface rocks, pH, K-Available	**S2**: Temperature, Rock Outcrops, Surface rocks, Effective Depth

Breadfruit	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	**S3:** Rock Outcrops, N-total, P-Available **S2:** Erosion, Effective Depth, Slope, Surface rocks, pH, K-Available	**S2** : Rock Outcrops, Surface rocks, Effective Depth
Snakefruit	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	**S3 :** Rock Outcrops, N-total, P-Available **S2 :** Rainfall, Erosion, Slope, Surface rocks, K-Available	**S2** : Rock Outcrops, Surface rocks
Longan	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	**S3 :** Rock Outcrops, N-total, P-Available **S2 :** Temperature, Rainfall, Erosion, Slope, Effective Depth, Surface rocks, K-Available	**S2** : Temperature, Rock Outcrops, Surface rocks, Effective Depth
Durian	• Barique/Natarbora • Laclo • Laclubar • Manatuto • Soibada	**N :** Flood **S3 :** Temperature, Rainfall, Slope, Rock Outcrops, N-total, P-Available **S2 :** Effective Depth, Surface rocks, K-Available	**S2** : Flood, Temperature, Rock Outcrops, Surface rocks, Effective Depth
Custard Apple	• Barique/Natarbora • Laclo • Laclubar • Manatuto • Soibada	**N :** Flood **S3 :** Rock Outcrops, N-total, P-Available **S2 :** Temperature, Rainfall, Effective Depth, Surface rocks, K-Available	**S2** : Flood, Temperature, Rock Outcrops, Surface rocks, Effective Depth
Pineapple	• Barique/Natarbora • Laclo • Laclubar • Manatuto • Soibada	**N :** Flood **S3 :** Rainfall, Rock Outcrops, N-total, P-Available **S2 :** Surface rocks, pH, K-Available	**S2** : Flood, Rock Outcrops, Surface rocks
Strawberry	• Barique/Natarbora • Laclo • Laclubar	**N :** Slope, Flood	**S2** : Flood, Temperature, Slope, Rock

	• Manatuto • Soibada	**S3 :** Rock Outcrops, N-total, P-Available **S2 :** Temperature, Erosion, Surface rocks, K-Available	Outcrops, Surface rocks
Grape	• Barique/Natarbora • Laclo • Laclubar • Manatuto • Soibada	**N :** Flood **S3 :** Rock Outcrops, N-total, P-Available **S2 :** Rainfall, Effective Depth, Surface rocks, K-Available	**S2** : Rock Outcrops, Surface rocks, Effective Depth
Passion Fruit	• Barique/Natarbora • Laclo • Laclubar • Manatuto • Soibada	**N :** Flood **S3 :** Rainfall, Slope, Rock Outcrops, N-total, P-Available **S2 :** Temperature, Effective Depth, Surface rocks, K-Available	**S2** : Flood, Temperature, Rock Outcrops, Surface rocks, Effective Depth
FLOWER HORTICULTURAL COMMODITIES			
Rose Aster	• Barique/Natarbora • Laclo • Laclubar • Manatuto • Soibada	**N:** Slope **S3 :** Drainage, Rock Outcrops **S2 :** Temperature, Erosion, Surface rocks, N-total P tersedia, K tersedia	**S2:** Slope, Rock Outcrops, Surface rocks, Temperature
Sunflower	• Barique/Natarbora • Laclo • Laclubar • Manatuto • Soibada	**N:** Slope **S3:** Drainage, Rock Outcrops, Rainfall **S2:** Erosion, Surface Rocks, K-Available	**S2:** Slope, Rock Outcrops, Surface Rocks
SPICE AND MEDICINAL COMMODITIES			
Ginger	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	**N :** Rainfall, Dry Month, Slope, Rock Outcrops, Flood **S3 :** Temperature, Erosion, Effective Depth, Surface rocks	**S3 :** Dry Month, Slope, Rock Outcrops, Temperature **S2 :** Rainfall, Effective Depth, Surface rocks, Flood

		S2 : Drainage	
Vetiver Root	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	**N :** Rainfall, Erosion, Slope, Flood **S3 :** Drainage, Effective Depth, Surface rocks, Rock Outcrops **S2 :** Temperature	**S2 :** Rainfall, Erosion, Slope, Effective Depth, Surface rocks, Rock Outcrops, Flood, Temperature
Lemongrass	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	**N :** Rainfall, Erosion, Slope, Flood **S3 :** Drainage, Surface rocks, Rock Outcrops **S2 :** Temperature, N-Total, P-Available , K-Available	**S2 :** Rainfall, Erosion, Slope, Flood, Temperature, Surface rocks, Rock Outcrops
Vanilla	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	**N :** Dry Month, Erosion, Slope, Flood **S3 :** Drainage, Surface rocks, Rock Outcrops **S2 :** Temperature, Rainfall, Effective Depth	**S3 :** Dry Month **S2 :** Erosion, Slope, Surface rocks, Rock Outcrops, Flood, Temperature
Candlenut	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	**N :** Dry Month **S3 :** Drainage, Rock Outcrops **S2 :** Effective Depth, Surface rocks	**S3 :** Dry Month **S2** : Rock Outcrops, Effective Depth, Surface rocks
Cinnamon	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	**N :** Dry Month **S3 :** Drainage, Slope, Rock Outcrops **S2 :** Temperature, Rainfall, Erosion, Effective Depth, Surface rocks	**S3 :** Dry Month **S2** : Temperature, Effective Depth, Surface rocks, Rock Outcrops
Nutmeg	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	**N :** Rainfall, Dry Month **S3 :** Drainage, Slope, Rock Outcrops **S2 :** Erosion, Effective Depth	**S3 :** Dry Month **S2 :** Rainfall, Effective Depth, Rock Outcrops

Pepper	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	**N :** Drainage, Dry Month **S3 :** Rock Outcrops **S2 :** Rainfall, Erosion, Slope, Surface rocks	**S3 :** Dry Month **S2 :** Drainage, Rock Outcrops, Surface rocks
Jatropha	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	**S3 :** Drainage, Rainfall, Rock Outcrops **S2 :** Erosion, Slope, Surface rocks	**S2 :** Rock Outcrops, Surface rocks
Aromatic Ginger	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	**N :** Rainfall, Slope, Flood **S2 :** Temperature, Drainage, Effective Depth, Surface rocks, Rock Outcrops, N-Total, P-Available, K-Available	**S2** : Temperature, Rainfall, Slope, Effective Depth, Surface rocks, Rock Outcrops, Flood
Turmeric	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	**N :** Slope, Flood **S3 :** Rock Outcrops **S2 :** Temperature, Drainage, Erosion, Effective Depth, Surface rocks	**S2 :** Temperature, Slope, Effective Depth, Surface rocks, Rock Outcrops, Flood
Galangal	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	**N :** Slope, Flood **S3 :** Effective Depth, Rock Outcrops **S2 :** Temperature, Drainage, Erosion, Surface rocks	**S2 :** Temperature, Slope, Effective Depth, Surface rocks Rock Outcrops, Flood
Cardamom	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto • Soibada	**N :** Rainfall, Slope, Flood **S3 :** Drainage, Effective Depth, Rock Outcrops **S2 :** Erosion, Surface rocks	**S2 :** Rainfall, Slope, Effective Depth, Surface rocks, Rock Outcrops, Flood
Sesame	• Barique/Natarbora • Laclo • Laclubar • Laleia • Manatuto	**N :** Rainfall, Dry Month, Slope, Flood **S3 :** Effective Depth, Rock Outcrops	**S3** : Dry Month **S2 :** Rainfall, Dry Month, Slope, Effective Depth,

	• Soibada	**S2 :** Drainage, Erosion, Surface rocks	Surface rocks, Rock Outcrops, Flood
	INDUSTRIAL COMMODITIES		
Rubber	• Barique/Natarbora • Laleia • Soibada • Laclo • Laclubar • Manatuto	**N :** Dry Month **S3 :** Slope, Rock Outcrops, N-total, P-Available, K-Available **S2 :** Temperature, Drainage, Rainfall, Effective Depth, Surface rocks	S3 : Dry Month S2 : Temperature, Rock Outcrops, Surface rocks, Effective Depth
Coconut	• Barique/Natarbora • Laleia • Soibada • Laclo • Laclubar • Manatuto	**S3 :** Dry Month, Slope, Rock Outcrops, N-total, P-Available, K-Available **S2 :** Rainfall, Surface rocks	S2 : Dry Month, Rock Outcrops, Surface rocks
Oil Palm	• Barique/Natarbora • Laleia • Soibada • Laclo • Laclubar • Manatuto	**N :** Dry Month **S3 :** Slope, Rock Outcrops, N-total, P-Available, K-Available **S2 :** Effective Depth, Surface rocks	S3 : Dry Month S2 : Rock Outcrops, Surface rocks, Effective Depth
Arabica Coffee	• Barique/Natarbora • Laleia • Soibada • Laclo • Laclubar • Manatuto	**N :** Temperature, Dry Month **S3 :** Rock Outcrops, N-total, P-Available, K-Available **S2 :** Effective Depth, Slope, Surface rocks	N : Temperature S2 : Rock Outcrops, Surface rocks, Effective Depth
Robusta Coffee	• Barique/Natarbora • Laleia • Soibada • Laclo • Laclubar • Manatuto	**S3 :** Rock Outcrops, N-total, P-Available, K-Available **S2 :** Temperature, Drainage, Dry Month, Effective Depth, Slope, Surface rocks	S2 : Temperature, Rock Outcrops, Surface rocks, Effective Depth
Cacao Clove	• Barique/Natarbora • Laleia	**N :** Dry Month	S3 : Dry Month

	• Soibada • Laclo • Laclubar • Manatuto	**S3 :** Rock Outcrops, Slope, N-total, P-Available, K-Available **S2 :** Effective Depth, Surface rocks	**S2** : Rock Outcrops, Surface rocks, Effective Depth
Tea	• Barique/Natarbora • Laleia • Soibada • Laclo • Laclubar • Manatuto	**N :** Dry Month **S3 :** Temperature, Rainfall, Slope, Rock Outcrops, N-total, P-Available, K-Available **S2 :** Effective Depth, Surface rocks	**S3** : Dry Month, Temperature **S2** : Rock Outcrops, Surface rocks, Effective Depth
Tobacco	• Barique/Natarbora • Laleia • Soibada • Laclo • Laclubar • Manatuto	**N :** Rainfall **S3 :** Slope, Rock Outcrops, N-total, P-Available , K-Available **S2:** Erosion, Surface rocks	**S2** : Rock Outcrops, Surface rocks
Sugarcane	• Barique/Natarbora • Laleia • Soibada • Laclo • Laclubar • Manatuto	**S3 :** Slope, Rock Outcrops, N-total, P-Available, K-Available **S2 :** Surface rocks	**S2** : Rock Outcrops, Surface rocks
Cashew	• Barique/Natarbora • Laleia • Soibada • Laclo • Laclubar • Manatuto	**N** : Dry Month **S3 :** Rainfall, Rock Outcrops, N-total, P-Available, K-Available **S2 :** Drainage, Slope, Surface rocks	**S3** : Dry Month **S2** : Rock Outcrops, Surface rocks
Melinjo	• Barique/Natarbora • Laleia • Soibada • Laclo • Laclubar • Manatuto	**N :** Dry Month **S3 :** Rock Outcrops, N-total, P-Available, K-Available **S2 :** Effective Depth, Slope, Surface rocks	**S3** : Dry Month **S2** : Rock Outcrops, Surface rocks, Effective Depth
Cotton	• Barique/Natarbora • Laleia • Soibada	**S3 :** Rainfall, Rock Outcrops, N-total, P-Available, K-Available	**S2 :** Temperature**,** Rock Outcrops, Surface rocks

	• Laclo • Laclubar • Manatuto	**S2:** Temperature, Erosion, Slope, Surface rocks	
Kapok	• Barique/Natarbora • Laleia • Soibada • Laclo • Laclubar • Manatuto	**S3 :** Rainfall, Slope, Rock Outcrops, N-total, P-Available, K-Available **S2 :** Temperature, Erosion, Effective Depth, Surface rocks	**S2** : Temperature, Rock Outcrops, Surface rocks, Effective Depth
Quinine	• Barique/Natarbora • Laleia • Soibada • Laclo • Laclubar • Manatuto	**S3 :** Temperature, Rock Outcrops, N-total, P-Available, K-Available **S2 :** Effective Depth, Slope, Surface rocks	**S3** : Temperature **S2** : Rock Outcrops, Surface rocks, Effective Depth
GRAZING AREAS AND LIVESTOCK FEED			
Elephantgrass Setaria	• Barique/Natarbora • Laclo • Laclubar • Manatuto • Soibada	**N :** Flood **S3 :** Rock Outcrops, N-total, P-Available, K-Available **S2 :** Surface rocks, Drainage, Rainfall, pH, BS	**S3 :** Rock Outcrops **S2 :** Flood, Surface rocks
Legumes	• Barique/Natarbora • Laclo • Laclubar • Manatuto • Soibada	**N:** Flood **S3 :** Rock Outcrops, N-total, P-Available, K-Available **S2 :** Surface rocks, Drainage, Rainfall, Erosion, Slope, BS	**S3 :** Rock Outcrops **S2 :** Flood, Surface rocks
Grazing	• Barique/Natarbora • Laclo • Laclubar • Manatuto • Soibada	**N:** Flood **S3 :** Dry Month, Rock Outcrops, N-total, P-Available, K-Available **S2 :** Surface rocks, pH	**S3 :** Rock Outcrops **S2 :** Flood, Dry Month, Surface rocks

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

7.4 LAND IMPROVEMENT EFFORTS

Efforts to improve each limiting factor are crucial for enhancing productivity and the sustainability of the agricultural sector. Constraints such as depth, poor drainage, erosion hazards, and surface rocks require appropriate solutions to maximize land potential. Chemical soil parameters, such as Organic Carbon and nutrients (N, P, K), which are relatively low in actual conditions, need land improvement efforts to elevate them into potential land for agricultural commodity development. Recommendations for improvement for each limiting factor, as a basis for implementing the enhancement of potential land suitability for agricultural and forestry commodity development, are provided in **Table 7.3**. The level of improvement of actual land quality to potential quality based on management level is presented in **Table 7.4**, which will serve as a guideline for researchers in transforming actual land suitability to potential suitability.

Table 7.3 Recommendations for Improvements on 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 - Rainfall during growth period	Irrigation, construction of reservoirs/drip irrigation Adjustment of planting patterns/planting calendar	Medium, high
3.	**Root Capacity (rc)** - Drainage - Texture - Effective Depth - Coarse Fragment	Improvement of drainage system, such as construction of drainage channels, ridges/beds Cannot be improved, can be mitigated by adding organic matter Generally cannot be improved, except in soft and shallow hardpan layers by breaking it during land preparation 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	Medium, High High Medium, High High

		more than 90%, called restricting layer, root growth is limited and difficult to improve	
4.	**Nutrient Retention (nr)** - CEC - BS - pH - C-organic	Addition of organic matter Liming, addition of organic matter Liming if soil pH is low, adding sulfur or ZA fertilizer if pH is high Addition of organic matter/fertilizer, and returning plant residues to the soil	Medium, High Medium, High Medium, High Medium, High
5.	**Nutrient Availability (na)** - N Total - P – Available - K – Available	Fertilization with N (urea and ZA) Fertilization with P (SP36 and TSP) Fertilization with K (KCl) Compound fertilizers (NPK)	Low, Medium, High Low, Medium, High 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 drainage, construction of infiltration well	High
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

Explanation:

- *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 moderate agricultural techniques.*
- *High management level: Management can only be carried out with relatively large capital, typically by the government or large or medium-sized enterprises.*

Table 7.4 Improvement of Actual Land Quality to Potential

No	Soil Quality and Characteristics	Management Level Medium	Management Level High	Type of Improvement
1	**Radiation Regime**	-	-	-
2	**Temperature Regime**	-	-	-
3	**Air Humidity Regime**	-	-	-
4	**Water Availability**			
	- Dry months	+	++	Crop combination irrigation
	- Rainfall	+	++	
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	**Ketersediaan hara**			
	- N-total	+	++	Urea Fertilizer
	- P-Available	+	++	SP36 and TSP Fertilizer
	- K- Available	+	++	KCL Fertilizer
8	**Flood**			
	- Period	+	++	-
	- Frequency	+	++	-
9	**Salinity**			Irrigation and addition of organic matter
	- Salinity	+	++	
10	**Toxicity**			Lime
	- Aluminium Saturation	+	++	Managing groundwater level
	- Pyrite depth	-	+	
11	**Ease of Cultivation**	-	+	Mechanization
12	**Terrain (land) potensi mechanization potential**	-	+	Terracing
13	**Erosion**	+	++	Soil Conservation efforts

Explanation:

- No improvement can be made
+ Improvement can be made and will result in an increase of one class level (S3 to S2)
++ Two-class improvement (S3 to S1)
***)** Poor drainage can be improved to better drainage by creating drainage channels, but very fast/rapid drainage is difficult to modify into moderate/good drainage.

7.5 LAND USE DIRECTIONS

The land use directions in this study are based on the results of the evaluation of potential land suitability after considering various improvements that can be made. This analysis refers to a matching approach between actual land characteristics and crop growth requirements, as outlined in **Table 7.3** and **Table 7.4**. This process results in land use recommendations that reflect not only the existing biophysical conditions but also the potential for improving suitability through land management and improvement actions. Land use directions for various agricultural commodities, forestry, and livestock forage/grazing areas 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 document. This assessment involves various primary limiting factors, such as water availability, root medium characteristics, retention capacity, and nutrient availability, erosion and flood risks, as well as the ease of land processing. Each of these factors is analyzed in terms of its improvement potential, whether through mechanical, chemical, or biological approaches.

It should be emphasized that although the evaluation results show that some specific commodities fall under the very suitable (S1) land suitability class, this does not mean that plants will automatically grow and develop optimally solely based on the physical land conditions. These recommendations assume that all land management actions are carried out optimally, including balanced fertilization according to the specific needs of the plants, proper agronomic management, appropriate irrigation systems, planting patterns suited to the local climate, and the implementation of proper soil and water conservation techniques.

Therefore, the land suitability classification presented in this document must 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 directions requires synergy between farmers, agricultural extension officers, and institutional support from the government in the form of policies, technical guidance, and access to production facilities.

These directions are expected to serve as a strategic reference in planning sustainable land resource use, while still considering productivity, efficiency, and environmental sustainability. Moreover, this document is expected to support decision-making in determining the zoning for the development of key commodities at both the site and regional planning scales.

Table 7.5 Land Use Directions (Recommendations) for the Development of Food, Industrial, Horticultural, Spice and Medicinal Commodities, Forestry, Livestock Feed, and Grazing Areas in Manatuto District

NO	DISTRICT	SUB-DISTRICT	FOOD CROPS	DRYLAND AGRICULTURE (PLANTATIONS & HORTICULTURE)	FORESTRY	LIVESTOCK FEED & GRAZING AREAS
1	Manatuto	Barique/ Natarbora	WETLAND FOOD CROPS **S1 :** Irrigated Rice DRYLAND FOOD CROPS **S2 :** Rainfed Rice **S3 :** Upland Rice, Peanut, Sorghum, Corn, Cassava, Soybean, Mung Bean, Cowpea, Taro, Sweet Potato	INDUSTRY **S2 :** Coconut, Robusta Coffee, Tobacco, Sugarcane, Cotton, Kapok **S3** : Rubber, Oil Palm, Cacao, Clove, Tea, Cashew, *Melinjo*, Quinine FRUITS **S2** : Papaya, Orange, Rambutan, Mango, Guava, Durian, Watermelon, Melon, Jackfruit, Soursop, Custard Apple, Breadfruit, Snakefruit, Pineapple, Longan, Strawberry, Grape, Passion Fruit **S3 :** Banana, Avocado VEGETABLES **S2** : Shallot, Green Bean, Broccoli, Chili, Bell Pepper, Caisim, Cucumber, Eggplant, Bitter Melon, Tomato Vegetable, Cabbage, Long Bean **S3** : Potato, Carrot, Garlic, FLOWERS **S2** : Rose, Aster, Sunflower	**S2** : Leucaena, Melaleuca **S3** : Teak, Mahogany, Agathis, Albizia, Acacia, Eucalyptus, Sandalwood	**S3 :** Elephantgrass, Setaria, Legumes, Grazing

				SPICES & MEDICINAL PLANTS **S2** : Vetiver Root, Lemongrass, Jatropha, Aromatic Ginger, Turmeric, Galangal, Cardamom **S3 :** Ginger, Vanilla, Candlenut, Nutmeg, Cinnamon, Pepper, Sesame		
2	Manatuto	Laleia	**WETLAND FOOD CROPS** **S1 :** Irrigated Rice **DRYLAND FOOD CROPS** **S2 :** Rainfed Rice **S3 :** Upland Rice, peanut, sorghum, corn, Cassava, Soybean, Mung Bean, Cowpea, Taro, Sweet Potato.	**INDUSTRY** **S2 :** Coconut, Robusta Coffee, Tobacco, Sugarcane, Cotton, Kapok **S3** : Rubber, Oil Palm, Cacao, Clove, Tea, Cashew, *Melinjo*, Quinine **FRUITS** **S2** : Papaya, Orange, Rambutan, Mango, Guava, Durian, Watermelon, Melon, Jackfruit, Soursop, Custard Apple, Breadfruit, Snakefruit, Pineapple, Longan, Strawberry, Grape, Passion Fruit **S3 :** Banana, Avocado **VEGETABLES** **S2** : Shallot, Green Bean, Broccoli, Chili, Bell Pepper, Caisim, Cucumber, Eggplant, Bitter Melon, Tomato Vegetable, Cabbage, Long Bean **S3** : Potato, Carrot, Garlic	**S2** : Leucaena, Melaleuca **S3** : Teak, Mahogany, Agathis, Albizia, Acacia, Eucalyptus, Sandalwood	-

				SPICES & MEDICINAL PLANTS **S2** : Vetiver Root, Lemongrass, Jatropha, Aromatic Ginger, Turmeric, Galangal, Cardamom **S3 :** Ginger, Vanilla, Candlenut, Nutmeg, Pepper, Cinnamon, Pepper, Sesame		
3	Manatuto	Soibada	**WETLAND FOOD CROPS** **S1 :** Irrigated Rice **DRYLAND FOOD CROPS** **S3 :** Upland Rice, peanut, sorghum, corn, Cassava, Soybean, Mung Bean, Cowpea, Taro, Sweet Potato.	**INDUSTRY** **S2 :** Coconut, Robusta Coffee, Tobacco, Sugarcane, Cotton, Kapok **S3** : Rubber, Oil Palm, Cacao, Clove, Tea, Cashew, *Melinjo*, Quinine **FRUITS** **S2** : Papaya, Orange, Rambutan, Mango, Guava, Durian, Watermelon, Melon, Jackfruit, Soursop, Custard Apple, Breadfruit, Snakefruit, Pineapple, Longan, Strawberry, Grape, Passion Fruit **S3 :** Banana, Avocado **VEGETABLES** **S2** : Shallot, Green Bean, Broccoli, Chili, Bell Pepper, Caisim, Cucumber, Eggplant, Bitter Melon, Tomato Vegetable, Cabbage, Long Bean **S3** : Potato, Carrot, Garlic,	**S2** : Leucaena, Melaleuca **S3** : Teak, Mahogany, Agathis, Albizia, Acacia, Eucalyptus, Sandalwood	S3 : Elephantgrass, Setaria, Legumes, Grazing

				FLOWERS **S2** : Rose, Aster, Sunflower **SPICES & MEDICINAL PLANTS** **S2** : Vetiver Root, Lemongrass, Jatropha, Aromatic Ginger, Turmeric, Galangal, Cardamom **S3** : Ginger, Vanilla, Candlenut, Nutmeg, Pepper, Cinnamon, Pepper, Sesame		
4	Manatuto	Laclo	**WETLAND FOOD CROPS** **S1 :** Irrigated Rice **DRYLAND FOOD CROPS** **S3** : Upland Rice, peanut, sorghum, corn, Cassava, Soybean, Mung Bean, Cowpea, Taro, Sweet Potato.	**INDUSTRY** **S2** : Coconut, Robusta Coffee, Tobacco, Sugarcane, Cotton, Kapok **S3** : Rubber, Oil Palm, Cacao, Clove, Tea, Cashew, *Melinjo*, Quinine **FRUITS** **S2** : Papaya, Orange, Rambutan, Mango, Guava, Durian, Watermelon, Melon, Jackfruit, Soursop, Custard Apple, Breadfruit, Snakefruit, Pineapple, Longan, Strawberry, Grape, Passion Fruit **S3 :** Banana, Avocado **VEGETABLES** **S2** : Shallot, Green Bean, Broccoli, Chili, Bell Pepper, Caisim, Cucumber, Eggplant, Bitter Melon, Tomato Vegetable, Cabbage, Long Bean	**S2** : Leucaena, Melaleuca **S3**: Teak, Mahogany, Agathis, Albizia, Acacia, Eucalyptus, Sandalwood	**S3** : Elephantgrass, Setaria, Legumes, Grazing

				S3 : Potato, Carrot, Garlic, FLOWERS **S2** : Rose, Aster, Sunflower SPICES & MEDICINAL PLANTS **S2** : Vetiver Root, Lemongrass, Jatropha, Aromatic Ginger, Turmeric, Galangal, Cardamom **S3** : Ginger, Vanilla, Candlenut, Nutmeg, Pepper, Cinnamon, Pepper, Sesame		
5	Manatuto	Laclubar	DRYLAND FOOD CROPS **S2 :** Rainfed Rice **S3 :** Upland Rice, peanut, sorghum, corn, Cassava, Soybean, Mung Bean, Cowpea, Taro, Sweet Potato.	INDUSTRY **S2 :** Coconut, Robusta Coffee, Tobacco, Sugarcane, Cotton, Kapok **S3** : Rubber, Oil Palm, Cacao, Clove, Tea, Cashew, *Melinjo*, Quinine FRUITS **S2** : Papaya, Orange, Rambutan, Mango, Guava, Durian, Watermelon, Melon, Jackfruit, Soursop, Custard Apple, Breadfruit, Snakefruit, Pineapple, Longan, Strawberry, Grape, Passion Fruit **S3 :** Banana, Avocado VEGETABLES **S2** : Shallot, Green Bean, Broccoli, Chili, Bell Pepper, Caisim, Cucumber, Eggplant, Bitter	**S2** : Leucaena, Melaleuca **S3** : Teak, Mahogany, Agathis, Albizia, Acacia, Eucalyptus, Sandalwood	**S3 :** Elephantgrass, Setaria, Legumes, Grazing

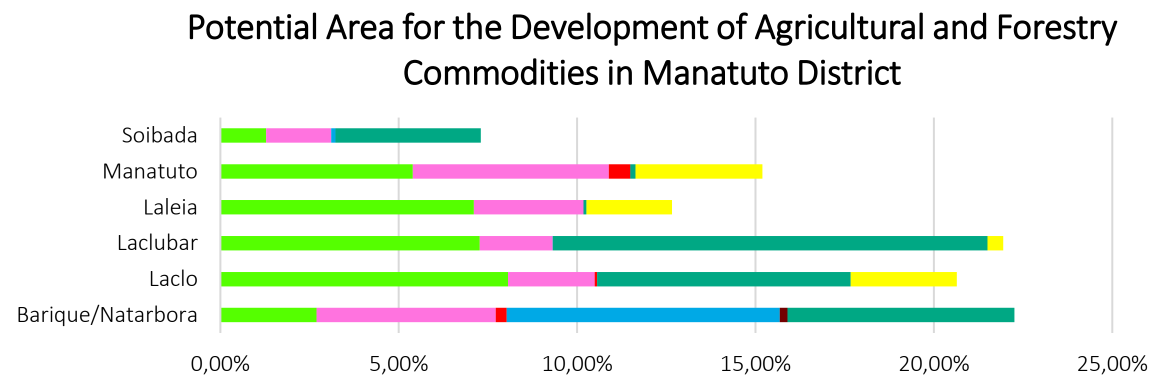
				Melon, Tomato Vegetable, Cabbage, Long Bean **S3** : Potato, Carrot, Garlic, **FLOWERS** **S2** : Rose, Aster, Sunflower **SPICES & MEDICINAL PLANTS** **S2** : Vetiver Root, Lemongrass, Jatropha, Aromatic Ginger, Turmeric, Galangal, Cardamom **S3 :** Ginger, Vanilla, Candlenut, Nutmeg, Pepper, Cinnamon, Pepper, Sesame		
6	Manatuto	Manatuto	**WETLAND FOOD CROPS** **S1 :** Irrigated Rice **DRYLAND FOOD CROPS** **S2 :** Rainfed Rice **S3 :** Upland Rice, peanut, sorghum, corn, Cassava, Soybean, Mung Bean, Cowpea, Taro, Sweet Potato.	**INDUSTRY** **S2 :** Coconut, Robusta Coffee, Tobacco, Sugarcane, Cotton, Kapok **S3** : Rubber, Oil Palm, Cacao, Clove, Tea, Cashew, *Melinjo*, Quinine **FRUITS** **S2** : Papaya, Orange, Rambutan, Mango, Guava, Durian, Watermelon, Melon, Jackfruit, Soursop, Custard Apple, Breadfruit, Snakefruit, Pineapple, Longan, Strawberry, Grape, Passion Fruit **S3 :** Banana, Avocado	**S2** : Leucaena, Melaleuca **S3**: Teak, Mahogany, Agathis, Albizia, Acacia, Eucalyptus, Sandalwood	**S3 :** Elephantgrass, Setaria, Legumes, Grazing

				VEGETABLES S2 : Shallot, Green Bean, Broccoli, Chili, Bell Pepper, Caisim, Cucumber, Eggplant, Bitter Melon, Tomato Vegetable, Cabbage, Long Bean S3 : Potato, Carrot, Garlic FLOWERS S2 : Rose, Aster, Sunflower SPICES & MEDICINAL PLANTS S2 : Vetiver Root, Lemongrass, Jatropha, Aromatic Ginger, Turmeric, Galangal, Cardamom S3 : Ginger, Vanilla, Candlenut, Nutmeg, Pepper, Cinnamon, Pepper, Sesame		

7.6 AGRICULTURAL POTENTIAL DEVELOPMENT ZONING

The research results indicate that Manatuto District has highly significant resource potential to support the development of the agricultural and forestry sectors. To maximize this potential, land suitability evaluation was conducted using a comprehensive scientific approach, including field observations, laboratory testing of soil samples, and matching crop growth requirements with the region's agro-climatic maps. This evaluation results in a systematic, scientifically-based zoning to identify the potential for developing various strategic commodities. This zoning reflects the diversity of land utilization potential to support agriculture, forestry, and livestock sustainably, contributing to food security, environmental protection, and improved community welfare. With structured and sustainable management efforts, the substantial potential of this region can be optimized through synergy between the government, policymakers, and local communities, allowing all stakeholders to benefit.

Manatuto District has land development potential divided into several main categories: irrigated rice fields covering 138.48 km² (7.77%), rainfed rice fields covering 167.14 km² (9.38%), grazing areas covering 17.17 km² (0.96%), dryland agriculture or mixed farms covering 354.38 km² (19.89%), agroforestry covering 566.78 km² (31.81%), mangrove forests covering 4.11 km² (0.23%), and protected and conservation forests covering 533.77 km² (29.96%), as shown in Figure 7.1. The spatial distribution of these areas is presented in Figure 7.2. This zoning reflects the diverse potential of land utilization to support agriculture and forestry sustainably, contributing to food security, environmental protection, and community welfare improvement.



	Barique/Natarbora	Laclo	Laclubar	Laleia	Manatuto	Soibada
Agroforestry	2,70%	8,06%	7,27%	7,10%	5,40%	1,28%
Dryland Farming	5,02%	2,43%	2,04%	3,07%	5,49%	1,83%
Grazing Area	0,31%	0,06%	0,00%	0,00%	0,59%	0,00%
Irrigated Rice Fields	7,65%	0,00%	0,01%	0,00%	0,00%	0,11%
Mangrove Forest	0,22%	0,00%	0,00%	0,00%	0,01%	0,00%
Protected Forest	6,36%	7,11%	12,19%	0,08%	0,14%	4,08%
Rainfed Rice Fields	0,00%	2,98%	0,44%	2,40%	3,56%	0,00%

Figure 7.1 Potential Area for the Development of Agricultural and Forestry Commodities in Manatuto District

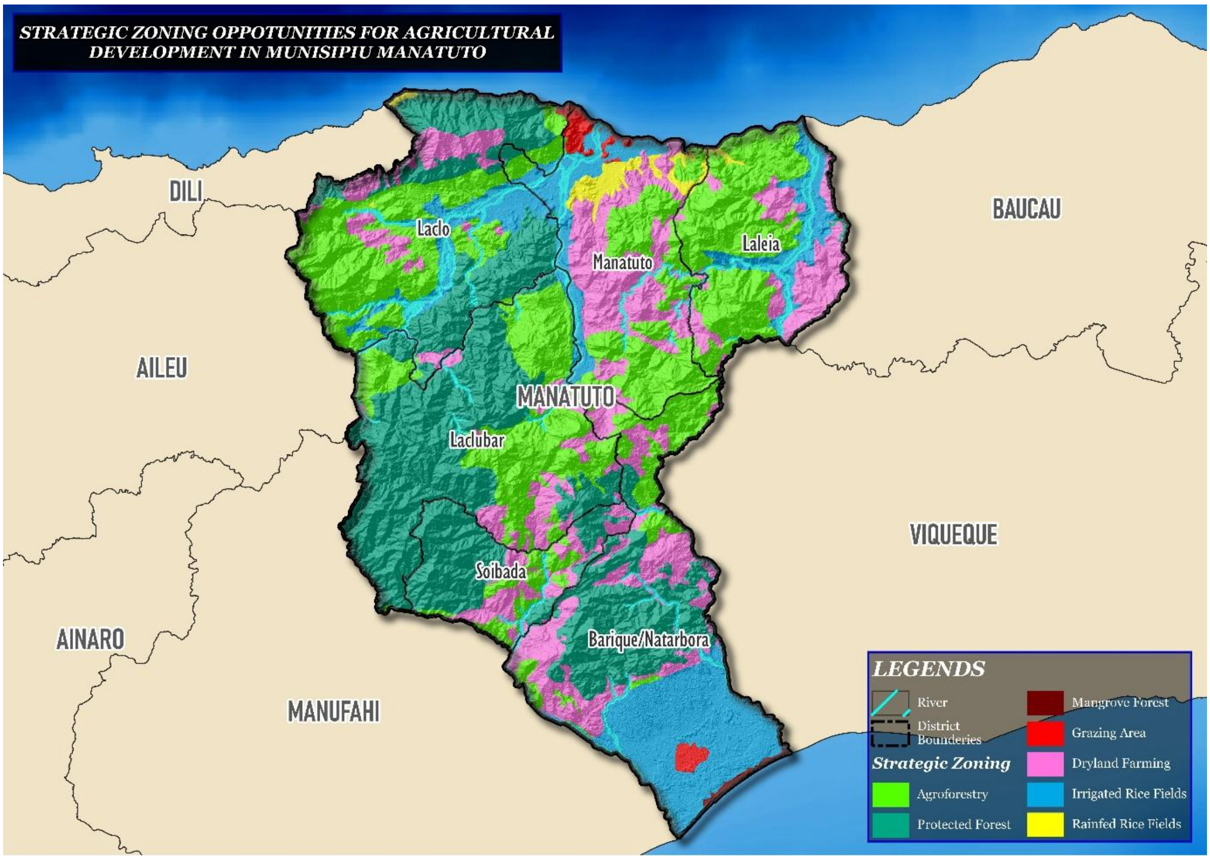


Figure 7.2 Spatial Distribution of Agricultural and Forestry Commodity Development in Manatuto District

A. Irrigated Rice Fields

The irrigated rice field zone in Manatuto District covers 138.48 km² (7.77% of the area) at an elevation of 0–100 m above sea level (masl) with slopes of 0–15%. The lithology is dominated by loose sediments ranging from clay to boulders and clay to gravel, with Entisols and Alluvial soils that are relatively fertile but prone to flooding. The monomodal agro-climatic regime allows for one main rice planting season per year, supported by water from rivers, reservoirs, and gravity-fed irrigation systems.

This area has experienced significant flooding that damaged rice fields, and during the dry season, it often faces water deficits. Commodities that can be developed in this zone include irrigated rice, so the development focus is on improving irrigation efficiency through network modernization, drainage improvement, water-saving techniques, precision land leveling, crop diversification, and post-harvest strengthening. As an adaptation to climate change, soil and water conservation strategies are implemented through riparian rehabilitation, upstream sediment control, and mangrove restoration, along with emergency response programs to reduce flood and drought risk.

B. Rainfed Rice Fields

The rainfed rice field zone in Manatuto District covers 167.14 km², or 9.38% of the total area. This area lies at an elevation of 0–100 masl with very gentle slopes of 0–3%, making it physiographically part of lowland alluvial plains. The lithology is dominated by loose sediments, ranging from clay to boulders, with Entisols, which are relatively young and prone to erosion and waterlogging. The monomodal agro-climatic regime with a single rainy season allows for only one main rice planting season, while the land is generally unproductive during the dry season due to limited water availability.

Development focus is directed at harvesting and storing rainwater through small reservoirs and infiltration wells, using drought-tolerant rice varieties, diversifying crops during periods of reduced rainfall, and applying conservation tillage systems to maintain soil moisture. Major risks include drought, crop failure, and declining productivity, which are managed through soil and water conservation, agroforestry for microclimate buffering, and strengthening farmers' capacity to adapt to climate change

C. Dryland Agriculture (Mixed Farms and Dryland Fields)

The dryland agriculture zone in Manatuto District covers 354.38 km^2 or 19.89% of the total area, extending from 0–1000 masl with slopes from flat to steep (>40%). Geologically, this area is dominated by calcilutite, marl, calcareous shale, and calcarenites, forming Entisols, Mollisols, and Inceptisols with varying fertility levels, from nutrient-poor young soils to relatively fertile soils with higher organic matter content. The monomodal agro-climatic regime with a single rainy season makes this agricultural system highly dependent on rainfall, allowing for only one main crop season and making it vulnerable to drought during the dry season.

Agricultural development focus in Manatuto District is directed at optimizing key commodities suited to the regional potential. Food crops such as corn, rice, *taro*, cassava, sweet potato, *porang*, and breadfruit are prioritized as sources of carbohydrates and food security. Horticulture is developed through tropical fruits (banana, mango, rambutan, papaya, durian, avocados, etc.) and economically valuable vegetables (pakchoi, tomatoes, spinach, long Bean, Caisim, water spinach, etc.) for consumption diversification and local markets.

D. Grazing Areas

The grazing zone in Manatuto District covers 17.17 km^2, or about 0.96% of the total area, located in lowland areas with elevations of 0–100 masl and slopes of 0–8%. Physiographically, this area is an alluvial plain with coarse-textured soils and lithology dominated by conglomerates and sandstones. The developed soil type is Entisols, which is generally shallow and nutrient-poor, limiting the productivity of natural pastures without management interventions. The agro-climatic regime is bimodal, allowing for two growing periods of forage, but during the dry season, this area is prone to drought and a decrease in forage supply.

The development of forage crops such as elephant grass, setaria, and legumes is reasonably suitable, although water limitation is the main constraint. Sprinkler irrigation is recommended to maintain continuous forage production in dryland areas. Management strategies focus on applying rotational grazing based on carrying capacity, establishing a forage bank with elephant grass and vetiver root on contours, and developing silvopasture with tree legumes to increase forage biomass and strengthen soil conservation. Livestock-plant integration is key to strengthening food security by providing animal protein and manure that supports rice and horticultural productivity.

VIII. FORESTRY POTENTIAL

8.1 LAND SUITABILITY ASSESSMENT RESULT

Land suitability analysis is a fundamental step in formulating strategies for sustainable management of forestry land resources. This evaluation was carried out using an integrated approach that combined the use of geospatial data, field observations, and physical and chemical soil analyses in the laboratory. This approach enabled the identification of the biophysical potentials and constraints of land that are relevant for the development of various forestry species.

Geospatial data were used to map topography, land use distribution, and rainfall patterns in each area. This information provided an initial overview of the spatial conditions that influence tree stand growth. Subsequently, field observations were conducted to obtain direct data on slope gradient and land cover, which are important factors in determining land carrying capacity for forestry species. Laboratory analyses complemented this process by measuring macro nutrient contents (N, P, K), soil organic matter, cation exchange capacity (KTK), base saturation (KB), soil pH, and soil texture, thereby providing a comprehensive understanding of soil fertility and soil characteristics.

The data collected were then analyzed based on the actual growth requirements of each forestry species, as well as the potential suitability after land improvement. The improvement measures considered included fertilization, addition of organic matter, and the application of soil conservation techniques such as terracing or the planting of cover crops. Thus, the evaluation did not only assess existing conditions, but also took into account the potential to increase productivity through appropriate technical interventions.

This scientific approach formed the basis for land suitability evaluation in Manatuto District, providing strategic guidance for determining priorities in forestry commodity development. The analysis also served to identify limiting factors that may constrain tree growth, while at the same time designing relevant technical solutions.

A. Land Suitability Evaluation for Barique/Natarbora Sub-District

Barique/Natarbora Sub-District has potential for the development of forestry species with land suitability levels ranging from S2 (moderately suitable) to S3 (marginally suitable). Leucaena and Melaleuca were classified as moderately suitable (S2) and can therefore be recommended for cultivation in Barique/Natarbora Sub-District. Other species such as teak, Albizia, acacia, and others were classified as S3 (marginally suitable), meaning that they can still be developed with appropriate technical improvements. Despite this potential, forestry development in Barique/Natarbora Sub-District faces several biophysical and soil chemical limiting factors. These limiting factors include temperature, the length of the dry month period, steep slope gradients, erosion severity, the presence of rock outcrops, surface rock fragments, shallow effective soil depth, and nutrient contents of nitrogen (N), phosphorus (P), and potassium (K).

Species such as Altingia and pine were not generally recommended for development because of permanently limiting temperature conditions. In addition to the species already mentioned, Table 8.1 presents alternative species that were considered suitable for forestry development in Barique/Natarbora Sub-District.

B. Land Suitability Evaluation for Laclo Sub-District

Laclo Sub-District has potential for the development of forestry species with land suitability levels ranging from S2 (moderately suitable) to S3 (marginally suitable). Leucaena and Melaleuca were classified as moderately suitable (S2) and can therefore be recommended for cultivation in Laclo Sub-District. Other species such as teak, mahogany, Agathis, and others were classified as S3 (marginally suitable), meaning that they can still be developed with appropriate technical improvements. Despite this potential, forestry development in Laclo Sub-District faces several biophysical and soil chemical limiting factors. These limiting factors include temperature, the length of the dry month period, steep slope gradients, erosion severity, the presence of rock outcrops, surface rock fragments, shallow effective soil depth, and nutrient contents of nitrogen (N), phosphorus (P), and potassium (K).

Species such as Altingia and pine were not generally recommended for development because of permanently limiting temperature conditions. In addition to the species already mentioned, **Table 8.1** presents alternative species that were considered suitable for agricultural development in Laclo Sub-District.

C. Land Suitability Evaluation for Laclubar Sub-District

Laclubar Sub-District has potential for the development of forestry species with land suitability levels ranging from S2 (moderately suitable) to S3 (marginally suitable). Leucaena and Melaleuca were classified as moderately suitable (S2) and can therefore be recommended for cultivation in Laclubar Sub-District. Other species such as acacia, eucalyptus, sandalwood, and others were classified as S3 (marginally suitable), meaning that they can still be developed with appropriate technical improvements. Despite this potential, forestry development in Laclubar Sub-District faces several biophysical and soil chemical limiting factors. These limiting factors include temperature, the length of the dry month period, steep slope gradients, erosion severity, the presence of rock outcrops, surface rock fragments, shallow effective soil depth, drainage, and nutrient contents of nitrogen (N), phosphorus (P), and potassium (K).

Species such as Altingia and pine were not generally recommended for development because of permanently limiting temperature conditions. In addition to the species already mentioned, **Table 8.1** presents alternative species that were considered suitable for forestry development in Laclubar Sub-District.

D. Land Suitability Evaluation for Laleia Sub-District

Laleia Sub-District has potential for the development of forestry species with land suitability levels ranging from S2 (moderately suitable) to S3 (marginally suitable). Leucaena and Melaleuca were classified as moderately suitable (S2) and can therefore be recommended for cultivation in Laleia Sub-District. Other species such as acacia, eucalyptus, sandalwood, and others were classified as S3 (marginally suitable), meaning that they can still be developed with appropriate technical improvements. Despite this potential, forestry development in Laleia Sub-District faces several biophysical and soil chemical limiting factors. These limiting factors include temperature, the length of the dry month period, steep slope gradients, erosion severity, the presence of rock outcrops, surface rock fragments, shallow effective soil depth, and nutrient contents of nitrogen (N), phosphorus (P), and potassium (K).

Species such as Altingia and pine were not generally recommended for development because of permanently limiting temperature conditions. In addition to the species already mentioned, **Table 8.1** presents alternative species that were considered suitable for forestry development in Laleia Sub-District.

E. Land Suitability Evaluation for Manatuto Sub-District

Manatuto Sub-District has potential for the development of forestry species with land suitability levels ranging from S2 (moderately suitable) to S3 (marginally suitable). Leucaena and Melaleuca were classified as moderately suitable (S2) and can therefore be recommended for cultivation in Manatuto Sub-District. Other species such as teak, Albizia, acacia, and others were classified as S3 (marginally suitable), meaning that they can still be developed with appropriate technical improvements. Despite this potential, forestry development in Manatuto Sub-District faces several biophysical and soil chemical limiting factors. These limiting factors include temperature, the length of the dry month period, steep slope gradients, erosion severity, the presence of rock outcrops, surface rock fragments, shallow effective soil depth, and nutrient contents of nitrogen (N), phosphorus (P), and potassium (K).

Species such as Altingia and pine were not generally recommended for development because of permanently limiting temperature conditions. In addition to the species already mentioned, **Table 8.1** presents alternative species that were considered suitable for forestry development in Manatuto Sub-District.

F. Land Suitability Evaluation for Soibada Sub-District

Soibada Sub-District has potential for the development of forestry species with land suitability levels ranging from S2 (moderately suitable) to S3 (marginally suitable). *Leucaena* and Melaleuca were classified as moderately suitable (S2) and can therefore be recommended for cultivation in Soibada Sub-District. Other species such as mahogany, eucalyptus, and others were classified as S3 (marginally suitable), meaning that they can still be developed with appropriate technical improvements. Despite this potential, forestry development in Soibada Sub-District faces several biophysical and soil chemical limiting factors. These limiting factors include temperature, the length of the dry month period, steep slope gradients, erosion severity, the presence of rock outcrops, surface rock fragments, shallow effective soil depth, and nutrient contents of nitrogen (N), phosphorus (P), and potassium (K).

Species such as Altingia and pine were not generally recommended for development because of permanently limiting temperature conditions. In addition to the species already mentioned, **Table 8.1** presents alternative species that were considered suitable for forestry development in Soibada Sub-District.

Table 8.1 Matrix of Land Suitability Evaluation Analysis for Forestry Species in Manatuto District

Commodities	Sub-District	Limiting Factors	Potential Land Suitability / Land Improvement Efforts
Teak	• Barique/Natarbora • Laleia • Soibada • Laclo • Laclubar • Manatuto	**N :** Dry month **S3** : Effective Depth, Rock Outcrops, N-total, P-Available, K-Available **S2**: Erosion, Slope, Surface Rocks	**S3 :** Dry month **S2 :** Effective Depth, Rock Outcrops, Surface Rocks
Mahogany	• Barique/Natarbora • Laleia • Soibada • Laclo • Laclubar • Manatuto	**N :** Dry month **S3** : Effective Depth, Rock Outcrops, N-total, P-Available, K-Available **S2** : Erosion, Slope, Surface Rocks, Texture	**S3 :** Dry month **S2 :** Effective Depth, Rock Outcrops, Surface Rocks, Texture
Agathis	• Barique/Natarbora • Laleia • Soibada • Laclo • Laclubar • Manatuto	**N :** Dry month **S3** : Effective Depth, Rock Outcrops, N-total, P-Available, K-Available **S2** : Temperature, Erosion, Slope, Surface Rocks, Texture	**S3 :** Dry month **S2 :** Temperature, Effective Depth, Rock Outcrops, Surface Rocks, Texture
Altingia	• Barique/Natarbora • Laleia • Soibada • Laclo • Laclubar • Manatuto	**N :** Temperature, Dry month **S3** : Effective Depth, Rock Outcrops, N-total, P-Available, K-Available **S2** : Erosion, Slope, Surface Rocks, Texture	**N :** Temperature **S3** : Dry month **S2 :** Effective Depth, Rock Outcrops, Surface Rocks, Texture
Albizia	• Barique/Natarbora • Laleia • Soibada • Laclo • Laclubar • Manatuto	**N :** Dry month **S3**: Effective Depth, Slope, Rock Outcrops, Surface Rocks, N-total, P-Available, K-Available **S2** : Erosion	**S3** : Dry month **S2 :** , Effective Depth, Rock Outcrops, Surface Rocks

Leucaena	• Barique/Natarbora • Laleia • Soibada • Laclo • Laclubar • Manatuto	**S3** : Rock Outcrops, N-total, P-Available, K-Available **S2** : Dry month, Erosion, Effective Depth, Slope, Surface Rocks, pH	**S2 :** Rock Outcrops, Dry month, Effective Depth, Surface Rocks
Acacia	• Barique/Natarbora • Laleia • Soibada • Laclo • Laclubar • Manatuto	**N :** Dry month **S3** : Rock Outcrops, N-total, P-Available, K-Available **S2** : Erosion, Effective Depth, Slope, Surface Rocks, pH, Texture	**S3** : Dry month **S2 :** Rock Outcrops, Effective Depth, Surface Rocks, Texture
Eucalyptus	• Barique/Natarbora • Laleia • Soibada • Laclo • Laclubar • Manatuto	**N :** Dry month **S3** : Rock Outcrops, N-total, P-Available, K-Available **S2** : Erosion, Effective Depth, Slope, Surface Rocks, Texture	**S3 :** Dry month **S2 :** Rock Outcrops, Effective Depth, Surface Rocks, Texture
Melaleuca	• Barique/Natarbora • Laleia • Soibada • Laclo • Laclubar • Manatuto	**S3** : Rock Outcrops, N-total, P-Available, K-Available **S2** : Effective Depth, Surface Rocks, pH	**S2 :** Rock Outcrops, Effective Depth, Surface Rocks
Pine	• Barique/Natarbora • Laleia • Soibada • Laclo • Laclubar • Manatuto	**N :** Temperature, Dry month **S3** : Rock Outcrops, N-total, P-Available, K-Available **S2** : Erosion, Effective Depth, Slope, Surface Rocks, Texture	**N** : Temperature **S3 :** Dry month **S2 :** Rock Outcrops, Effective Depth, Surface Rocks, Texture
Sandalwood	• Barique/Natarbora • Laleia • Soibada • Laclo • Laclubar • Manatuto	**N :** Rock Outcrops **S3** : N-total, P-Available, K-Available **S2** : Temperature, Coarse Fragments, Erosion, Surface Rocks, pH, C-organic	**S3 :** Rock Outcrops **S2 :** Temperature, Coarse Fragments, Surface Rocks

8.2 LAND IMPROVEMENT MEASURE

Land improvement in the context of forestry is a strategic measure to ensure the sustainability of forest ecological functions while supporting the productivity of timber and non-timber forest products. Land used for forestry often faces limiting factors such as extreme temperatures, long dry periods, steep slope gradients, high erosion severity, the presence of rock outcrops, shallow effective soil depth, and limitations in macro nutrients (N, P, K).

Most of these constraints can still be addressed through the application of integrated conservation and appropriate technical interventions. The impact of long dry periods, for example, can be reduced by scheduling planting during the rainy season so that plant growth proceeds more optimally. On land with steep slopes and high erosion severity, rehabilitation measures can be implemented through reforestation by replanting endemic tree species with strong root systems. These efforts can be combined with the establishment of ground cover vegetation, such as legumes or soil-binding grasses, which function to reduce the loss of the topsoil layer.

Constraints in the form of shallow soil depth can be mitigated by constructing planting holes that are adapted to soil conditions, while rock outcrops can be utilized by making planting holes in the spaces between them. Surface rock fragments can be controlled through effective land clearing. To overcome nutrient limitations, fertilization tailored to soil requirements becomes important. For instance, nitrogen additions can accelerate early seedling growth, phosphorus supports root development, and potassium enhances plant tolerance to environmental stress. In areas with long dry periods, optimizing simple irrigation or water harvesting structures, such as small reservoirs or infiltration wells, can help maintain water availability for young plants that are vulnerable to drought.

However, temperature is a permanent limiting factor that cannot be modified technically. Therefore, ecology-based adaptation strategies become crucial. Tree species selection must be matched with local agroclimatic conditions. For example, in highland areas with low temperatures, species such as *Pinus merkusii* or *Alnus nepalensis* are more adaptive, whereas in lowland areas with high temperatures, species such as *Tectona grandis* or *Acacia mangium* are more suitable. This strategy ensures that forestry systems remain productive despite environmental constraints.

8.3 FORESTRY DEVELOPMENT ZONING

Forestry development zoning in Manatuto District reflects systematic efforts to manage forest resources sustainably. The area is divided into three main categories, namely agroforestry, protected and conservation forest, and mangrove forest, based on biophysical characteristics, geological conditions, soil types, and the prevailing agroclimatic regime. This zoning not only functions as a spatial planning instrument, but also as a strategic framework to optimize the ecological, economic, and social potentials of each zone.

In general, forests in Manatuto District developed under a bimodal agroclimatic regime with dominant soil orders of Mollisols and Entisols, and lithology consisting of calcilutite, marl, calcareous shale, calcarenites, and chaotic boulder fragments in a scaly clay matrix. The combination of these factors gives forest areas a vital role as ecological buffers, as well as productive resources that can be managed to support environmental and socio-economic resilience.

Zoning enables the identification of specific potentials: agroforestry as a basis for integrating production and conservation with diversification of high-value commodities; protected and conservation forest as a terrestrial ecosystem buffer that maintains water regulation and biodiversity; and mangrove forest as a natural coastal barrier that protects areas from abrasion and seawater intrusion

A. Agroforestry

Agroforestry is a land use system with a strategic role in supporting ecological sustainability while increasing community welfare. The agroforestry zone in Manatuto District covers approximately 566.78 km² or 31.81 % of the total area, making it the dominant zone in the land use structure. The largest distribution is in Laclo Sub-District (8.06 %), Laclubar Sub-District (7.27 %), and Laleia Sub-District (7.10 %) (Figure 7.1 in Chapter VII).

One of the leading commodities developed within the agroforestry system in this area is coffee. Coffee is generally cultivated in a multistrata system, in which coffee plants grow under the shade of timber trees. This pattern provides significant ecological benefits, including reducing erosion rates through the root systems of shade trees, increasing soil moisture, and enriching soil organic matter through leaf litter. In addition, the multistrata system creates a more complex habitat, thereby supporting biodiversity conservation. From an economic perspective, coffee has high market value both domestically and internationally.

This potential could increase further if management follows environmentally friendly principles, as coffee produced through sustainable practices has the potential to obtain premium prices in global markets.

In current conditions, coffee in Manatuto District has mainly been developed in Laclubar Sub-District and Soibada Sub-District. In Soibada Sub-District, particularly in Manufahi Village, there is a substantial coffee production center that serves as one of the main production areas. The existence of this center indicates that coffee has long been an important component of local farming systems. However, production levels have not yet reached optimal yields. This condition is primarily due to the absence of suitable management systems, both in terms of the selection of superior varieties, implementation of sustainable cultivation practices, and post-harvest processing that meets quality standards. As a result, coffee as a leading commodity in the agroforestry system has not yet provided significant added value for farmers.

Figure 8.1 Agroforestry Systems in Manatuto District
(Source: Research Documentation, 2025)

Land suitability evaluation showed that Arabica coffee was not recommended for development in Manatuto District. This was due to the limiting factor of relatively high temperatures, which are permanent and cannot be improved through technical interventions. Arabica coffee generally requires highland conditions with lower temperatures to grow optimally, whereas most of Manatuto District lies in zones with less suitable temperatures. Robusta coffee is more strongly recommended for development in Manatuto District **(Table 7.2 in Chapter VII).** Robusta coffee has higher tolerance to heat, is more adaptive to local agroclimatic conditions, and is relatively more resistant to pests and diseases. With appropriate management, the development of robusta coffee in agroforestry systems has the potential to achieve more stable productivity and to strengthen the competitiveness of Manatuto coffee in domestic and international markets.

Thus, the extensive agroforestry land, agroclimatic conditions that are favorable for robusta coffee, and community traditions of coffee cultivation, especially in Laclubar and Soibada, constitute important assets for positioning this commodity as a key driver of the local economy. A well-directed development strategy will ensure that robusta coffee from Manatuto functions not only as a flagship regional product, but also as a symbol of the integration between economic productivity, environmental conservation, and social empowerment.

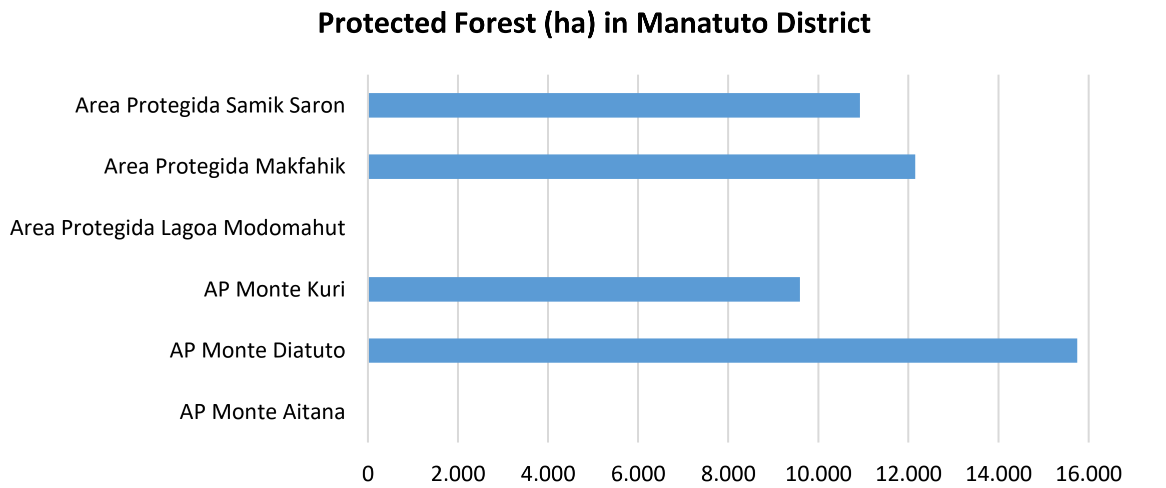
Figure 8.2 Coffee Plants in Manatuto District
(Source: Research Documentation, 2025)

B. Protected and Conservation Forest

The protected and conservation forest zone covers 533.77 km² or 29.96 % of the total area. The largest distribution is in Laclubar Sub-District (12.19 %), Laclo Sub-District (7.11 %), and Barique/Natarbora Sub-District (6.36 %) **(Figure 7.1 in Chapter VII)**. This zone plays an important role in maintaining ecosystem balance, protecting water regulation, and preventing land degradation. It has a strategic function in maintaining ecosystem equilibrium, safeguarding water resources, and reducing land degradation. In addition, protected forest serves as an important habitat for local flora and fauna and as an ecological buffer that supports the sustainability of agricultural systems and community livelihoods in surrounding areas.

Administratively, protected forest areas in Manatuto District consist of several designated protected areas (Area Protegida, AP). These areas include AP Monte Aitana, AP Monte Diatuto, AP Monte Kuri, Area Protegida Lagoa Modomahut, Area Protegida Makfahik, and Area Protegida Samik Saron. Each area has distinct biophysical characteristics, but all function to maintain water regulation, reduce erosion and landslide risks, and conserve biodiversity.

The hydrological function of protected forest ensures water availability for domestic, agricultural, and industrial needs. Its ecological function prevents land degradation, reduces landslide risk, and maintains wildlife habitat. From a socio-economic perspective, this zone can be utilized in a limited manner through non-extractive activities such as ecotourism, harvesting of non-timber forest products, and the development of conservation-based agroforestry. Thus, protected and conservation forest is not only a protection zone, but also a space for human–nature interaction that emphasizes sustainability principles.



	AP Monte Aitana	AP Monte Diatuto	AP Monte Kuri	Area Protegida Lagoa Modomahut	Area Protegida Makfahik	Area Protegida Samik Saron
Manatuto	6,11	15746,76	9587,19	1,03	12151,60	10917,26

Figure 8.3 Protected Forest Area (ha) in Manatuto District

C. Mangrove Forest

The mangrove forest zone in Manatuto District covers 4.11 km², or 0.23% of the total area. Although its area is relatively small, the mangrove forest plays a crucial ecological role. The mangrove forest zone along the coastal area of Manatuto District acts as a natural barrier protecting the coastline from abrasion and large waves. This ecosystem also functions as an effective carbon sink and provides essential habitat for various marine species.

In addition to its ecological functions, the mangrove forest has economic value by supporting coastal fisheries and providing potential for conservation-based ecotourism development. From a social perspective, the rehabilitation of mangroves involving coastal communities strengthens collective awareness of the importance of maintaining the ecosystem while fostering a sense of ownership over the natural resources that sustain their livelihoods. In the context of climate change and rising sea levels, the sustainability of mangrove forests is key to ensuring coastal resilience.

8.4 SANDALWOOD PLANT DEVELOPMENT POTENTIAL

Sandalwood (*Santalum album* L.) is a high-value tree species with ecological, economic, and cultural benefits. Its wood is known to produce high-quality essential oil, which is used in the perfume, cosmetics, and pharmaceutical industries. Sandalwood also holds symbolic value in the traditions and cultures of the Asian region, including Timor-Leste. In addition to its wood and oil, sandalwood is also utilized for handicrafts, carvings, and artistic products, making it a commodity with a broad and sustainable market appeal.

In Manatuto District, sandalwood has naturally grown for a long time and has become part of the local vegetation landscape. Sandalwood is relatively abundant, particularly in Laclo and Laclubar Sub-Districts, which have a semi-dry agroclimatic condition with varied topography. The presence of sandalwood in these areas indicates good adaptation to marginal land, including rocky soils and limited rainfall. However, despite its existing population, the management and utilization of sandalwood have not been optimized, so its economic potential has not been fully realized by the community.

Based on land suitability evaluation results, the potential category for sandalwood development in Manatuto falls under the S3 (Marginally Suitable) class. This category indicates that land can still be used for sandalwood cultivation, although there are limiting factors that need to be addressed through technical interventions, such as selecting appropriate planting locations, maintaining host trees, and applying suitable silvicultural techniques. With proper management, these limitations should not prevent sandalwood from becoming a flagship regional commodity.

Moreover, the government of Timor-Leste has recently initiated a sandalwood tree inventory program as a strategic step to secure investment and ensure the sustainability of resource management. The program aims to catalog the number, distribution, and condition of sandalwood trees in various regions, including Manatuto, to provide a basis for more targeted and data-driven development planning.

Therefore, the development of sandalwood in Manatuto District has significant prospects. The presence of natural populations in Laclo and Laclubar, government policy support through national inventory efforts, and the high economic value of sandalwood wood and essential oil provide essential assets to make it a prominent commodity. If managed sustainably, sandalwood can not only serve as a source of income for local communities but also as a symbol of cultural identity and the successful conservation of local resources.

IX. LIVESTOCK POTENTIAL

9.1 INTRODUCTION

Timor-Leste is a country largely consisting of mountains and highlands. Administratively, Timor-Leste is divided into 14 districts: Ainaro, Aileu, Ataúro, Bobonaro, Baucau, Covalima, Dili, Ermera, Lautém, Liquiçá, Manufahi, Manatuto, Região Administrativa Especial Oe-Cusse Ambeno (RAEOA), and Viqueque. The country experiences two seasons: the dry season, which lasts from June to November, and the rainy season, from December to May. The topography, dominated by hills, combined with its proximity to the Australian continent, makes Timor-Leste influenced by the dry east monsoon winds. As a result, some areas experience drought, and the low rainfall impacts the growth of vegetation across the country.

The hilly topography and low rainfall not only affect vegetation growth and agricultural life but also constrain the availability of forage for the livestock sector. The development of the livestock sector heavily depends on the land resource potential, appropriate land use, and management methods. These factors are crucial for the provision of forage, which typically consists of grasses and legumes.

Forage can be sourced both naturally and through cultivation, including from grazing fields (Priyanto, 2016). The optimal use of livestock land is determined by anthropogenic factors and the biophysical condition of the land. Therefore, the application of various technological innovations and institutional strategies is necessary to ensure that land resources are utilized effectively and optimally (Suryana and Rahman, 2006).

In general, the livestock sector in Timor-Leste faces numerous challenges. One major reason is that the livestock management system is still traditional and extensive, resulting in suboptimal production. The low level of awareness, knowledge, and technological adoption among farmers is another barrier, particularly in meeting the requirements for quality forage, both in terms of type and quality. Livestock is often kept as a household savings asset, to be sold in emergencies. Additionally, some communities still use livestock as labor in land cultivation, adhering to traditional management systems.

The success of livestock farming depends on three main factors: breeding, feed, and management (Aman *et al.,* 2019). These three factors form an interconnected system: if any one of them is neglected or receives insufficient attention, the effective management of the others will not yield optimal results. Livestock productivity, especially in ruminants, greatly depends on effective feed management, including the quantity, quality, and sustainability of forage availability (Rokhayati and Evadewi, 2023). According to Winarni and Sukaesih (2015), feed plays an important role in supporting livestock development, as it directly affects production, productivity, and animal health. The quality of forage is influenced by the variety of forage, genotype, harvest maturity, season, and management practices (Adesogan *et al.,* 2015).

One of the initial steps to be taken in the development of the livestock sector in Timor-Leste is optimizing land use for the sustainable provision of forage. To achieve this, the characteristics of the land must align with the types of forage to be cultivated. Therefore, land suitability evaluation is essential for 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 management practices applied (Nugroho *et al.,* 2014). Land suitability evaluation requires environmental data and soil quality information for a specific area. This assessment involves identifying various land characteristics, such as topography, climate, soil condition and quality, and other physical environmental factors (Iswan *et al.,* 2019). Through this evaluation process, information regarding biophysical land resources, including climate and soil, is obtained, allowing the classification of land suitability and identifying limiting factors that need to be improved (Jawang *et al.,* 2018).

9.2 RESEARCH METHODS

The research was conducted using a survey method and descriptive analysis method on selected study areas, specifically the KTS (Karau Timor Susubeen) center and recommended livestock lands. The data collected included quantitative and qualitative data derived from primary and secondary sources. Primary data included interview results on livestock production and socio-economic conditions, as well as field observations of land biophysical characteristics and soil suitability for forage production. Biophysical and soil properties were further analyzed according to laboratory standards. Secondary data used included the 2019 Timor-Leste agricultural census data.

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

A. Research Procedure

1. Observation of Livestock Production and Socio-Economic Aspects

Observations were conducted through interviews with parameters such as: livestock types, livestock population, land area, management and housing systems, feed and nutrition management systems, water sources, breeding systems, livestock health management, livestock products, marketing, infrastructure, farmer characteristics, and customs/traditions.

2. Livestock Forage Land Suitability

The procedure for evaluating livestock forage land suitability has been described in Chapter III (Methodology).

9.3 GENERAL DESCRIPTION

A. Overall Existing Conditions

The livestock sector plays an important role in supporting the livelihoods of many households in Manatuto District. The distribution of households engaged in livestock farming shows significant differences across sub-districts. Barique/Natarbora Sub-District has the largest number of households involved in livestock farming, with 300 households (50.34%). In contrast, Laclubar Sub-District has the smallest number of households engaged in livestock farming, with only 11 households (7.05%).

Nevertheless, their contributions remain significant in fulfilling local needs and preserving the livestock traditions that have become part of the local community’s way of life. With these differences, each sub-district contributes to the sustainability of the livestock sector in Manatuto. The number of agricultural households engaged in livestock farming is shown in **Figure 9.1**.

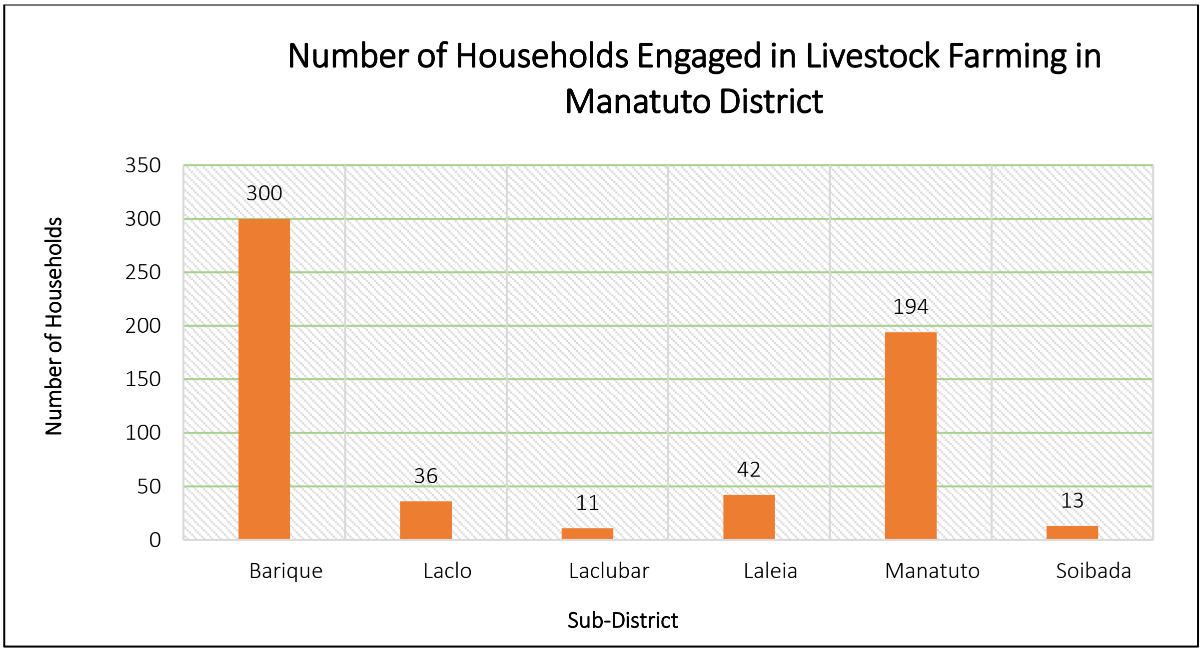


Figure 9.1 Number of Households Engaged in Livestock Farming
(Source: Timor-Leste Agriculture Census, 2019)

Large livestock, primarily cattle, dominate the livestock farming in Manatuto District. Barique/Natarbora Sub-District has the highest number of cattle-keeping households, with 573 households (40.99%) and a total cattle population of 10,567. Meanwhile, Soibada Sub-District has the smallest number of cattle-keeping households, with 127 households (9.08%) and a total of 512 cattle **(Figures 9.2 and 9.3).** The highest number of horse-keeping households is found in Laclubar Sub-District, with 635 households (65.73%) and a population of 4,925 horses. On the other hand, the lowest number of horse-keeping households is found in Manatuto Sub-District, with 34 households (3.52%) and a population of 68 horses **(Figures 9.2 and 9.3).**

For buffalo, Laclo Sub-District shows dominance in buffalo farming, with 509 households (30.48%) and a population of 3,044 buffalo. In contrast, Barique Sub-District has the smallest number of buffalo-keeping households, with 108 households (6.47%) and a population of 940 buffalo **(Figures 9.2 and 9.3).** Dairy cattle are only kept in three sub-districts, with only one household each in Barique/Natarbora and Laclubar Sub-Districts **(Figures 9.2 and 9.3).**

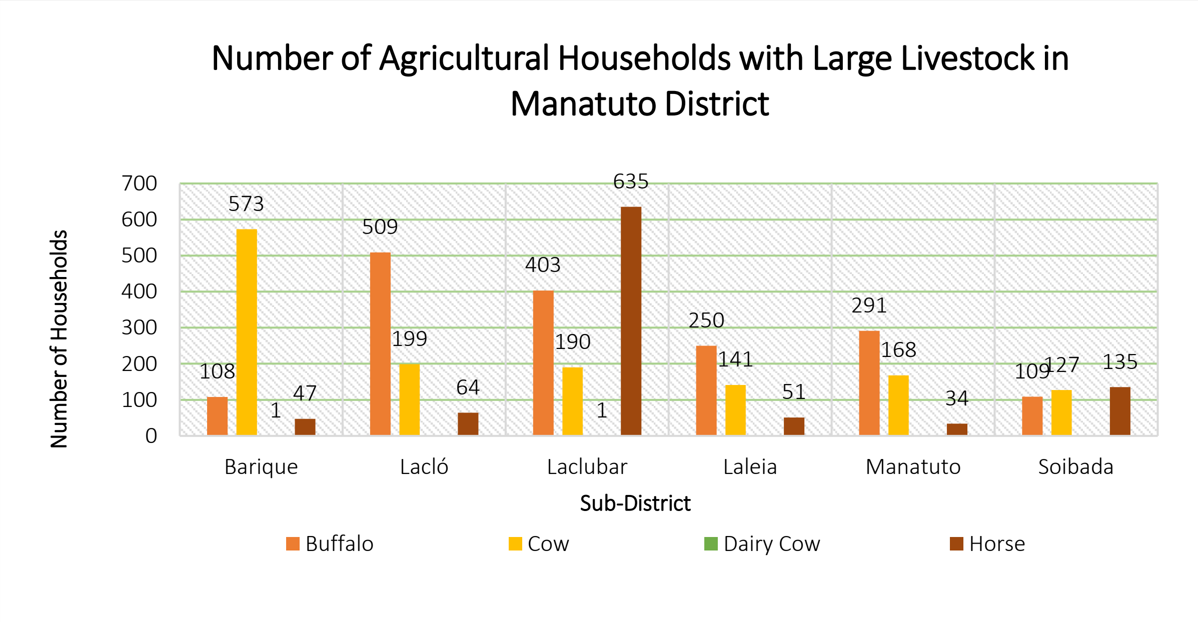


Figure 9.2 Number of Agricultural Households with Large Livestock
(Source: Timor-Leste Agriculture Census, 2019)

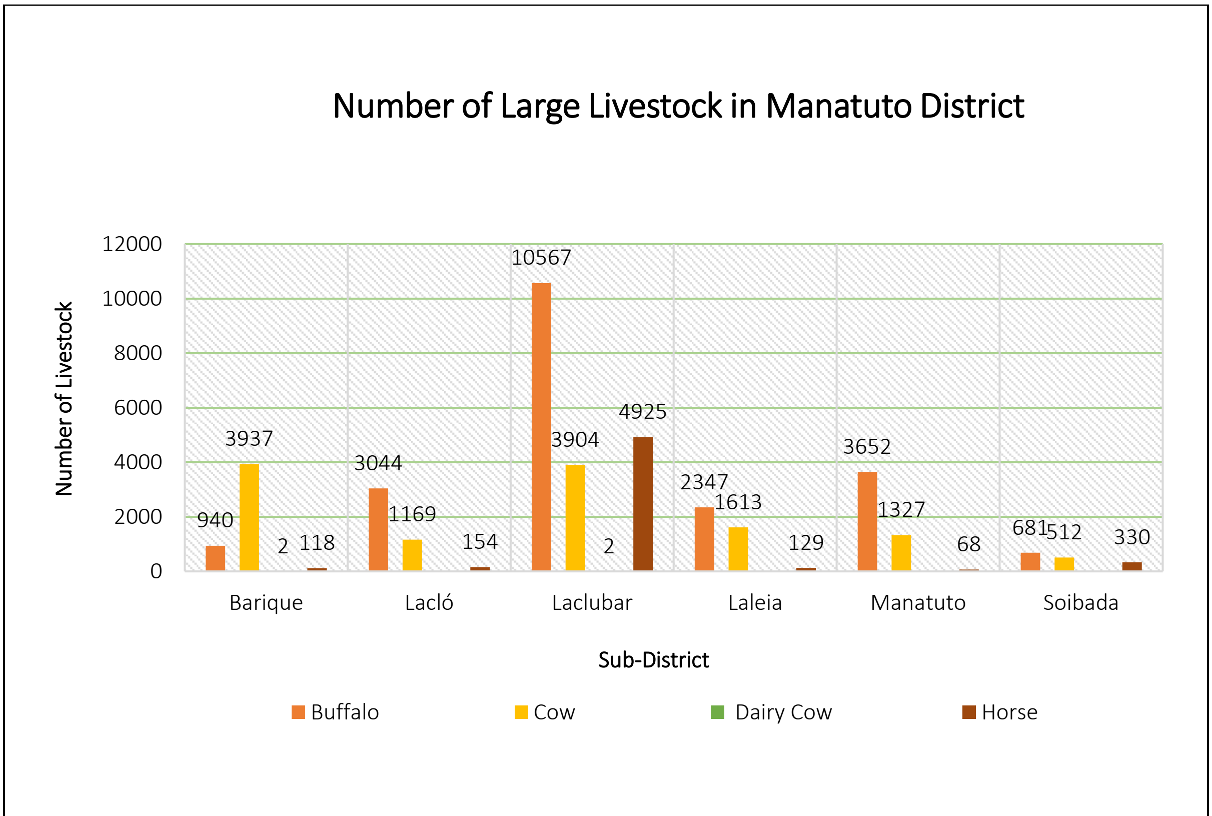


Figure 9.3 Number of Large Livestock
(Source: Timor-Leste Agriculture Census, 2019)

In Manatuto District, pigs are the most commonly kept small livestock. Laclubar Sub-District has the highest number of pig-keeping households, with 1,089 households (25.45%) and a total of 36,766 pigs. In contrast, Soibada Sub-

District has the lowest number of pig-keeping households, with 356 households (8.32%) and a total of 1,753 pigs **(Figures 9.4 and 9.5).**

The number of households keeping goats shows a varied distribution. Laclubar Sub-District has the highest number of goat-keeping households, with 510 households (29.81%) and a total of 12,371 goats, while Barique Sub-District has the fewest goat-keeping households, with 81 households (4.73%) and a population of 463 goats **(Figures 9.4 and 9.5).**

In addition to goats, sheep are also kept, but in relatively small numbers. Manatuto Sub-District has 55 households (53.40%) keeping sheep, the fewest being in Barique, with only 2 sheep-keeping households (1.94%).

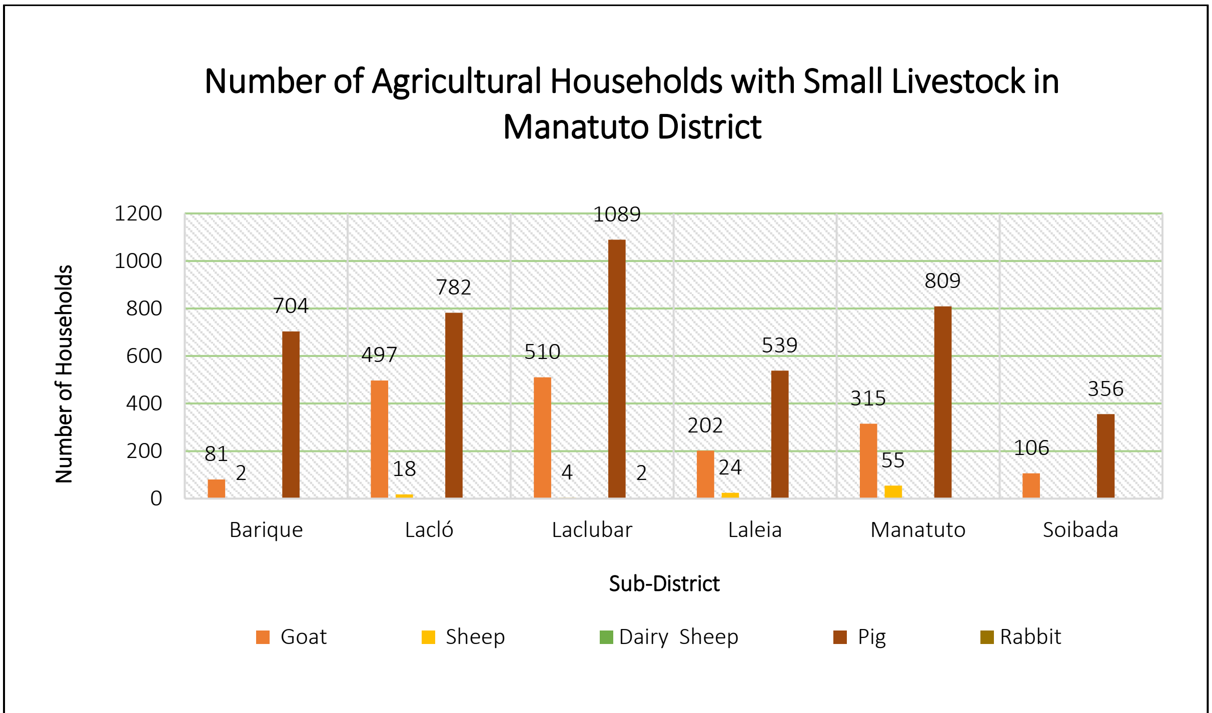


Figure 9.4 Number of Agricultural Households with Small Livestock
(Source: Timor-Leste Agriculture Census, 2019)

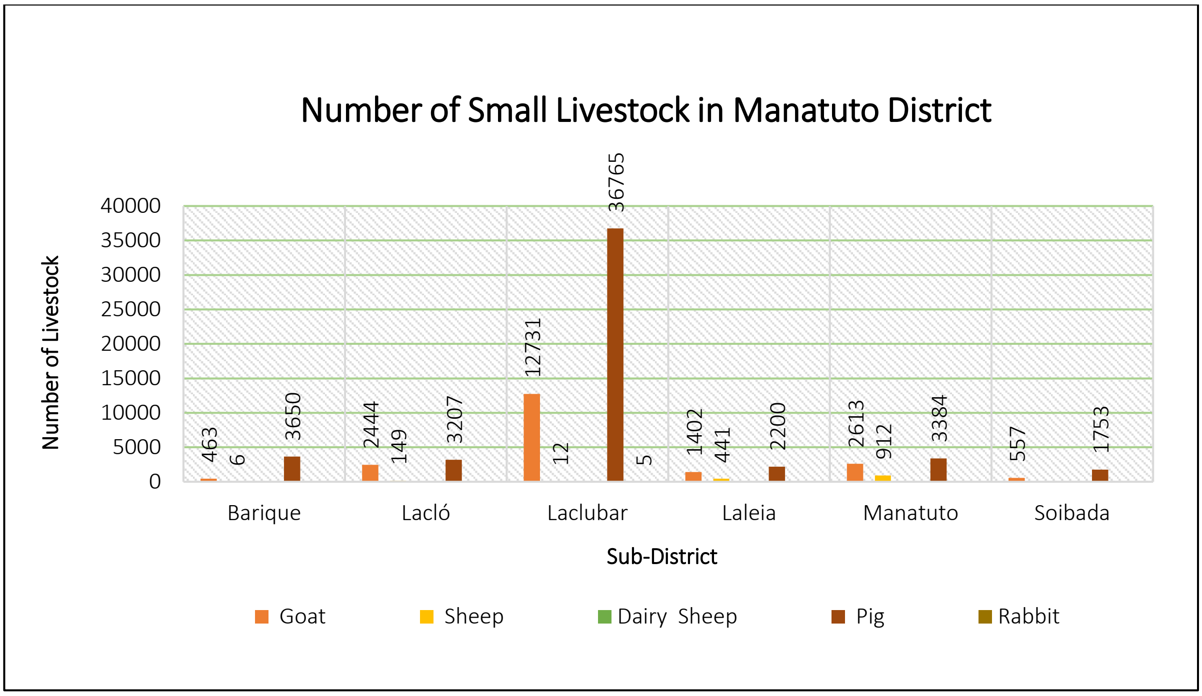


Figure 9.5 Number of Small Livestock
(Source: Timor-Leste Agriculture Census, 2019)

The number of households keeping poultry in Manatuto District shows significant differences between sub-districts, with chickens being the most commonly kept poultry species **(Figure 9.6).** Laclubar Sub-District has the largest number of chicken-keeping households, with 32,330 households (42.90%) and a total of 37,683 chickens. Meanwhile, Soibada Sub-District has the fewest chicken-keeping households, with 378 households (9.54%) and a total of 5,128 chickens **(Figures 9.6 and 9.7).**

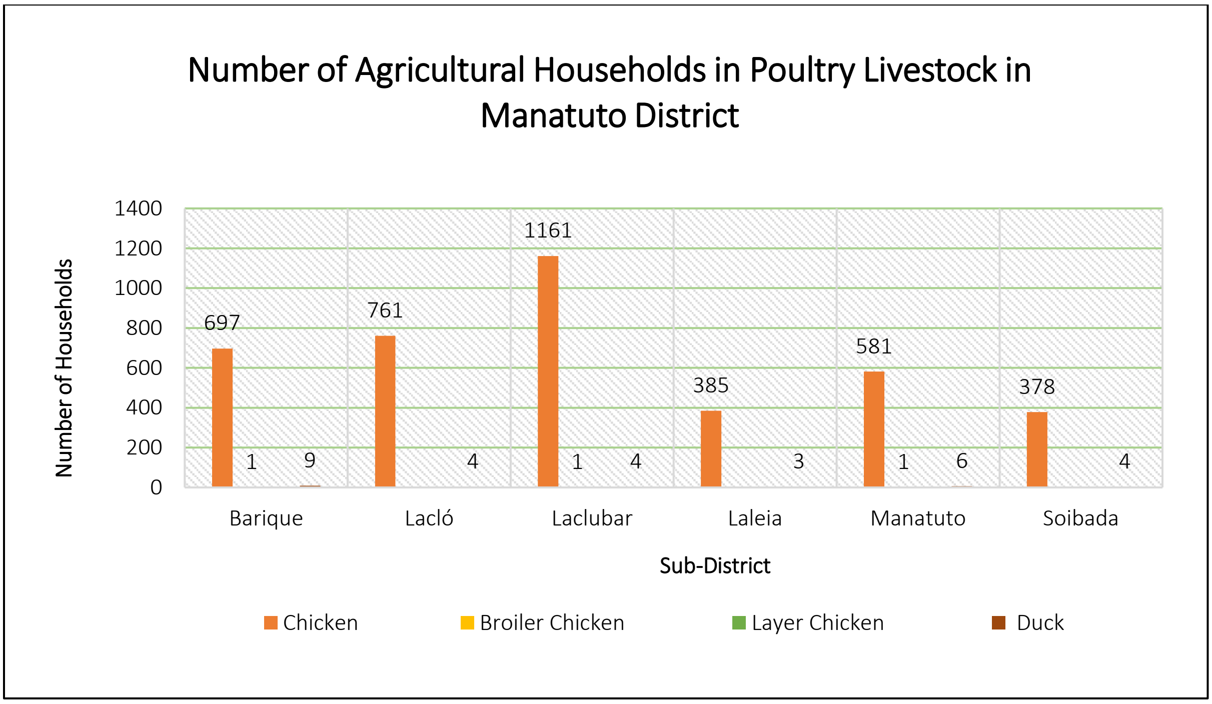


Figure 9.6 Number of Agricultural Households in Poultry Livestock
(Source: Timor-Leste Agriculture Census, 2019)

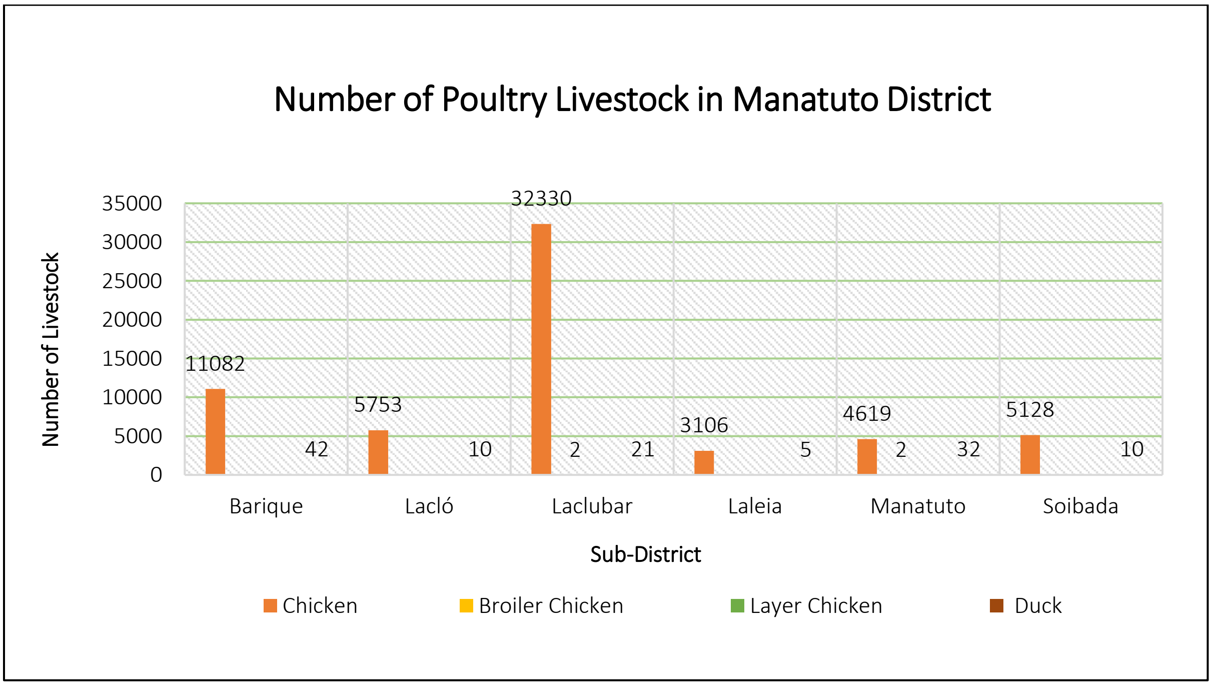


Figure 9.7 Number of Poultry Livestock
(Source: Timor-Leste Agriculture Census, 2019)

Grazing lands are an important asset that can serve as a primary source of livestock feed, especially for animals such as cattle, goats, and sheep, which require high-quality grass to support growth and production in sustainable livestock farming. Manatuto District has two types of grazing land, temporary and permanent grazing fields.

The extent of grazing land in Manatuto District varies across sub-districts. Laclo Sub-District has the largest area of both permanent and temporary grazing fields, with areas of 36.02 ha (91.69%) and 4.01 ha (77.77%), respectively. Based on this data, Laclo Sub-District has a significant advantage in both permanent and temporary grazing land, making it the sub-district with the largest grazing land area compared to others. Barique/Natarbora Sub-District has the second-largest area of both permanent and temporary grazing fields, with areas of 1.51 ha (3.84%) and 1.10 ha (21.35%), respectively. Laleia Sub-District has both permanent and temporary grazing land, with areas of 1.75 ha (4.46%) and 0.01 ha (0.19%), while Laclubar and Manatuto Sub-Districts only have temporary grazing land, with each area being just 0.02 ha. Soibada Sub-District does not have grazing land. The extent of grazing land is presented in **Figure 9.8**.

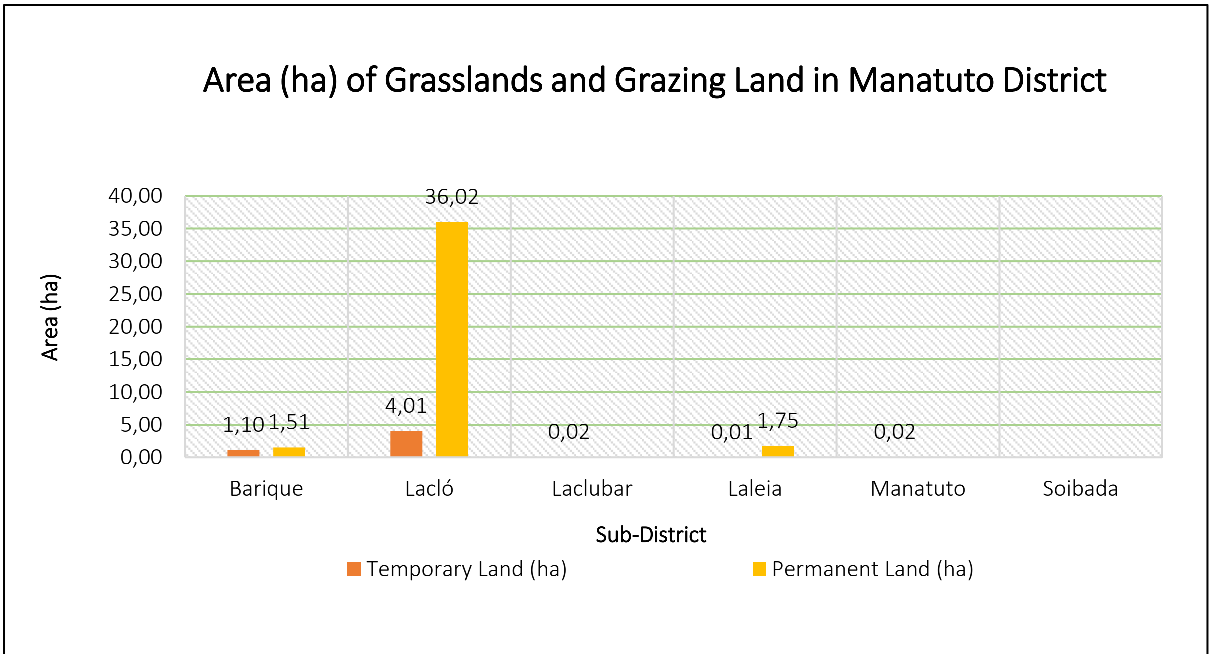


Figure 9.8 Area (ha) of Grasslands and Grazing Land
(Source: Timor-Leste Agriculture Census, 2019)

B. Existing Survey Locations

Observations in Manatuto District were carried out at two locations: the KTS Natarbora Center and Aiteas. The KTS Natarbora Center covers approximately 40 ha and is the most complete KTS center, supporting the maintenance of 10 Timor buffalo (1 male and 9 females). This center is equipped with a permanent housing facility and milking barn, which are not available at other KTS centers in the region. The available livestock forage includes elephant grass, Gamal, and corn, which are suitable for the soil characteristics and capable of achieving maximum productivity. Based on interviews, the animal health services at this center are conducted routinely, including providing vitamins, vaccinations, blood sampling, and physical examinations. The KTS Natarbora Center is managed by skilled human resources and supported by adequate livestock technology. In the future, it is hoped that the addition of quality forage varieties and the integration of livestock technologies will improve efficiency and productivity.

Figure 9.9 Existing Survey Location in Manatuto
(Source: Research Documentation, 2025)

Further observations were made at Aiteas on an 81 ha land owned by Mr. Manuel Soares. This land is developed with a free-range management system that integrates various types of livestock, including bali cattle, buffalo, goats, sheep, and poultry such as pigs and native chickens. The grazing system implemented is open, with an approach that prioritizes natural principles. Support for the development of this land is expected, particularly in terms of livestock farmer training, providing forage cultivation technology, and developing more effective paddock systems.

9.4 DISCUSSION

A. Livestock Forage Land Suitability Evaluation

The land suitability analysis for livestock forage in Manatuto District is a method used to evaluate the compatibility of various forage species and grasses on grazing fields in a specific area. This analysis aims to facilitate the development of livestock feed resources while ensuring their optimal availability. According to Djaenudin *et al.* (2003), land suitability is defined as the degree of appropriateness of land for a particular 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 used a matching method that compares land characteristic and quality data with suitability criteria based on the growth requirements of the evaluated plants. Several types of livestock forage commodities that align with land resource potential, such as elephant grass (*Pennisetum purpureum*), legumes, and field grasses, have been mapped.

The results of the land suitability evaluation in Manatuto District, including Barique/Natarbora, Laclo, Laclubar, Manatuto, and Soibada Sub-Districts, show potential for the development of livestock forage such as elephant grass, *Setaria*, legumes, and grazing fields, as presented in Table 7.3 of this report. The table indicates that grazing land suitability varies from S2 (moderately suitable) to N (not suitable) with limiting factors such as N-total, available K, drainage, rainfall, effective depth, erosion, slope gradient, rock outcrops, and surface rocks. Additionally, flooding is a limiting factor for *Setaria* and dry periods for grazing. These factors can still be improved technically, including adding NPK fertilizer, organic material, creating drainage channels, making planting holes, planting cover crops, and terracing with supporting plants. For the flooding limiting factor, embankments can be built, and for the dry period limiting factor, planting can be scheduled according to the rainy season. However, surface rocks and rock outcrops cannot be improved as they are permanent limiting factors.

The KTS Center (Karau Timor Susubeen) Barique/Natarbora and Manatuto, as the observation and survey areas, have land potential for livestock forage, including elephant grass, *Setaria*, and grazing areas, with a land suitability class of S2. Limiting factors include soil fertility, such as pH, N-total, P-total, and K-total. Technical improvements can be made through fertilizer management and organic material management, such as using organic fertilizers, which can increase land suitability to S1. Based on observations, the KTS Natarbora Center has been planted with forage crops, including *Lamtoro*, elephant grass, and *Gamal*, for the Timor buffalo. This area has vast land that has great potential for livestock forage production as well as other food commodities. The diversification between livestock forage and food commodities offers additional benefits in environmental, social, and economic sustainability. It is expected that land productivity will increase as the diversification of outputs grows, impacting the sustainable availability of both food and forage.

In efforts to enhance livestock development locations, particularly in the development of livestock forage (HPT) in Timor-Leste, several important steps should be taken to improve both the quantity and quality of forage, including:

1. **Planting legume forage species**

Planting legumes is a priority, as legumes typically contain higher nutrients compared to grasses. However, due to the limitations in their use, attention should be given to the proportion of legumes in the forage composition. As a reference, Susetyo (1980) recommends that the ideal composition of grazing fields consist of 60% grass and 40% legumes. Furthermore, according to Skerman (1977), legumes also play a role in combating erosion, even more effectively than forests, due to their strong and deep root systems.

2. **Increasing forage species diversity, both legumes and grasses**

Increasing the diversity of forage species, both legumes and grasses, is an important aspect of livestock feed development. The more diverse the species consumed by livestock, particularly ruminants, the more likely the nutritional needs will be met comprehensively. Some high-nutrient legume species with potential for development include *Indigofera*, *Kaliandra*, *Turi*, and *Stylo*. Local legume species commonly found include *Lamtoro Taramba*. It should be noted that *Lamtoro* should be given carefully to pregnant livestock. Although it has high nutritional content, *Lamtoro* leaves contain anti-nutritional substances such as mimosine and cyanide acid, which are toxic if consumed in excess. This can be mitigated by providing moderate amounts of *Lamtoro*, mixed with other feed, and ensuring that it is given in a dried form (air-dried), which reduces the anti-nutrient content.

B. Potential and Ecological Suitability for Livestock

Manatuto District has a total area of 137,509.98 ha, with 105,027.27 ha designated for livestock sector development. Optimizing this potential requires the empowerment of human resources and effective utilization of available land. A key factor in determining a region's potential for livestock development is its ecological suitability or environmental conditions. Areas that do not meet ecological suitability criteria are categorized as less suitable for livestock development. Therefore, livestock farming in Manatuto District must consider ecological suitability factors.

After measurements for each parameter in the field, including geophysical parameters such as rainfall, temperature, and chemical soil parameters such as soil organic carbon, total K, available K, CEC, and base saturation, the data was analyzed using a Geographic Information System (GIS) application to determine the ecological suitability for five types of livestock: sheep, beef cattle, dairy cattle, pigs, and buffalo. The ecological suitability map for livestock in Manatuto District is shown in **Figure 9.10.**

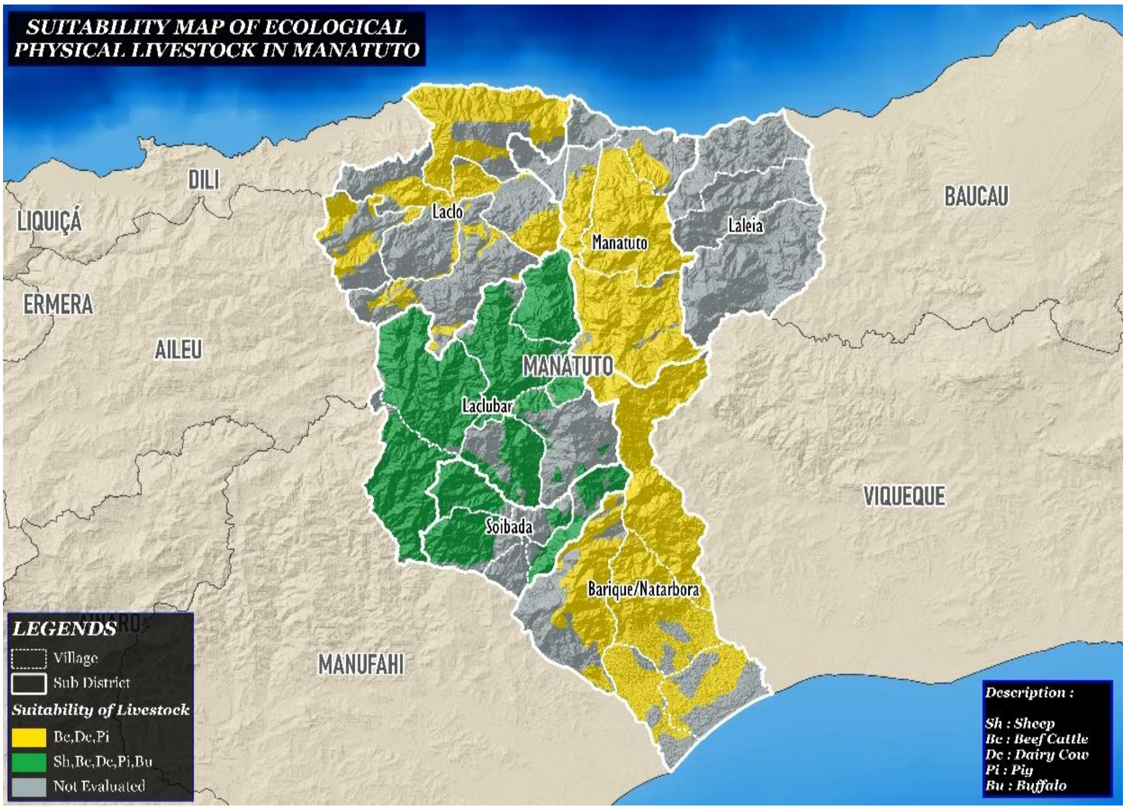


Figure 9.10 Ecological Suitability Map for Livestock in Manatuto District
(Source: Timor-Leste Agriculture Census, 2019)

The available land for livestock development in Manatuto District includes mixed gardens and grazing lands. These lands are considered available because they are assumed to be able to produce forage crops such as grass and legumes or crop residues. Lands categorized as not available for livestock development include forests and rice fields. Technically, these issues can be addressed through proper housing systems with good ventilation and air circulation. However, for dairy cattle, temperature is a critical factor that must be met in their cultivation.

Table 9.1 Area for Livestock Development in Manatuto District

Sub-District	Livestock Development Suitability Results for Large Livestock					Area (ha)
	Sheep	Beef Cattle	Dairy Cattle	Pig	Buffalo	
Barique/Natarbora	N	S	S	S	N	29.773,51
Laclo	N	S	S	S	N	15.833,19
Laclubar	S	S	S	S	S	30.515,29
Manatuto	N	S	S	S	N	20.229,70
Soibada	S	S	S	S	S	8.675,58

Based on the data analysis presented in **Table 9.1**, the ecological suitability of land for the development of large livestock, including sheep, beef cattle, dairy cattle, pigs, and buffalo, shows spatial distribution variations across the study area. Laclubar Sub-District is the most dominant region for large livestock development in Manatuto District, followed by Barique/Natarbora, Manatuto, and Laclo. Meanwhile, Soibada Sub-District occupies the smallest area for livestock development. Laclubar and Soibada Sub-Districts are suitable for the development of sheep, beef cattle, dairy cattle, pigs, and buffalo. Livestock development in Barique/Natarbora, Laclo, and Manatuto Sub-Districts is suitable for beef cattle, dairy cattle, and pigs but not suitable for sheep and buffalo due to limiting factors such as temperature and rainfall.

The ecological suitability of land for poultry in the study area shows very high and uniform suitability, with a 100% coverage. This reflects the biological characteristics of poultry, which have a broad ability to adapt to various environmental conditions, enabling poultry farming in almost all types of available land.

To support the livestock sector development program, identification and mapping of areas primarily used for livestock farming and forage cultivation are necessary. It is known that Manatuto District has an average environmental temperature of 24.24°C and annual rainfall of 1,573.78 mm/year, providing an ecological potential conducive to optimal livestock farming. This condition also supports the sustainable availability of livestock forage throughout the year. Environmental temperature plays a central role in determining thermal comfort and livestock productivity. Extremely low temperatures can cause cold stress in livestock, leading to increased heat production and basal metabolic rate. If this condition persists without adequate feed support, the livestock's metabolic energy will decrease, reducing its resistance to extreme temperatures. This will affect livestock growth, productivity, and significantly increase the risk of disease.

On the other hand, excessively high environmental temperatures cause livestock to reduce feed consumption and increase water intake. This decrease in nutrient intake directly impacts livestock performance. Therefore, optimal environmental management, especially temperature and humidity regulation, is essential for sustainable livestock farming systems. This effort aims to create conditions that support the physiological balance of livestock, ensuring maximum productivity.

C. Socio-Economic Aspects of Livestock Farming

For the people of Manatuto District, livestock plays a vital and multifunctional role, far exceeding its value as a mere food source. Livestock is an integral part of the subsistence farming system and the developing civilization. It is still common for communities to use livestock such as cattle, buffalo, and horses as draft animals for plowing rice fields and gardens. The use of draft animals allows farmers to cultivate larger areas and significantly improve agricultural productivity. Moreover, in some cultures, livestock holds social, economic, or ritual significance. For example, in some traditions, livestock is used as a dowry or offering in ceremonial events. Furthermore, the number of livestock owned by an individual is often seen as a measure of wealth and social status within the community.

One of the endemic livestock species in Timor-Leste is the Timor buffalo (*karaw timor*). The Timor buffalo holds an important role in the social life of Timor-Leste's communities, especially as offerings in death, birth, and marriage ceremonies. The Timor buffalo is also used in traditional transactions such as land sales, its manure is used as fertilizer, and the milk is consumed as an animal protein source. Therefore, the Timor buffalo is considered valuable and expensive.

Timor buffalo milk has been consumed by the community for generations and is a popular alternative to cow and goat milk. It is thicker and has a distinctive odor compared to cow milk. In the past, the community consumed Timor buffalo milk directly without further processing, making it an important part of the cultural identity.

Livestock farming is generally still practiced using a traditional extensive grazing system. According to Williamson and Payne (1993), in the extensive management system, livestock are kept freely and graze on available forage. In this system, livestock are released with a mix of males and several females in one population. The main characteristic of extensive management is the absence of shelters and supplemental feeding (Jamili, M.A., 2022). The advantages of the extensive system are its low labor requirements, short working hours, and the ability of livestock to find food in grazing fields and former agricultural land. However, the drawbacks include difficulty in controlling the nutritional intake of livestock and the susceptibility of livestock to diseases and death. Unsupervised livestock can also lead to social issues, such as theft and damage to farmers' crops caused by roaming animals.

The livestock farming model still relies on traditional knowledge passed down through generations. The lack of large-scale livestock industries has resulted in suboptimal livestock production, with many aspects needing improvement. Livestock distribution in the community remains low due to limited capital and the lack of breeding practices. This is because increasing the livestock population requires significant costs and time. As a result, livestock is not used as a primary income source, leading to low livestock production in the area (Serey *et al.,* 2014).

Interviews revealed that the community received cattle and buffalo assistance in 2014 from MAPPF. However, over time, due to low supervision and insufficient education, the assistance has not grown as initially intended. The community used the livestock assistance for household needs or as a dowry. Consequently, attention to the sustainability of livestock breeding has been neglected, which may hinder long-term development.

Other challenges in livestock farming are complex, ranging from upstream to downstream issues, as well as the need for better infrastructure. In terms of breeding, the community still practices natural breeding without adopting modern artificial insemination (AI) technology, making sustainable livestock breeding difficult. Furthermore, the community has limited knowledge of effective livestock management and has not been educated about good feed practices for productivity. Additionally, farmers only sell live livestock, making it difficult to increase livestock prices. Although access from Dili to other districts has improved, many areas still lack adequate road infrastructure. This remains a barrier for farmers in marketing their livestock products.

Given the numerous challenges from pre-production to post-production, attention is needed to address these issues and establish a foundation for designing a livestock development master plan. Recommendations for improvement could start with educating the community on breeding and introducing artificial insemination technology. Additionally, livestock management education is essential to motivate the community to view livestock farming as an economic activity rather than just a household savings tool. The government should not only educate but also provide financial support through credit loans to facilitate the development of livestock businesses. Improving the sales value of livestock products can be achieved by educating and opening new marketing channels beyond just selling live animals.

X. FRESHWATER FISHERIES POTENTIAL

10.1 INTRODUCTION

Timor-Leste is a tropical archipelagic country with significant potential for the development of the aquaculture sector, including brackish and freshwater systems. The development of aquaculture based on local potential has become a key strategy in supporting food security, improving community income, and fostering national economic growth. One area with great potential for aquaculture development is Manatuto District, located in the central part of Timor Island, bordering the Timor Sea to the north.

Manatuto District has a unique geographical characteristic, with a landscape consisting of coastal plains, hills, and dry inland areas. The district features a long coastline and several seasonal river streams, which can be utilized for freshwater aquaculture. With a predominance of dry climate and irregular rainfall throughout the year, the people of Manatuto largely depend on dryland agriculture and traditional fisheries for their livelihood. However, limited access to stable water sources and the use of simple aquaculture technologies present significant challenges to optimizing the aquaculture potential in this region.

Developing pond-based aquaculture has emerged as a promising strategy for Manatuto to improve local food security, create alternative employment opportunities, and reduce pressure on coastal natural resources. In addition to alleviating poverty, the aquaculture sector also plays a strategic role in supporting the achievement of the Sustainable Development Goals (SDGs), such as SDG 1 (No Poverty), SDG 2 (Zero Hunger), and SDG 8 (Decent Work and Economic Growth).

Although aquaculture production in Manatuto remains relatively low, its development potential is substantial if supported by the selection of suitable locations, the application of efficient aquaculture technologies, and adaptive resource management that aligns with local conditions. One key approach to supporting the success of aquaculture is through land suitability evaluation, which considers biophysical factors such as topography, soil properties, water quality, and local climatic conditions.

Topography is an important factor in planning pond locations as it influences water flow and the risk of erosion. Physical and chemical soil properties, such as pH, organic matter content, and clay proportion, determine the soil's capacity to retain water and support the growth of cultured organisms. Water quality is another critical parameter in determining the feasibility of aquaculture. Factors such as temperature, salinity, total dissolved solids (TDS), pH, dissolved oxygen (DO), and ammonia are crucial in influencing the health and growth of aquaculture organisms. Climatic factors, such as rainfall and long dry seasons, must also be considered as they affect water availability and pond management.

The land suitability evaluation in Manatuto is conducted using a multidisciplinary approach, which includes laboratory soil tests, field water quality measurements, and analysis of local climate conditions. Each parameter is evaluated and weighted according to its impact on aquaculture success, resulting in a comprehensive assessment of location suitability. The study focuses exclusively on freshwater aquaculture, particularly on aquaculture activities carried out by communities in lowland and coastal areas. The findings of this study are expected to serve as a technical reference for selecting pond sites, designing aquaculture systems, and implementing adaptive and sustainable aquaculture practices.

This approach, which integrates both ecological and technical aspects, not only addresses the practical needs of aquaculturists in Manatuto District but also contributes to the achievement of the Sustainable Development Goals (SDGs), particularly in enhancing food security, creating decent jobs, and promoting inclusive economic growth. At the same time, it supports the development of more inclusive, resilient, and sustainable regions.

By integrating both ecological and technical scopes, this research not only responds to the practical needs of aquaculture practitioners in Manatuto District but also makes a significant contribution to achieving the Sustainable Development Goals (SDGs), particularly in ensuring food security (SDG 2), decent work and responsible economic growth (SDG 8), and the conservation of terrestrial ecosystems (SDG 15).

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.**

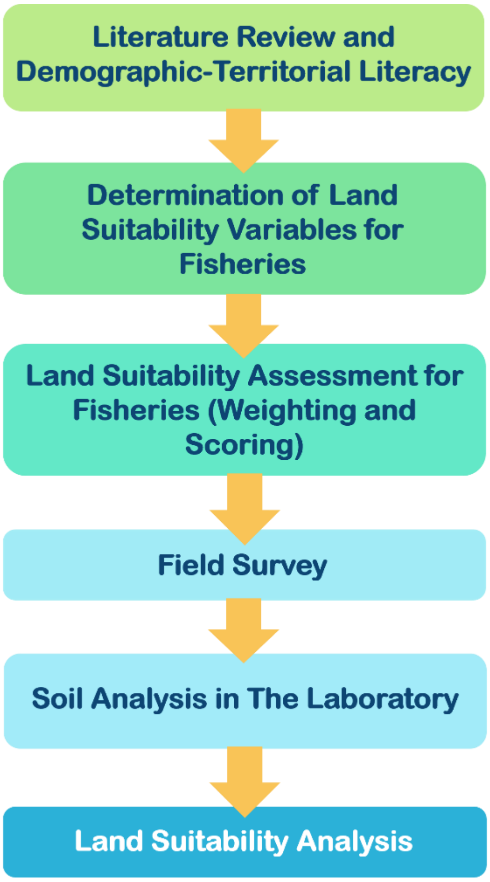


Figure 10.1 Flowchart of the Research Process for Land Suitability in the Aquaculture Sector

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.,* 2007; 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/ Climatology	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 / pH-meter	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 NH3 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 shown in **Table 10.3** below.

Table 10.3 Land Suitability for Pond Aquaculture Parameter

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	
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	4 (Highly Suitable)
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 by Area in Manatuto District

No.	Schedule	Sub-District	Village	Purpose (Ownership)
1	11 May 2025	Laclo	Lacumesak	Business (Individual)
2	11 May 2025	Manatuto	Ma`Abat	Business (Individual)
3	12 May 2025	Barique/Natarbora	Aubeon	Business (Group)

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

A. Capture Fisheries

According to the official report from the Ministry of Agriculture and Fisheries of Timor-Leste, the fisheries sector in Manatuto District shows promising development prospects, particularly in optimizing the utilization of both coastal and inland water resources. Government interventions through capacity-building programs, such as technical training for fishermen, the provision of sustainable fishing gear, and the development of supporting infrastructure, including fish landing facilities and cold chain systems, have contributed to improved efficiency and production in the fisheries sector. In addition, active participation from local communities and collaboration with various stakeholders have strengthened efforts for integrated and sustainable sector development.

1. Number of Fishing Households

Based on **Figures 10.2** and **10.3**, which illustrate the distribution of the number and percentage of registered fishing households across each Sub-District in Manatuto District, it is apparent that fishing activities are highly concentrated in certain areas. Manatuto Sub-District records the highest number of fishing households, with 127 households (42.33% of the total), followed by Lacló with 106 households (35.33%), and Laleia with 46 households (15.33%). Other Sub-Districts, such as Barique/Natarbora and Laclubar, have much fewer households, recording only 20 (6.67%) and 1 (0.33%) fishing households, respectively. Soibada Sub-District, on the other hand, has no registered fishing households (0%).

This uneven distribution suggests a concentration of fishing activities in specific coastal areas, most likely influenced by geographical factors such as proximity to the coastline, availability of water resources, and infrastructure and access to fisheries facilities. In contrast, more remote areas or those lacking direct access to marine resources show very low or no fishing household presence. Thus, this data provides valuable insight into the distribution patterns of fishing households in Manatuto District, which can serve as a foundation for more equitable and sustainable planning for the maritime and fisheries sector.

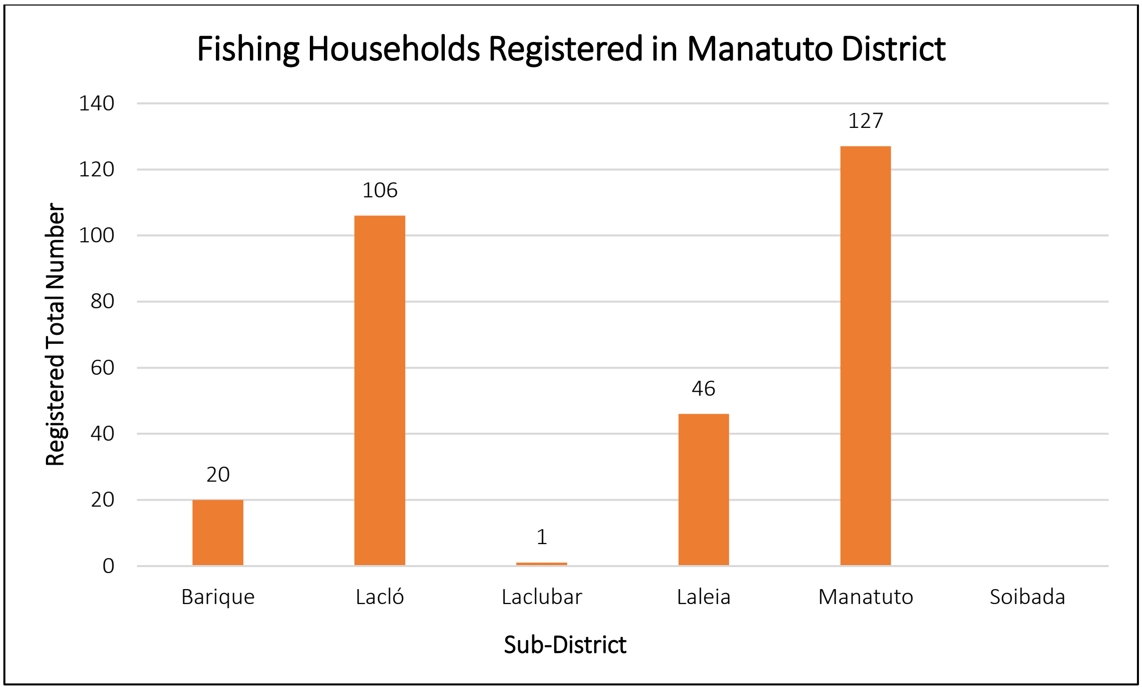


Figure 10.2 Fishing Households in Manatuto District
(Source: Timor-Leste Agriculture Census, 2019)

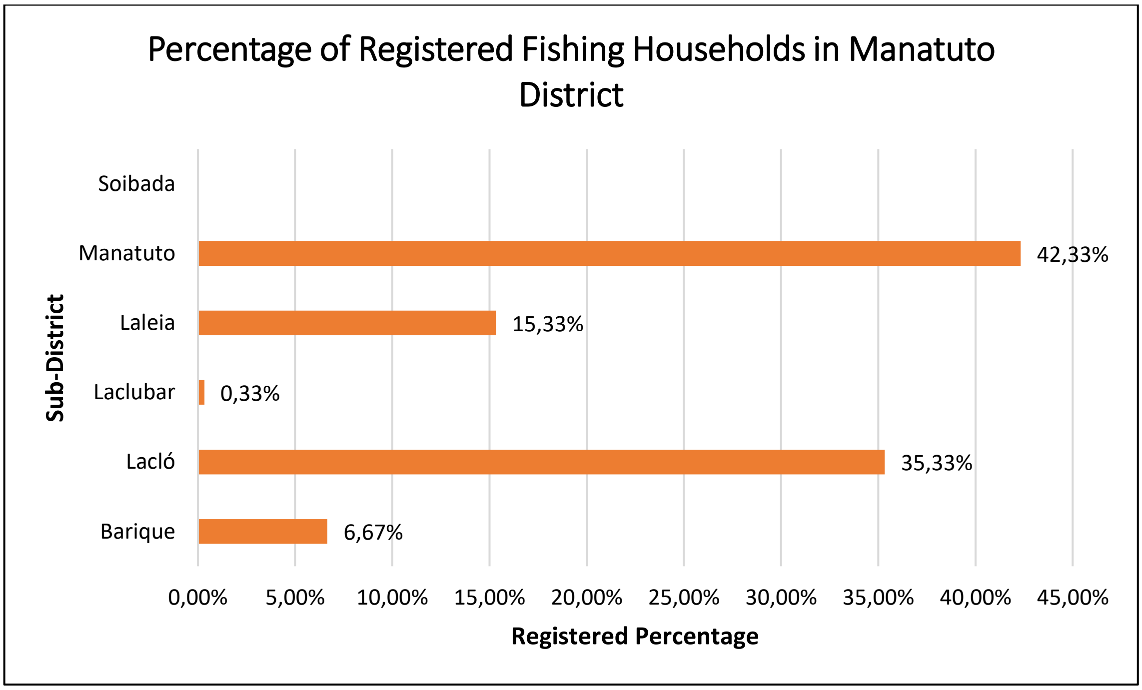


Figure 10.3 Percentage of Fishing Households in Manatuto District
(Source: Timor-Leste Agriculture Census, 2019)

2. Households Involved in Fishing Activities

Figures 10.4 and **10.5** present data on household involvement in fish capture activities in Manatuto District based on the primary purpose of their involvement, both in total numbers and percentages. The three activity categories observed include: (1) consumption and social obligations, (2) consumption and occasional sales, and (3) direct sales.

As seen in Figure 10.4, the majority of households involved in fish capture activities are located in Manatuto Sub-District, with the highest participation recorded in the "consumption and occasional sales" category, comprising 105 households, followed by Lacló with 98 households in the same category. Laleia ranks third with significant participation in all categories, particularly "consumption and occasional sales" with 32 households. Meanwhile, Laclubar and Barique/Natarbora show very low participation, with Laclubar recording only two households, and no households involved in direct fish sales.

Figure 10.5 shows the participation proportions in percentages. Manatuto Sub-District has a relatively balanced distribution, with the highest percentage in the "consumption and occasional sales" category (42.51%), followed by "direct sales" (40.91%) and "consumption and social obligations" (36%). Lacló also dominates the "consumption and occasional sales" category (39.68%), but with lower participation in direct sales (22.73%). Laleia shows a fairly balanced participation, with 24% for consumption and social obligations and 25% for direct sales. Barique/Natarbora and Laclubar show much lower participation compared to other Sub-Districts.

Overall, the data indicates that most fishing households in Manatuto District not only use their catch for personal or social consumption but also engage in economic activities through sales, both occasionally and directly. The high percentage of direct sales in certain Sub-Districts like Manatuto and Laleia indicates a potential local market or good access to fish distribution channels. The differences across Sub-Districts highlight the importance of region-based policies for developing the fisheries sector, considering household participation levels and catch utilization patterns.

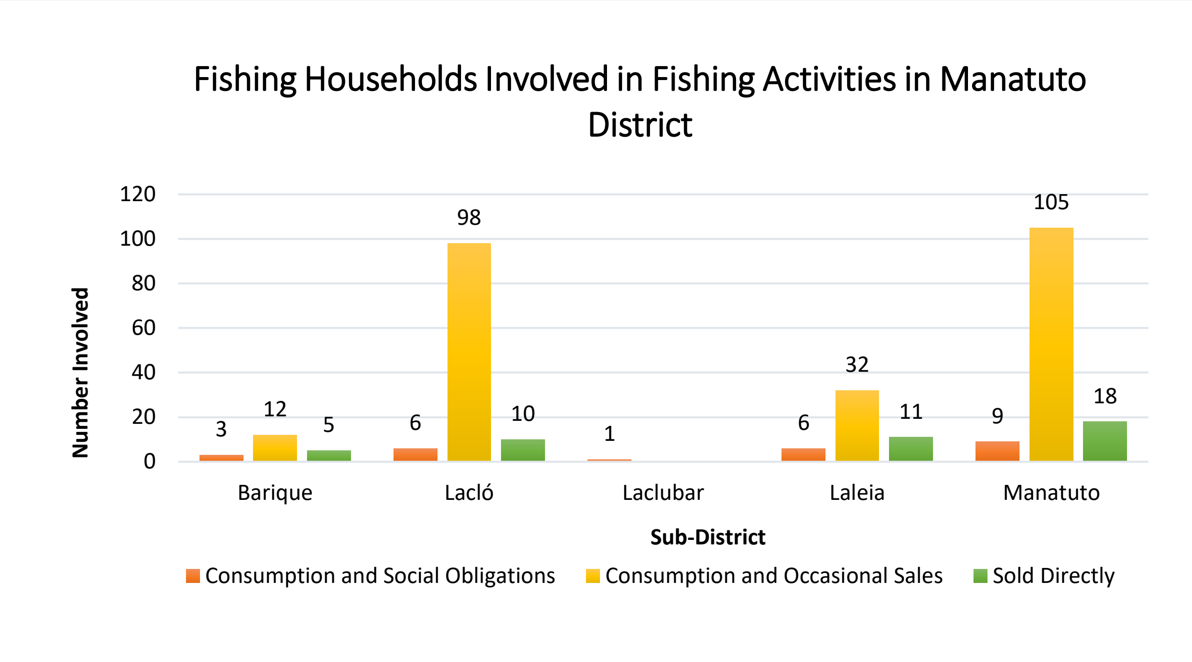


Figure 10.4 Number of Households Involved in Fishing Activities
(Source: Timor-Leste Agriculture Census, 2019)

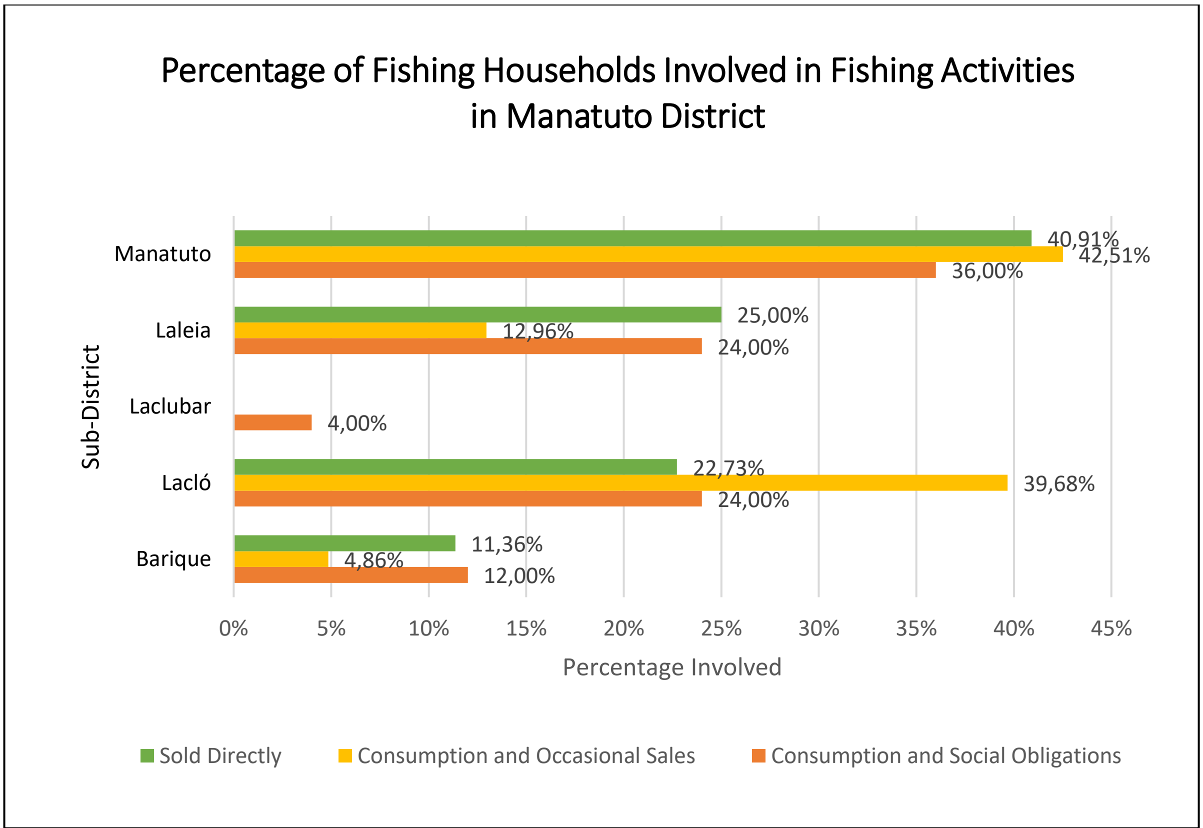


Figure 10.5 Number of Households Involved in Fishing Activities
(Source: Timor-Leste Agriculture Census, 2019)

B. Aquaculture

The aquaculture sector in Manatuto District shows strategic potential for sustainable development, given the district's geographical characteristics, including a long coastline and the availability of inland and coastal water resources that support aquaculture activities. According to data from the Directorate of Fisheries, Aquaculture, and Marine Resource Management (2022), the consumption of aquaculture fish in this region remains low, although there has been a stable upward trend in recent years. In 2019, consumption was recorded at 0.35 kg per capita per year, with a marginal increase to 0.37 kg per capita per year in 2020, and projections suggest it will remain around this level until 2023.

This low consumption rate is closely linked to limitations in aquaculture infrastructure and the uneven distribution of aquaculture products across the district, especially in areas without direct access to coastal regions, such as Laclubar and Soibada. Conversely, Sub-Districts like Manatuto and Lacló, which have direct connectivity to the coastal areas, show greater capacity for aquaculture development. Therefore, through an integrated approach that strengthens technical capacity, provides aquaculture infrastructure, and supports region-based policies, aquaculture development in Manatuto District has the potential to play an important role in improving protein-based food security from fish and contributing to the economic welfare of local fishing households.

1. Proportion of Land for Aquaculture

Figures 10.6 and **10.7** show data regarding the distribution of aquaculture land in Manatuto District, both in hectares (ha) and as a percentage of total available aquaculture land. Quantitatively (**Figure 10.6**), Soibada Sub-District has the largest area of aquaculture land, with 2.105 ha, followed by Manatuto (2.095 ha) and Lacló (2.051 ha). Meanwhile, Barique/Natarbora and Laleia have very limited land, with only 0.19 ha and 0.04 ha, respectively. No aquaculture land was recorded in Laclubar Sub-District. From a percentage perspective (**Figure 10.7**), the three Sub-Districts that dominate the total aquaculture land in the district are Soibada (32.48%), Manatuto (32.33%), and Lacló (31.65%). Collectively, these three Sub-Districts account for over 96% of the total aquaculture land available. In contrast, Barique/Natarbora contributes only 2.93%, Laleia 0.62%, and Laclubar contributes 0.00%.

This uneven distribution reflects disparities in aquaculture development potential across the Sub-Districts of Manatuto. Sub-Districts with more strategic geographic access and supporting infrastructure appear better positioned to support aquaculture activities. Conversely, land limitations in other areas highlight the need for localized development strategies that consider physical, social, and spatial policy conditions to promote more equitable utilization of water resources, supporting food security and local economic development.

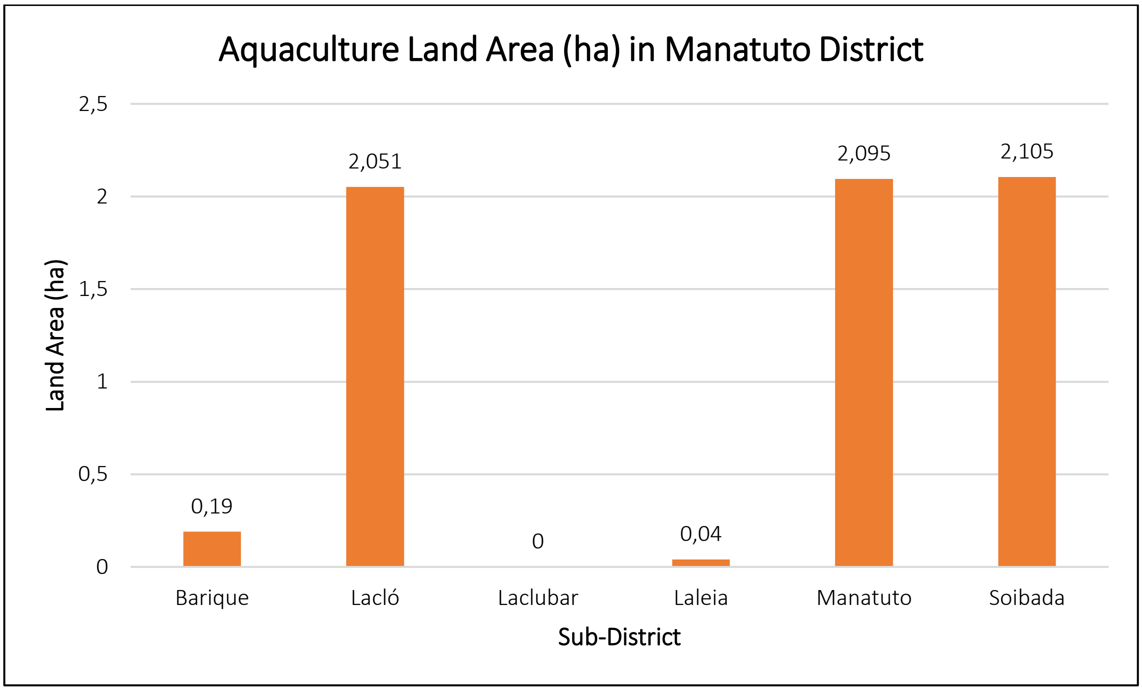


Figure 10.6 Aquaculture Land Area in Manatuto District
(Source: Timor-Leste Agriculture Census, 2019)

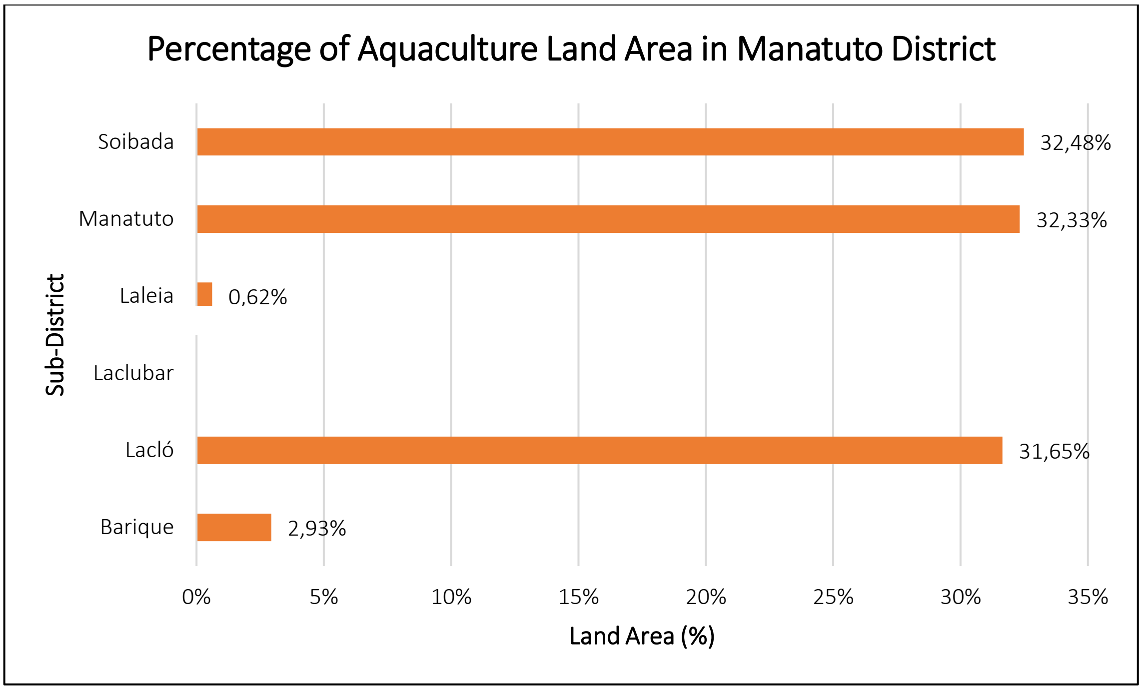


Figure 10.7 Percentage of Aquaculture Land in Manatuto District
(Source: Timor-Leste Agriculture Census, 2019)

2. Aquaculture Households

Figures 10.8 and **10.9** provide an overview of the number and percentage distribution of households involved in aquaculture activities in Manatuto District. According to **Figure 10.8**, the highest number of aquaculture households is recorded in Lacló, with 23 households, followed by Soibada and Barique, with 17 households each. Meanwhile, Manatuto and Laclubar have lower numbers of aquaculture households, with 8 and 7 households, respectively, and Laleia has the lowest number, with only 2 households actively engaged in aquaculture.

In terms of percentages (**Figure 10.9**), Lacló dominates with a contribution of 31.08% of the total aquaculture households in Manatuto District, followed by Soibada and Barique/Natarbora, each contributing 22.97%. Laclubar and Manatuto contribute smaller percentages of 9.46% and 10.81%, while Laleia has the lowest participation rate at 2.70%.

The differences in the number and proportion of aquaculture households reflect variations in the level of adoption of aquaculture activities in each Sub-District, likely influenced by the availability of water resources, access to production infrastructure, and the level of technical assistance and the adoption of aquaculture-related technologies and information. The dominance of Lacló, Soibada, and Barique/Natarbora indicates that these areas have more social and ecological capacity to support aquaculture activities. On the other hand, the low participation in Laleia and Laclubar suggests the need for policy interventions to encourage the development and participation of households in this sector, ultimately improving aquaculture production and supporting food security and rural community welfare.

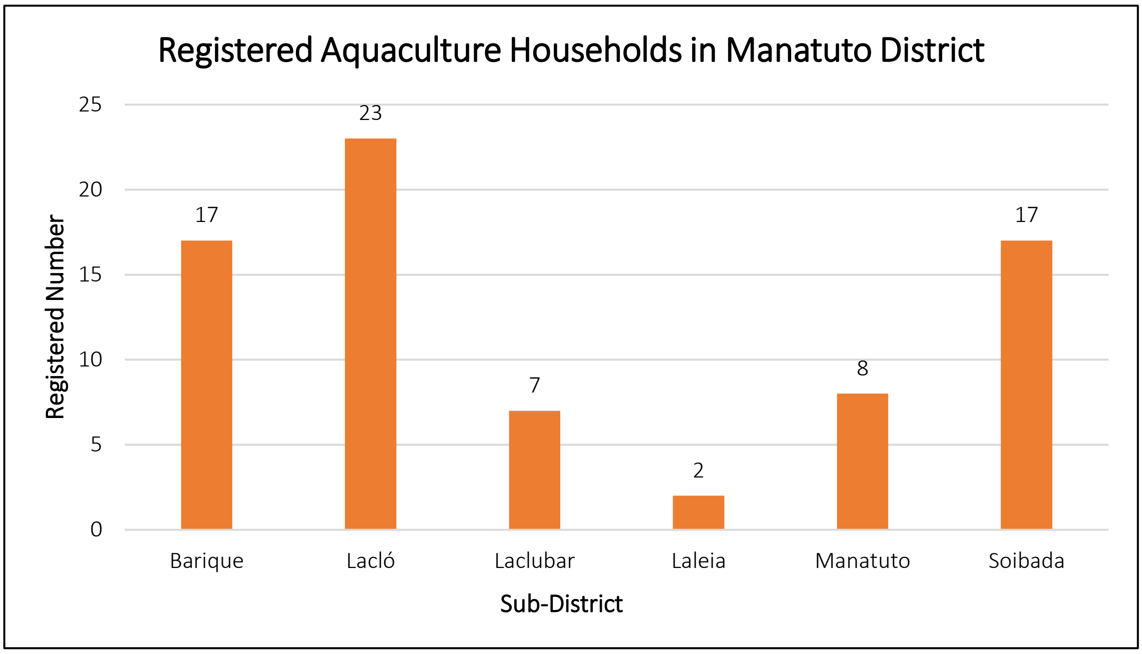


Figure 10.8 Aquaculture Households in Manatuto District
(Source: Timor-Leste Agriculture Census, 2019)

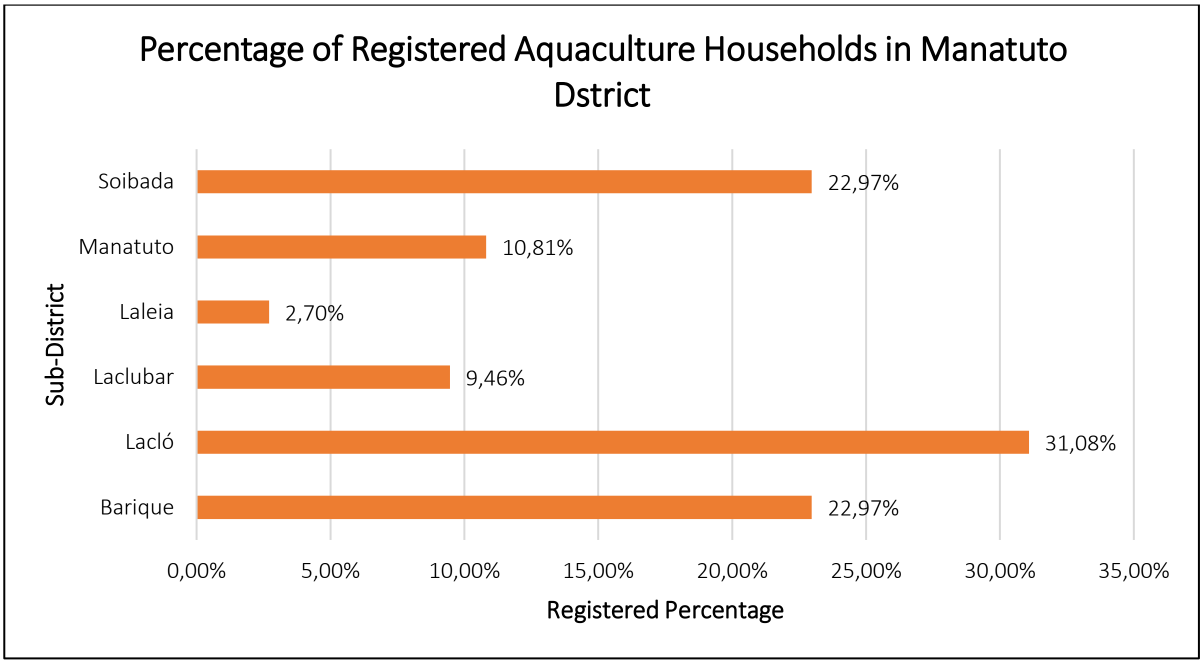


Figure 10.9 Percentage of Aquaculture Households in Manatuto District
(Source: Timor-Leste Agriculture Census, 2019)

3. Aquaculture Systems

Manatuto District demonstrates diversity in the implementation of aquaculture systems, which can be observed through the distribution of aquaculture units across its six administrative regions: Barique/Natarbora, Lacló, Laclubar, Laleia, Manatuto, and Soibada. According to the data presented (**Figure 10.10**), there are a total of 124 fish pond units spread across the district, with the highest concentration in Soibada (46 units), followed by Laclubar (25 units) and Barique/Natarbora (21 units). Additionally, there are three fish pond units in Barique/Natarbora, Laclubar, and Manatuto, and only one fish cage unit in Barique/Natarbora. The mina padi system is represented by five units, spread across four regions, with Lacló and Manatuto each having two units, and Barique/Natarbora and Laleia one unit each. No fish hatchery units were recorded in Manatuto District.

The percentage contribution of each region to the type of aquaculture system is shown in **Figure 10.11**. Proportionally, Soibada contributes 37.10% of the total fish ponds in Manatuto District, making it the region with the highest intensity of fish ponds. Laclubar follows with 20.16%, and Barique/Natarbora contributes 16.94%. Fish ponds are evenly distributed across the three regions, with each contributing 33.33% of the total. Interestingly, fish cages are only found in Barique, contributing 100%, indicating the exclusivity of this method in the area. In the case of mina padi, Lacló and Manatuto each contribute 40%, while Barique/Natarbora and Laleia contribute 20% and 0%, respectively. Overall, this data shows that fish ponds are the dominant and most widespread aquaculture method across the district, while methods such as fish cages and mina padi remain limited, suggesting potential for further development in diversifying aquaculture systems in Manatuto District.

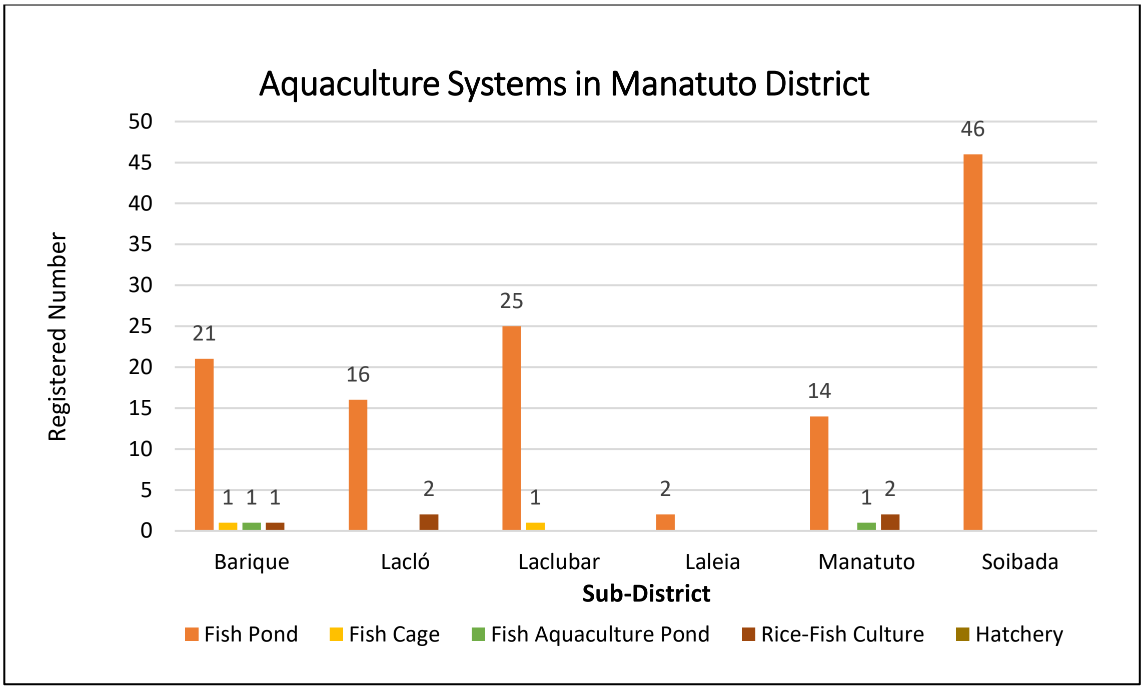


Figure 10.10 Aquaculture Systems in Manatuto District
(Source: Timor-Leste Agriculture Census, 2019)

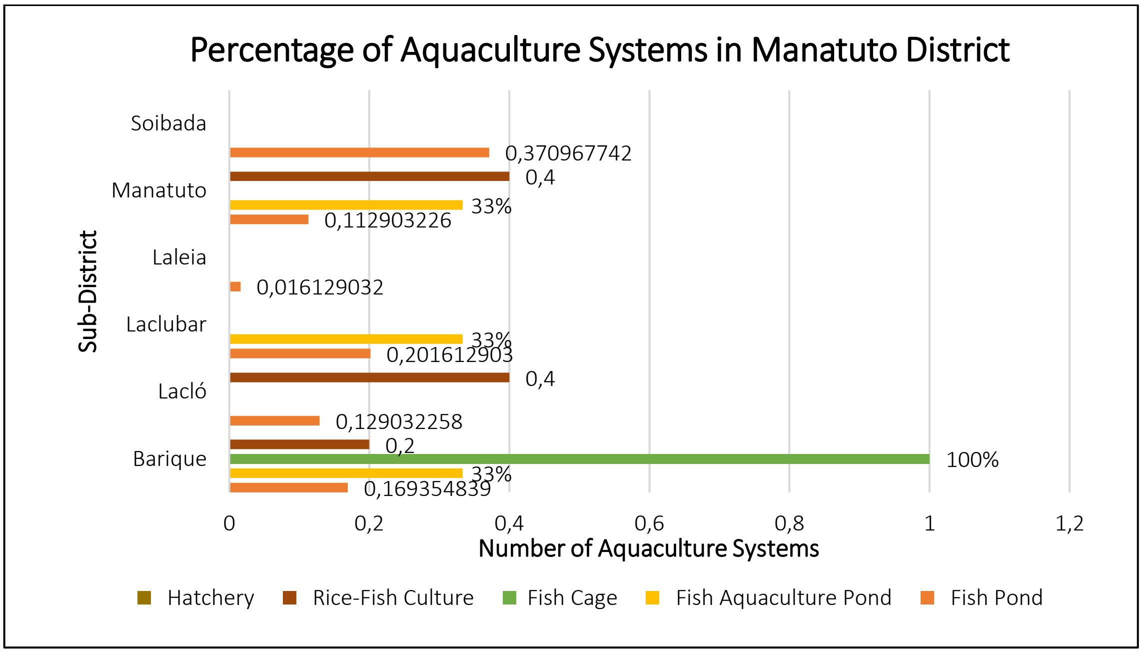


Figure 10.11 Percentage of Aquaculture Systems in Manatuto District
(Source: Timor-Leste Agriculture Census, 2019)

C. Field Observation Results

Manatuto District features a variety of fisheries systems with differing characteristics in each observation site, reflecting both the potential and challenges in managing fishery resources. In Manatuto Sub-District, there is a fish pond for farming milkfish, which was previously managed by a community group. However, aquaculture activities ceased after the tornado disaster in 2022.

Figure 10.12 Fish Pond in Manatuto Sub-District
(Source: Researcher Documentation, 2025)

This pond is located along the coastline and consists of two units, each measuring 80x40 meters. It is near mangrove vegetation and has a large flat area that has yet to be utilized. The water source for this pond comes from tidal seawater and a small river stream that flows into the pond area as a freshwater supply.

Figure 10.13 Small River as Freshwater Source
(Source: Researcher Documentation, 2025)

In Lacumesak Village, there is an area planned for the development of tilapia farming by the local community. This location is near a river that experiences drought during the dry season. The available water source is from a borehole stored in a reservoir, which will be structured and directed to support aquaculture activities.

Figure 10.14 Planned Aquaculture Development Area in Lacumesak Village
(Source: Researcher Documentation, 2025)

In Aubeon Village, fish farming has been underway since 2014, focusing on three main commodities: GIFT tilapia (Genetic Improvement of Farmed Tilapia), carp, and giant freshwater prawn. The ponds in this area are privately owned by the farming families. Furthermore, there are plans to expand the aquaculture area by one hectare. The water source for the ponds comes from a spring channeled through a ditch, although aeration systems have not been applied. The water level in the ponds is around 80 cm, and the survival rate for tilapia is 60%, with past harvests showing yields of about 6,000 fish from an initial 10,000 fingerlings.

Figure 10. 15 Aquaculture Pond in Aubeon Village
(Source: Researcher Documentation, 2025)

In Aubeon Village, the economic aspect of tilapia farming focuses more on the purchase of fingerlings and feed, as labor comes from the farming family.

Fingerling prices range from 3 to 5 cents per fish, with an average of 4 cents, so the total expenditure on fingerlings per cycle amounts to 400 dollars. Feed consumption over a six-month production period involves 6-7 sacks at 60 dollars per sack, bringing total production costs (excluding labor) to 460 dollars per pond.

Overall, the fisheries systems in Manatuto District display varying management levels, from halted projects to planned development areas and ponds that have been in production for several years. The utilization of water resources, infrastructure improvement, and fish health management are key factors in enhancing aquaculture productivity in this region.

10.4 COMPREHENSIVE LAND SUITABILITY ANALYSIS FOR AQUACULTURE

A. Aquaculture Land Suitability in Manatuto District

Land suitability refers to the extent to which an area of land is suitable for a specific use, in this case, for the aquaculture industry. This means assessing whether a piece of land has the physical, chemical, and climatic characteristics that support the optimal and sustainable cultivation of specific aquatic commodities. Land suitability assessment can be evaluated based on two conditions: the actual condition (current) and the potential condition (after improvements).

The assessment of actual land suitability is based on field survey data and reflects the land's capacity in its natural state without any additional intervention. This assessment does not take into account the improvements and management interventions that can be made to address constraints or limiting factors present in each land unit. To determine the class of actual land suitability, an initial evaluation is conducted for each land quality based on limiting factors. Then, scoring and final evaluation values are applied. This provides an honest depiction of the existing challenges.

Potential land suitability refers to the land's suitability after land improvements. For example, land that is only marginally suitable (S3) due to specific constraints may be upgraded to moderately suitable (S2) or even highly suitable (S1) after appropriate improvements, such as topographic modification or water quality adjustments. The assessment of potential land suitability is conducted by making possible improvements to the land quality that serve as limiting factors, thereby increasing its suitability.

With the application of management efforts, lands that naturally have low land suitability (actual suitability) can be upgraded to higher suitability classes (potential suitability). However, not all land qualities or characteristics can be improved with current technologies, or may require a high level of management. In land use planning for aquaculture, the main focus is on potential land suitability, as this assessment provides a picture of the land's maximum potential for various uses after improvements are made. Therefore, potential land suitability aids in planning land use effectively and sustainably, as well as determining the necessary improvement measures to achieve optimal results.

B. Results of Aquaculture Land Suitability Evaluation Manatuto District

Land suitability analysis is a fundamental step in designing strategies for sustainable land resource management for aquaculture. This evaluation process is based on an integrated approach that includes the use of geospatial data, field observations, and laboratory analysis of the physical and chemical properties of water and soil. This approach allows for the identification of the land's bio-physical potential and limitations for the development of various aquaculture commodities.

The data obtained are analyzed based on the growth requirements of each aquatic commodity in both actual and potential suitability conditions after land improvements, such as topographic modification, water quality management, or the implementation of adaptive cultivation techniques. This process generates comprehensive information to determine the priority of commodity development, identify limiting factors, and design relevant technical solutions. This scientific approach forms the basis for the land suitability evaluation in Manatuto District.

The results of this analysis provide strategic guidance to maximize land productivity while maintaining the sustainability of water resources in each area. Field and laboratory data used as the basis for land suitability assessment are presented in the relevant supporting documents. The distribution map of soil in aquaculture land is shown in Figure 10.16.

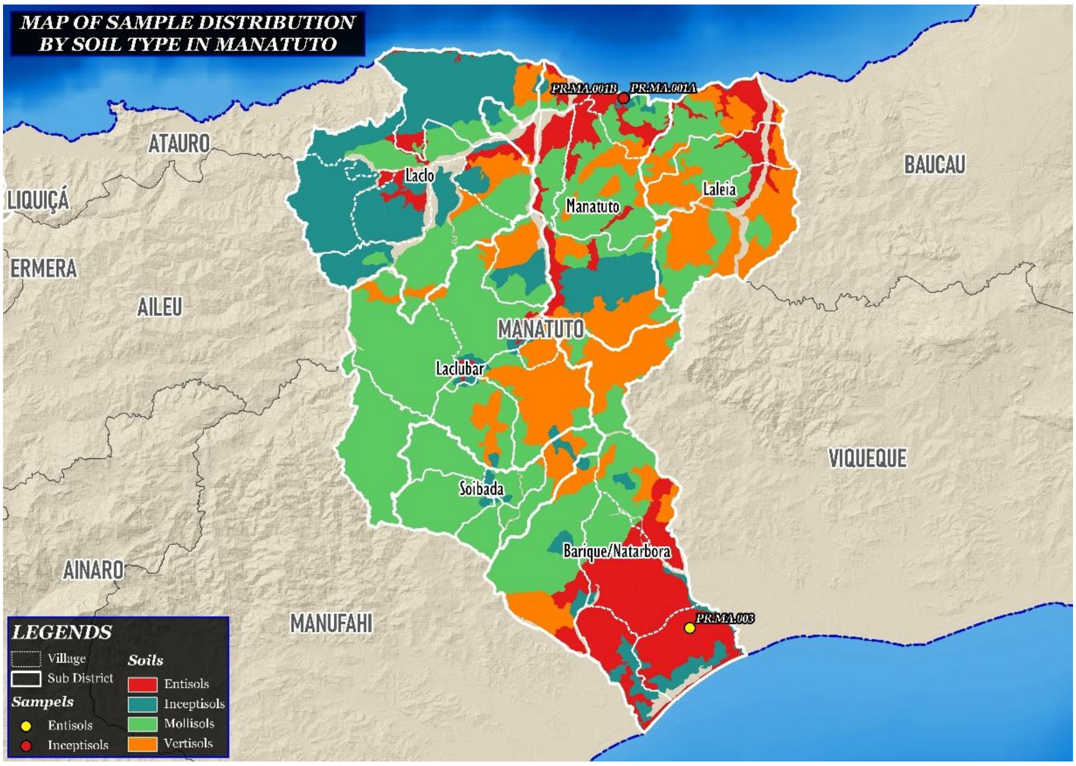


Figure 10.16 Map of Soil Distribution on Aquaculture Land in Manatuto District

a. Land Suitability Evaluation in Barique/Natarbora Sub-District

Barique/Natarbora Sub-District is one of the areas assessed in the land suitability analysis for aquaculture development, both for freshwater and brackish water commodities. Based on the evaluation results, almost all the commodities analyzed, including gourami, catfish, carp, tilapia, milkfish, mangrove crab, and vannamei shrimp, face similar constraints. Two main limiting factors that are most significant in this Sub-District are slope gradient and the length of the dry season (dry months). These two factors are categorized as "not suitable" (N), making them the primary challenges for fish farming development in the area. However, solutions can be implemented to improve land suitability through corrective measures, which can be seen in the direct cultivation without improvement efforts, as suggested in **Table 10.12.**

Slope gradient directly impacts pond construction, both technically and economically. Steep topography complicates the construction of conventional ponds due to the risk of erosion, difficulty in pond filling and draining, and high construction costs. To address this, the fisheries sector recommends using a terraced pond system, which allows adaptation to sloped land while maintaining water circulation efficiency and aquaculture waste management. Although the management difficulty of this method is relatively high, the result enables the land suitability class to increase from N to S3 (marginally suitable), which is sufficient for small to medium-scale aquaculture.

The dry season factor is a natural limiting factor that cannot be improved because it is directly related to the area's climate. Water availability during the dry months is very limited, affecting the sustainability of production. This condition impacts all commodities, both freshwater and brackish water, because water is a key component in aquaculture. Since this limitation is permanent and cannot be technically intervened, the land suitability value for this parameter remains in the "not suitable" (N) category in the potential land suitability evaluation.

In addition to these two main factors, secondary limitations such as low rainfall, low dissolved oxygen (DO), and low salinity for brackish water commodities also exist. These factors can still be improved. To address low DO, two approaches are recommended: first, the use of simple aeration such as gravity or fountains, which is low-cost and easy to implement; second, the use of mechanical aerators such as windmills or aeration machines, although they require higher operational costs. With these improvement efforts, land suitability could increase from S3 to S2 for some commodities.

Low rainfall, although limiting, is also a constraint that cannot be technically improved. However, the use of rainwater infiltration systems or additional water sources may be a long-term solution, although it is not yet included in the direct technical recommendations.

For brackish water commodities such as milkfish and vannamei shrimp, low salinity is a major challenge in the Barique/Natarbora Sub-District, which is part of a highland area. The salt content in the water is below the ideal threshold for these commodities. Improvement recommendations include the conventional mixing of seawater or the use of pumps, but both have high difficulty levels and logistical costs, making them economically unfeasible in some cases.

In general, the potential for aquaculture development in Barique/Natarbora Sub-District should focus on freshwater commodities, particularly catfish and tilapia, which are relatively more tolerant of varying environmental conditions. With the application of adaptive technologies and proper land management strategies, this area still holds potential for sustainable development despite significant natural constraints.

Table 10.9 Land Suitability Analysis for Aquaculture Commodities in Barique Sub-District

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: Rainfall S2: pH, DO	3	N: Dry months S3: Slope gradient S2: Rainfall	3.4
Catfish (*Clarias batrachus*)	N: Slope gradient, dry months S3: Rainfall S2: DO	3.07	N: Dry months S3: Slope gradient S2: Rainfall	3.4
Carp (*Cyprinus carpio*)	N: Slope gradient, dry months S3: DO, rainfall S2: High temperature	2.87	N: Dry months S3: Slope gradient S2: Rainfall	3.4
Tilapia (*Oreochromis niloticus*)	N: Slope gradient, dry months S3: DO, rainfall	2.92	N: Dry months S3: Slope gradient S2: Rainfall	3.4
Milkfish (*Chanos chanos*)	N: Slope gradient, dry months S3: Low salinity S2: DO, rainfall	2.93	N: Dry months S3: Slope gradient S2: Rainfall	3.4
Mangrove crab (*Scylla serrata*)	N: Low salinity, dry months S3: DO, slope gradient S2: Rainfall	2.95	N: Dry months S2: Rainfall, slope gradient	3.52
Vannamei (*Litopenaeus vannamei*)	N: Slope gradient, dry months S3: Low salinity, DO, rainfall	2.94	N: Dry months S3: Slope gradient S2: Rainfall	3.4

b. Land Suitability Evaluation in Laclo Sub-District

The land suitability evaluation for aquaculture development in Laclo Sub-District shows that almost all the commodities analyzed face significant barriers due to bio-physical land limitations. Freshwater commodities such as gourami, catfish, carp, and tilapia, as well as brackish water commodities such as milkfish, mangrove crab, and vannamei shrimp, all face primary constraints in slope gradient, low rainfall, and long dry seasons. These three parameters are generally classified as not suitable (N) in the actual land evaluation, meaning direct cultivation without improvement efforts, as suggested in **Table 10.12**, is not viable.

Slope gradient, as a physical limiting factor, hinders the construction of stable and cost-effective pond infrastructure. Without technical intervention, the potential risks of landslides, difficulties in water management, and high construction costs will be very high. Therefore, the main recommendation for improvement is the use of a terraced pond system. Although the management and construction of this method are complex, it allows for the adaptation of sloped land to make it more suitable for aquaculture, so the suitability rating can increase to S3 or even S2 depending on the specific site conditions.

Low rainfall and long dry seasons are significant climate constraints. Unfortunately, both of these are considered limiting factors that cannot be improved as they are directly related to the local climate, which is permanent. Aquaculture dependency on water availability makes these two parameters crucial. Therefore, even if technical interventions are applied to other parameters, the land suitability for rainfall and dry seasons remains unchangeable. Long-term strategies such as constructing water storage ponds or utilizing rainwater may be considered, though they are not currently included in the technical recommendations.

In addition to these three primary factors, there are additional limitations such as low DO, high temperatures, suboptimal water pH, and low salinity (especially for brackish water commodities). For DO, simple solutions such as gravity aeration systems or mechanical aerators like windmills are effective, but they require technical support and additional costs. For high temperatures, shading trees, using paranet roofing, or even constructing indoor ponds can be used to maintain optimal water temperature ranges. For pH issues, whether too low or too high, solutions include regular water exchange and the use of zeolite, a natural material capable of stabilizing the chemical conditions of the water.

For brackish water commodities facing low salinity, seawater mixing remains the only viable option, either done conventionally or with seawater pumps. However, this intervention involves moderate to high difficulty and can be economically unfeasible, particularly in remote areas far from seawater sources.

Considering all these factors, aquaculture development in Laclo Sub-District should focus on freshwater commodities that are more tolerant of environmental fluctuations, such as catfish and tilapia. These commodities are not only more adaptable to varying water qualities but also have a faster production cycle and lower operational costs. With the right technical interventions and planned management, the land in Laclo Sub-District still holds potential for sustainable freshwater fishery production.

Table 10.10 Land Suitability Analysis for Aquaculture Commodities in Laclo Sub-District

Commodity	Current Land Suitability Limiting Factors	Current Final Evaluation	Potential Land Suitability Limiting Factors	Potential Final Evaluation
Gourami (*Ospronemus gouramy*)	N: Slope gradient, rainfall, dry months S3: High temperature S2: DO	2.91	N: Dry months, rainfall S3: Slope gradient	3.28
Catfish (*Clarias batrachus*)	N: Slope gradient, rainfall, dry months S2: High temperature, DO	2.96	N: Dry months, rainfall S3: Slope gradient	3.28
Carp (*Cyprinus carpio*)	N: Slope gradient, rainfall, dry months S3: DO, High temperature	2.76	N: Dry months, rainfall S3: Slope gradient	3.28
Tilapia (*Oreochromis niloticus*)	N: Slope gradient, rainfall, dry months S3: DO S2: pH, High temperature	2.81	N: Dry months, rainfall S3: Slope gradient	3.28
Milkfish (*Chanos chanos*)	N: Slope gradient, rainfall, dry months S3: Low salinity S2: High temperature, Ph, DO	2.69	N: Dry months, rainfall S3: Slope gradient	3.28
Mangrove crab (*Scylla serrata*)	N: Low salinity, rainfall, dry months S3: DO, slope gradient S2: High temperature	2.63	N: Dry months, rainfall S3: Slope gradient	3.28
Vannamei (*Litopenaeus vannamei*)	N: Slope gradient, rainfall, dry months S3: Low salinity, DO S2: High temperature, pH	2.54	N: Dry months, rainfall S3: Slope gradient	3.28

c. Land Suitability Evaluation in Manatuto Sub-District

Manatuto Sub-District exhibits more complex and varied land constraints compared to the previous two sub-districts. Aquaculture commodities, both freshwater such as gourami, catfish, carp, and tilapia, and brackish water such as milkfish, mangrove crab, and vannamei shrimp, face challenges from multiple limiting factors. The most dominant factors are high salinity, high Total Dissolved Solids (TDS), and slope gradient, all of which are classified as not suitable (N) in actual land conditions. In addition, the long dry season and low rainfall are also very serious and permanent constraints.

High salinity in Manatuto Sub-District is a serious limiting factor for freshwater aquaculture. Excessive salt concentration causes osmotic stress in freshwater fish, leading to reduced growth or even mortality. To address this, the technical recommendation is to mix freshwater into the ponds to reduce salinity to a level that can be tolerated by fish such as catfish and tilapia. Although this method is of moderate difficulty, its effectiveness heavily depends on the availability of freshwater sources and an efficient distribution system.

High TDS also presents a major challenge. Excessive dissolved solids can impact fish osmoregulation and degrade the quality of the aquaculture environment. A technical solution for this is the use of filtration systems, either simple sand filters or more advanced Reverse Osmosis (RO) systems. However, RO systems are expensive and require regular maintenance, making them more suitable for intensive farming operations with adequate financial support.

Steep slopes in some parts of Manatuto Sub-District also present a physical obstacle for pond development. As in other sub-districts, the available solution is the implementation of terraced pond systems, which allow for adaptation to sloped land. Meanwhile, the long dry season and low rainfall remain two limiting factors that cannot be improved due to macroclimate conditions. This means that even if all other factors are addressed, water availability remains a limiting issue for production capacity.

Additionally, parameters that can still be improved include low DO, low temperatures, and low salinity for brackish water commodities. For low temperatures, shallow ponds or ponds with dark bottoms are recommended to enhance heat absorption. For low DO, aeration remains the primary solution.

Overall, Manatuto Sub-District has potential for freshwater aquaculture development, but technical interventions on water quality are crucial and often require additional costs. Therefore, development strategies should focus on commodities that are tolerant of both physical and chemical water conditions while also considering the sustainability of water supply amidst climate challenges.

Table 10.11 Land Suitability Analysis for Aquaculture Commodities in Manatuto Sub-District

Commodity	Current Land Suitability Limiting Factors	Current Final Evaluation	Potential Land Suitability Limiting Factors	Potential Final Evaluation
Gourami (*Ospronemus gouramy*)	N: High salinity, TDS, slope gradient, rainfall, dry months S2: Low temperature, pH	2.53	N: Dry months, rainfall S3: Salinity, slope gradient	3.08
Catfish (*Clarias batrachus*)	N: High salinity, TDS, slope gradient, rainfall, dry months	2.65	N: Dry months, rainfall S3: Salinity, slope gradient	3.08
Carp (*Cyprinus carpio)*	N: High salinity, TDS, slope gradient, rainfall, dry months S2: DO	2.5	N: Dry months, rainfall S3: Salinity, slope gradient	3.08
Tilapia (*Oreochromis niloticus*)	N: TDS, slope gradient, rainfall, dry months S3: High salinity S2: DO, Low temperature	2.55	N: Dry months, rainfall S2: Salinity, slope gradient	3.18
Milkfish (*Chanos chanos*)	N: TDS, slope gradient, rainfall, dry months S2: Low temperature	2.9	N: Dry months, rainfall S3: Slope gradient	3.28
Mangrove crab (*Scylla serrata*)	N: TDS, rainfall, dry months S3: Slope gradient S2: Low temperature, Low salinity, DO	2.77	N: Dry months, rainfall S2: Slope gradient	3.4
Vannamei (*Litopenaeus vannamei*)	N: TDS, slope gradient, rainfall, dry months S2: Low temperature, Low salinity, DO	2.65	N: Dry months, rainfall	3.46

C. Aquaculture Land Improvement Efforts

The results of the actual land suitability evaluation in Manatuto District show various limiting factors that make most areas either unsuitable or only marginally suitable for aquaculture. To improve these land suitability classes, land improvement or corrective actions for the limiting factors are required, as far as possible. Land improvement in aquaculture contexts includes technical interventions aimed at improving the bio-physical conditions of the land and water environment to better meet the needs of the cultivated commodities. Improvements can include habitat modification (e.g., physically improving pond conditions), water quality manipulation, or the provision of supporting infrastructure.

Based on **Table 10.12**, there are types of improvements with varying management difficulty levels. The management difficulty levels are categorized as low, medium, and high. These levels are then used to assess the assumptions for upgrading the actual land suitability class to potential suitability, as shown in **Table 10.13**.

Table 10.12 Recommended Improvement Measures for Limiting Parameters

No	Parameter	Improvement Measures	Management Difficulty Level
1	Low Temperature	- Use of shallow ponds - Use of dark-colored ponds - Use of water heaters	- Low - Low - High
2	High Temperature	- Planting shade trees - Use of paranet roofing - Construction of indoor ponds	- Low - Medium - High
3	High Salinity	- Mixing freshwater	- Medium
4	Low Salinity	- Conventional seawater mixing - Seawater mixing with pumps	- Medium - High
4	Water pH	- Regular water exchange - Use of zeolite	- Medium - High
6	TDS	- Use of simple filtration methods - Use of modern filtration methods (RO filter machines)	- Medium - High
7	DO	- Use of simple gravity aeration systems - Use of mechanical aerators/windmills	- Low - High
8	Slope Gradient	- Use of terraced pond systems	- High
9	Rainfall	- Cannot be improved	
10	Dry Months	- 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 10.13 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. RECOMMENDATIONS

11.1 AGRICULTURE SECTOR

1) Land Potential and Spatial Distribution

Irrigated rice land has been identified in Haturalan Village, Lifau, Cairui (Laleia Sub-District), Sau Ma'abat Village, Ilihеu (Manatuto Sub-District), Umacaduac Village, Uma Naruc, Lacumesac (Laclo Sub-District), and Umaboco Village (Barique/Natarbora Sub-District). Rainfed rice land is found in Aiteas Village (Manatuto Sub-District). The dominant forage zones are located in Abat Oan Village (Barique/Natarbora Sub-District) with elephant grass (*Pennisetum purpureum*), gamal (*Gliricidia sepium*), leucaena (*Leucaena leucocephala*), and turi (*Sesbania grandiflora*).

2) Commodity Portfolio and Local Market Opportunities

Main food crops: corn, taro, rice, cassava, sweet potato, *porang*, breadfruit. Horticulture: banana, mango, guava, rambutan, watermelon, jackfruit, melon, orange, durian, papaya, dragon fruit, soursop, avocado, snakefruit, pumpkin, pineapple, persimmon, jujube, and vegetables such as pakchoi, spinach, tomato, bitter melon, long bean, cucumber, green caisim, water spinach, turkey berry. Industry: coconut, palmyra palm, castor, nipah palm, sago, areca nut, cashew, tobacco, coffee. Spices and herbs: turmeric, vanilla, ginger, candlenut, lemongrass. Forestry: pine, cedar, teak, *Gmelina arborea* (white teak), eucalyptus, mahogany, sandalwood, tropical almond, flamboyant, coconut wood. This combination allows for the establishment of a city food supply chain and inter Sub-District markets, provided simple logistics and good packaging are in place.

3) High-Value Food and Horticulture Centers: Natarbora and Soibada

Natarbora Sub-District is recommended as a food center due to its high soil fertility and large land availability. Priorities include rice, maize, and cassava with good micro-irrigation management, plot consolidation, light mechanization, and the provision of adaptive seeds. Agricultural development in Natarbora must follow spatial planning guidelines to avoid overlap with the Liquefied Natural Gas (LNG) project. A buffer zone, environmental impact analysis, and an operational schedule that does not interfere with planting and harvesting seasons should be implemented.

Soibada Sub-District is designated as a high-value horticulture center, focusing on arabica coffee, robusta coffee, and vanilla. For coffee: apply multistrata shading, production pruning, balanced fertilization based on soil tests, mechanical weed control, selective harvesting, as well as wet processing and controlled drying. For vanilla: use living trellises, scheduled manual pollination, garden sanitation, and gradual drying until curing to achieve export-grade quality. Both crops can be integrated into a buyer partnership and quality certification scheme.

4) Optimization of Irrigated and Rainfed Rice Land

Rehabilitate canals, sluices, and water storage systems (ponds and shallow wells). Use simple piping networks to connect plots. Apply Alternate Wetting and Drying (AWD) for irrigated rice to save water without reducing yields. For horticulture, use drip irrigation to efficiently manage water and nutrients. In Aiteas Village, create a planting calendar that aligns with the peak rainfall season, select early-maturing varieties, and maximize household and group-scale rainwater harvesting.

5) Flood and Erosion Mitigation in Laclo Sub-District and Steep Slope

Construct functional drainage channels, sediment retention ponds, and embankments at critical runoff points. On steep slopes such as Hohorai Village, apply contour planting, bench terraces, organic mulching, and vegetative buffer strips along watercourses. This approach reduces topsoil loss and maintains long-term productivity.

6) Recovery of Orange Orchards ±100 ha in Hohorai Village (Laclo Sub-District)

Apply contour planting, terracing, regular pruning, and balanced fertilization based on soil and leaf tests. Add mature compost and improve drainage to prevent waterlogging during the rainy season and excessive drying during the dry season. Use thick mulch around tree bases to retain moisture and suppress weeds.

7) Easy to Adopt Soil and Water Conservation Techniques

Standardize fertilizer application Standard Operating Procedure, including dose, timing, and simple methods. Add organic matter through mature compost, use leguminous cover crops to fix biological nitrogen, and apply agricultural lime to acidic soils based on pH results. Provide windbreaks in horticultural orchards.

8) Grazing and Forage: Productivity Without Land Degradation

In Abat Oan Village, manage pastures with rotational paddocks (fenced grazing plots) for forage recovery. Implement a cut-and-carry system in sensitive areas, establish forage banks for dry season reserves, and develop silvopasture (forage trees combined with pasture) to reduce erosion and enhance livestock comfort.

9) Extension Services, Infrastructure, and Supporting Policies

Provide integrated training on fertilization management, soil and water conservation, and Integrated Pest Management. Prioritize subsidies for fertilizers and adaptive seeds, improve farm to market roads, and provide simple post-harvest facilities such as grading, packaging, and communal cold chains. Map commodity zoning based on bio-physical suitability and local economic potential. Strengthen cooperatives for input procurement, access to financing, and marketing contracts.

10) Realistic Implementation Stages

Quick wins: Improve irrigation and drainage channels at critical points, establish AWD demo plots for rice, contour planting demo plots in the orange orchards of Hohorai Village, household-scale rainwater harvesting, and activate unproductive land with mulch and cover crops.

Medium term: Communal ponds, simple pipe distribution networks for horticulture, block-scale terracing on priority slopes, coffee and vanilla processing centers in Soibada Sub-District, and agricultural spatial planning in Barique/Natarbora Sub-District aligned with the LNG project zones and corridors.

11.2 LIVESTOCK SECTOR

Barique/Natarbora KTS Center is aligned with the national plan for the development of Timor buffalo to meet local milk needs. Short-term recommendations start with preparing high-nutrient forage land to enhance milk productivity. The government may introduce forage varieties such as Setaria grass and legumes like Gliricidia, kaliandra, and indigofera. In feeding, the composition of forage should be 60% grass and 40% legumes. Additionally, supplemental feed such as bran, concentrate, or flushing feed should be provided in certain buffalo conditions.

Long-term recommendations include improving reproductive technologies and training human resources. There must be a strong focus on reproductive aspects, which directly affect milk production, through workforce training. A potential challenge could be silent heat, which may occur in buffalo. This can be addressed if workers are educated and skilled in reproduction to detect heat accurately. Further training can be enhanced through certified artificial insemination (AI) training, enabling Barique/Natarbora KTS Center to adapt to livestock technologies that increase milk production efficiency. Once facilities are adequate, Barique/Natarbora KTS Center can implement sexing methods in breeding, as a strategy to increase female births for breeding stock and milk production.

11.3 FISHERIES SECTOR

Field studies in several villages across Timor-Leste highlight various challenges in managing fisheries and aquaculture. Major issues include the lack of fish feed, water pollution threats, and limited access to clean water. Since each location has unique problems, specific technical recommendations tailored to the local conditions are necessary. These location-specific strategies are crucial for improving productivity, sustainability, and economic resilience in the fisheries sector. Detailed technical recommendations for each location can be found in Table 11.1.

Table 11.1 Technical and Strategic Recommendations by Location

Location	Key Issues	Technical and Strategic Recommendations
Manatuto Sub-District (Grupo Radudu)	• Milkfish ponds have been inactive since the 2022 tornado event • High TDS and salinity constrain freshwater fish • Water infrastructure is not yet properly managed	• Rehabilitate damaged ponds and raise embankments • Install flood-control systems and clean seawater channels • Focus on brackish-water commodities (milkfish and vannamei shrimp)
Laclo Sub-District (Lacumesak Village)	• Steep slopes and prolonged drought • Production infrastructure is not yet available • No hatchery units • Limited rainfall and surface water	• Select flat sites close to shallow groundwater sources • Construct pond units and water channels • Facilitate small-scale hatcheries for beginner groups
Barique/Natarbora Sub-District (Village Aubeon)	• Aeration systems have not yet been applied • Productivity is not yet optimal (survival rate ±60 %) • Feed management is still basic	• Install simple aeration systems (blower or venturi) • Provide training on stocking density management and feed efficiency • Provide technical support for the planned expansion of 1 ha of farming area

1. Pilot Project Location Selection

Based on bio-physical, socio-economic studies, and community institutional readiness, Aubeon Village (Barique/Natarbora Sub-District) is recommended as the Pilot Project site for Family-Based Freshwater Fish Farming. This selection is based on:

1. Historical success in farming tilapia, carp, and giant freshwater prawn since 2014 with self-managed systems by the farming families,
2. Availability of spring water flowing year-round as the main water source for ponds,
3. Potential land expansion of one hectare for farming, planned by the community, and
4. Efficient production costs based on family labor, making this system suitable for replication at the household scale.

2. Policy Recommendations for Local Government (City and Sub-District)

To ensure sustainable, inclusive, and locally-based aquaculture development in Manatuto District, the following strategic steps are necessary:

1. Establish local seed production units in Manatuto Sub-District or periodically distribute high-quality seeds from national hatcheries to guarantee the availability of seeds for freshwater species such as tilapia, carp, catfish, and giant freshwater prawn at priority locations like Aubeon and Lacumesak.
2. Provide basic fisheries infrastructure, particularly water channels, reservoirs, and rehabilitation of post-disaster ponds (e.g., at pada Grupo Radudu, Ma'abat Village), which should be carried out collaboratively between local government and development partners.
3. Conduct regular community-based technical and management training programs, involving vocational education institutions, fisheries extension officers, and civil society organizations. Training should focus on: feed management, optimal stocking density, simple aeration techniques, and adaptation to dry climates.
4. Facilitate access to production tools (feed, aeration, pond plastics, pumps, etc.) through conditional subsidies or micro-credit schemes based on group collaboration, with priority for active farmers who have demonstrated independence and commitment.
5. Integrate aquaculture into regional development plans, especially in potential locations like Aubeon and Lacumesak Village, using a cross-sector approach that considers its linkages with agriculture, water conservation, and food security.
6. Strengthen monitoring and evaluation systems based on spatial and thematic data, involving collaboration between the Fisheries Department, national research institutions, and universities, to regularly monitor land suitability dynamics, the impacts of climate change, and policy intervention effectiveness.

REFERENCE

Aditiyas, W., Haji, A. T. S., & Rahadi, J. B. (2014). Analisis Spasial Untuk Evaluasi Kesesuaian Lahan Tanaman Apel Di Kota Batu - Jawa Timur. Jurnal Sumberdaya Alam Dan Lingkungan, 1, 1–7.

Administrasaun Munisípiu Manatuto. (2025). Dadus Munisípiu Ba Dezenvolvimentu Sustentável Iha Timor-Leste : Autoridade Munisipal Manatuto. Portal Municipio. https://manatuto.gov.tl/

Adviany, I., D. D, Maulana. (2019). Pengaruh Pupuk Organik dan Jarak Tanam terhadap C-Organik, Populasi Jamur Tanah dan Bobot Kering Akar serta Hasil Padi Sawah pada Inceptisols Jatinangor, Sumedang. Jurnal Agrotechnology Research. 3 (1): 28–35.

Amam, A., & Harsita, P. A. (2019). Tiga Pilar Usaha Ternak: Breeding, Feeding, And Management. Jurnal Sain Peternakan Indonesia, 14(4), 431-439.

Armanto, M. E., Wildayana, E., & Syazili, A. (2024). Agrogeologi Dan Produktivitas Tanah. Universitas Sriwjaya.

Arriola, K. G., Queiroz, O. C. M., Romero, J. J., Casper, D., Muniz, E., Hamie, J., & Adesogan, A. T. (2015). Effect Of Microbial Inoculants On The Quality And Aerobic Stability Of Bermudagrass Round-Bale Haylage. Journal Of Dairy Science, 98(1), 478-485.

ATSEA Program. Arafura And Timor Seas Ecosystem Action Program. Diakses Pada 13 Maret 2025, Dari Https://Atsea-Program.Com

Balai Penelitian Tanah. (2005). Evaluasi Kualitas Tanah untuk Pertanian Berkelanjutan. Bogor: Balittanah.

Barry, R. G., & Chorley, R. J. (2009). *Atmosphere, weather and climate* (9th ed.). Routledge.

Baryła, A., & Pierzgalski, E. (2008). Ridged Terraces – Functions, Construction And Use. Journal Of Environmental Engineering And Landscape Management, 16(2), Ia - If.

Bettencourt, E. M. V., Tilman, M., Narciso, V., Carvalho, M. L. D. S., & Henriques, P. D. D. S. (2015). The Livestock Roles In The Wellbeing Of Rural Communities Of Timor-Leste. Revista De Economia E Sociologia Rural, 53, 63-80.

Bose, A.N., Ghosh, S.N., Yang, C.T., & Mitra, A. (1991). Coastal Aquaculture Engineering. Chapman And Hall, Inc., New York, 365 Pp.

Boyd, C.E. (1995). Bottom Soils, Sediment, And Pond Aq

Brady, N.C. & Weil, R.R. (2008). The Nature and Properties of Soils. 14th ed. Pearson Education.

Brady, N.C., & Weil, R.R. (2016). The Nature and Properties of Soils. 15th Ed. Pearson Education.

Bray, W.A., Lawrence, A.L., & Leung-Trujillo, J.R. (1994). The Effect Of Salinity On Growth And Survival Of Penaeus Vannamei, With Observations On The Interaction Of IHHN Virus And Salinity. Aquaculture, 122: 133-146.

Browne, M., Goncalo, L., Ximenes, A., Lopes, M., & Erskine, W. (2016). The Place Of Ceremonial Observances In Sustainable Livelihoods Of Crop Producers In Timor-Leste.

Brunet, J., Murphy, G. C., Terra, R., Figueiredo, J., & Serey, D. (2014). Do Developers Discuss Design?. In Proceedings Of The 11th Working Conference On Mining Software Repositories (Pp. 340-343).

Carney, D. (1999). Approaches To Sustainable Livelihoods. DFID.

Chanratchakool, P., Turnbull, J.F., Funge-Smith, S., & Limsuwan, C. (1995). Health Management In Shrimp Ponds. Second Edition. Aquatic Animal Health Research Institute, Department Of Fisheries, Kasetsart University Campus, Bangkok, 111 Pp.

Cogné, M., & Lescuyer, G. (2024). The Role Of Agroforestry In Farmers' Strategies And Its Contribution To The Well-Being Of Rural People In Timor-Leste. Forests, Trees And Livelihoods. Https://Doi.Org/10.1080/14728028.2023.2298986

Da Costa, A. J., Sunarminto, B. H., Gunawan, T., & Utami, S. N. H. (2015). EVALUASI LAHAN UNTUK DASAR PENGEMBANGAN PERTANIAN TANAMAN SEMUSIM (Kasus Di Raumoco Lautem Timor Leste) Evaluation Of Land For Agricultural Development Basic Seasonal Crops (Case Studies In Lautem Raumoco Timor Leste). Jurnal Galung Tropika, 4(2).

Day, M. D., Brito, A. A., Da Costa Guterres, A., Da Costa Alves, A. P., Paul, T., & Wilson, C. G. (2013). Biocontrol Of Chromolaena Odorata In Timor Leste. Proceedings Of The Eighth International Workshop On Biological Control And Management Of Chromolaena Odorata And Other Eupatorieae, Nairobi, Kenya, 1-2 November 2010

Deng, C., Zhang, G., Liu, Y., Nie, X., Li, Z., Liu, J., & Zhu, D. (2021). Advantages And Disadvantages Of Terracing: A Comprehensive Review. International Soil And Water Conservation Research, 9(13). Https://Doi.Org/10.1016/J.Iswcr.2021.03.002

DFID. (1999a). Sustainable Livelihoods Guidance Sheets. Department For International Development.

DFID. (1999b). Sustainable Livelihoods Framework. Department For International Development.

Do, F. H., La, N., Bergkvist, G., Dahlin, A. S., Mulia, R., Nguyen, V. T., & Öborn, I. (2023). Agroforestry With Contour Planting Of Grass Contributes To Terrace Formation And Conservation Of Soil And Nutrients On Sloping Land. Agriculture, Ecosystems & Environment, 345. Https://Doi.Org/10.1016/J.Agee.2022.108323

Fanzo, J., & Bonis-Profumo, G. (2019). Timor-Leste Agriculture Sector Review. The Ministry Of Agriculture And Fisheries The Democratic Republic Of Timor-Leste.

FAO, Food And Agriculture Organization. (2015). The State Of Food Insecurity In The World 2015. Food And Agriculture Organization Of The United Nations. Retrieved From Http://Www.Fao.Org/3/A-I4646e.Pdf

FAO. (2021). Special Report – 2021 FAO Crop And Food Supply Assesment Mission (CFSAM) To The Democratic Republic Of Timor Leste. Food And Agriculture Organization Of The United Nations. Diakses Pada Halaman Https://Doi.Org/10.4060/Cb5245en

Food And Agriculture Organization (FAO). (1976). A Framework For Land Evaluation. In FAO Soil Bulletin 32. Soil Resources Management And Conservation Service And Water Development Division, FAO, Rome, 72 Pp

Food And Agriculture Organization. Strategies For Sustainable Animal Agriculture In Developing Countries. Retrieved April 13, 2025, From Https://Www.Fao.Org/4/T0582E/T0582E27.Html

Foth, H.D. (1990). Fundamentals of Soil Science. 8th Ed. John Wiley & Sons.

Fox JJ. (2003). Drawing From The Past To Prepare For The Future: Responding To The Challenges Of Food Security In East Timor. In Da Costa H, Piggin C, Cruz CJ, Fox JJ. Eds. Agriculture: New Directions For A New Nation East Timor (Timor-Leste). ACIAR Proceedings No. 11. Canberra, Australia: Australian Centre For International Agricultural Research. Pp 105–114.

Ganguly, R. K., Al-Helal, M. A., & Chakraborty, S. K. (2022). Management Of Invasive Weed Chromolaena Odorata (Siam Weed) Through Vermicomposting: An Eco-Approach Utilizing Organic Biomass Valorization. Environmental Technology & Innovation, 28, 102952.

General Directorate of Statistics, M. of F. and the M. of A. and F. (2020). Timor-Leste Agriculture Census 2019.

Godinho, M., Artati, Y., Bhatta, K. P., Maulana, A. M., Baral, H., & Finlayson, R. F. (Eds.). (2023). Agroforestry Manual For Timor-Leste. Center For International Forestry Research (CIFOR) And Nairobi, Kenya: World Agroforestry (ICRAF).

Government Of The Democratic Republic Of Timor-Leste.

Haidar, J. (2009). Sustainable Livelihoods: A Conceptual Framework For Rural Development.

Hardjowigeno, S. (2003). Ilmu Tanah. Jakarta: Akademika Pressindo.

Hastari, I. F., Kurnia, R., & Kamal, M. M. (2017). Analisis Kesesuaian Budidaya KJA Ikan Kerapu Menggunakan SIG Di Perairan Ringgung Lampung. Jurnal Ilmu Dan Teknologi Kelautan Tropis, 9(1), 151–159.

Holilullah, A., & Novpriansyah, H. (2015). KARAKTERISITK SIFAT FISIK TANAH PADA LAHAN PRODUKSI RENDAH DAN TINGGI DI PT GREAT GIANT PINEAPPLE. Jurnal Agrotek Tropika, 3(2), 278–282.

Hossain, M.S., Chowdhury, S.R., Das, N.G., & Rahaman, M.M. (2007). Multi-Criteria Evaluation Approach To Gisbased Land-Suitability Classification For Tilapia Farming In Bangladesh. Aquaculture International, 15(6): 425- 443.

Houze Jr., R. A. (2012). *Cloud dynamics* (2nd ed.). Academic Press.

Huang, B., Yuan, Z., Zheng, M., Liao, Y., Nguyen, K. L., Nguyen, T. H., Sombatpanit, S., & Li, D. Q. (2022). Soil And Water Conservation Techniques In Tropical And Subtropical Asia: A Review. Sustainability, 14(9). Https://Doi.Org/10.3390/Su14095035

Ilyas, S., Cholik, F., Poernomo, A., Ismail, W., Arifudin, R., Daulay, T., Ismail, A., Koesoemadinata, S., Rabegnatar, I N.S., Soepriyadi, H., Suharto, H.H., Azwar, Z.I., & Ekowardoyo, S.

(1987). Petunjuk Teknis Bagi Pengoperasian Unit Usaha Pembesaran Udang Windu. Pusat Penelitian Dan Pengembangan Perikanan, Jakarta, 100 Hlm. Ismail, A., Poernomo

Irawan, M. F., Hidayat, Y., & Tjahjono, B. (2018). Penilaian Bahaya Dan Arahan Mitigasi Banjir Di Cekungan Bandung. Jurnal Ilmu Tanah Dan Lingkungan, 20(1), 1–6. Https://Doi.Org/10.29244/Jitl.20.1.1-6

Ismail, A., Poernomo, A., Sunyoto, P., Wedjatmiko, Dharmadi, & Budiman, R.A.I. (1993). Pedoman Teknis Usaha Pembesaran Ikan Bandeng Di Indonesia. Pusat Penelitian Dan Pengembangan Perikanan, Jakarta, 73 Hlm

Iswan, S., Zhiddiq, S. Dan Maru, R. (2019). Evaluasi Kesesuaian Lahan Untuk Tanaman Cengkeh (Eugenia Aromatica L) Di DAS Takapala Sub DAS Hulu Jeneberang Kabupaten Gowa. Journal Of UNM Geographic 2(2):121-129, Doi:10.26858/Ugj.V2i2.11575

Jamatia, K., Mazumder, R., Ikbal, A. M. A., & Manna, K. (2024). Chromolaena Odorata (L.) RM King & H. Rob. (Asteraceae): A Comprehensive Scientific Review Of Phytochemistry, Pharmacology, And Its Medicinal Potential. Pharmacological Research-Natural Products, 100098.

Jong, J., & Pereira, A. (2021). Evaluating The Opportunities For Smallholder Livestock Keepers In Timor Leste.

Karthik, M., Suri, J., Saharan, N., & Biradar, R.S. (2005). Brackish Water Aquaculture Site Selection In Palghar Taluk, Thane District Of Maharashtra, India, Using The Techniques Of Remote Sensing And Geographical Information System. Aquacultural Engineering, 32: 285- 302.

La N, Catacutan DC, Roshetko JM, Mercado AR, Tran HM, Vu TH, Thuong PH, Do VH, Phuong NM. (2016). Agroforestry Guide For Sloping Lands In Northwest Viet Nam. Viet Nam: World Agroforestry Centre (ICRAF). 33p

Laswanto, Sunarti, & Zuhdi, M. (2025). Pemanfaatan Data Digital Terrain Model Dan Metode Topographic Wetness Index Untuk Pembuatan Peta Rawan Banjir Daerah Aliran Sungai (DAS) Kenali Besar Kota Jambi. Jurnal Ilmiah Universitas Batanghari Jambi, 25(1), 767–771. Https://Doi.Org/10.33087/Jiubj.V25i1.5544

Lehmann, J., & Joseph, S. (2009). Biochar for Environmental Management: Science and Technology. London: Earthscan.

Liu, Z. Y., Yang, H. L., Yan, Y. Y., Seerengaraj, V., Zhang, C. X., Ye, J. D., And Sun, Y. Z. (2021). Supplementation Of Tributyrin, Alone And In Combination With Fructooligosaccharide In High Soybean Meal Diets For Shrimp (Litopenaeus Vannamei): Effects On Growth, Innate Immunity And Intestinal Morphology. Aquaculture Nutrition, 27(2) : 592-603.

López-Angarita J, Hunnam KJ, Pereira M, Mills DJ, Pant J, Teoh SJ, Eriksson H, Amaral L And Tilley A. (2019). Fisheries And Aquaculture Of Timor-Leste In 2019: Current Knowledge And Opportunities. Penang, Malaysia: Worldfish. Program Report: 2019-15.

MAF. (2018). Final Country Report Of The Land Degradation Neutrality Target Setting Programme In Timor-Leste.

Mahfut, T., Afandi, Buchari, H., Manik, K. E. S., & Cahynono, P. (2015). Kandungan Bahan Kasar Dan Sifat Fisik Tanah Ultisol Di Lahan Perkebunan Nanasterbanggi Besar Lampung Tengah. Jurnal Agrotek Tropika, 3(1), 155–159.

Mansyur, N. I., Antonius, & Titing, D. (2023). Karakteristik Fisika Tanah Pada Beberapa Lahan Budidaya Tanaman Hortikultura Lahan Marginal. Jurnal Ilmiah Respati, 14(2), 190–200.

Marschner, H. (2012). Marschner's Mineral Nutrition of Higher Plants. 3rd Ed. Academic Press.

Mills DJ, Tilley A, Pereira M, Hellebrandt D, Fernandes AP And Cohen PJ. (2017). Livelihood Diversity And Dynamism In Timor-Leste: Insights For Coastal Resource Governance And Livelihood Development. Marine Policy Vol 82, 206-215.

Ministry Of Agriculture And Fisheries. (2022). National Strategy And Technical Guidelines Agroforestry Development Timorleste (DRAFT). Dili, Timor-Leste: Ministry Of Agriculture And Fisheries.

Molyneux, N., Da Cruz, G. R., Williams, R. L., Andersen, R., & Turner, N. C. (2012). Climate Change And Population Growth In Timor Leste: Implications For Food Security. Ambio, 41(8), 823-840. DOI 10.1007/S13280-012-0287-0

Mugwedi, L. (2020). Harnessing Opportunities Provided By The Invasive Chromolaena Odorata To Keep It Under Control. Sustainability, 12(16), 6505.

Muhammad, Z. N. (2021). Potensi Dan Strategi Pengembangan Peternakan Sapi Potong Dilahan Bekas Tambang Emas Martabe PT. Agincourt Resources Kecamatan Batang Toru Kabupaten Tapanuli Selatan (Doctoral Dissertation, Universitas Andalas).

Mustafa, A., Rachmansyah, & Hanafi, A. (2007a). Kelayakan Lahan Untuk Budi Daya Perikanan Pesisir. Dalam Prosiding Simposium Nasional Hasil Riset Kelautan Dan Perikanan Tahun 2007. Badan Riset Kelautan Dan Perikanan, Jakarta, Hlm. 1-29.

Mustafa, A., Radiarta, I N., & Rachmansyah. (2011). Profil Dan Kesesuaian Lahan Akuakultur Mendukung Minapolitan. Sudradjat, A. (Ed.) Pusat Penelitian Dan Pengembangan Perikanan Budidaya, Jakarta, 91 Hlm.

Mustafa, A., Sapo, I., Hasnawi, & Sammut, J. (2007b). Hubungan Antara Faktor Kondisi Lingkungan Dan Produktivitas Tambak Untuk Penajaman Kriteria Kelayakan Lahan: 1. Kualitas Air. J. Ris. Akuakultur, 2(3): 289-302.

National Statistic Directorate, Ministry Of Finance. (2019). Timor Leste Agriculture Census 2019. Government Of The Democratic Republic Of Timor Leste.

National Statistics Directorate, Ministry Of Finance. (2019). Timor-Leste Agriculture Census 2019.

Neely, C., Sutherland, K., & Johnson, J. (2004). Sustainable livelihoods and rural development: A new approach to poverty alleviation. International Institute for Environment and Development.

Novizan, (2005). Petunjuk Pemupukan yang Efektif. PT Agro Media Pustaka, Tangerang.

Pant, J., Philipps, M., Andrew, N. (2020). Aquaculture In Timor-Leste. Coral Triangle Initiative On Coral Reefs, Fisheries, And Food Security.

Pant, J., Teoh, S. J., Gomes, J., Pereira, M., & Kam, S. P. (2020). Report Of The 2nd Timor-Leste National Aquaculture Forum. Monographs.

Paudel, S., Baral, H., Rojario, A., Bhatta, K. P., & Artati, Y. (2022). Agroforestry: Opportunities And Challenges In Timor-Leste. Forests, 13(1). Https://Doi.Org/10.3390/F13010041

Payne, D., O'reilly, M., & Williamson, D. (1993). The K88 Fimbrial Adhesin Of Enterotoxigenic Escherichia Coli Binds To Beta 1-Linked Galactosyl Residues In Glycosphingolipids. Infection And Immunity, 61(9), 3673-3677.

Peniwiratri, L., & Arbiwati, D. (2022). Potential Of Kirinyuh (Chromolaena Odorata) And Cow Manure For Available Phosphor Supply On Sandy Beach Soil And P Uptake By Onion (Allium Cepa L.). In IOP Conference Series: Earth And Environmental Science (Vol. 1018, No. 1, P. 012026). IOP Publishing.

Pinatih, I. D., T. B. Kusmiyarti., dan K. D. Susila. (2015). Evaluasi Status Kesuburan Tanah Pada Lahan Pertanian Di Kecamatan Denpasar Selatan. E-Jurnal Agroekoteknologi Tropika Vol. 4, No. 4, hal 282 – 292

Poernomo, A. (1979). Budidaya Udang Di Tambak. Dalam Soegiarto, A., Toro, V., & Soegiarto, K.A. (Eds.) Udang: Biologi, Potensi, Budidaya, Produksi, Dan Udang Sebagai Bahan Makanan Di Indonesia. Lembaga Oseanologi Nasional-Lembaga Ilmu Pengetahuan Indonesia, Jakarta, Hlm. 77-174.

Poernomo, A. (1988). Pembuatan Tambak Udang Di Indonesia. Seri Pengembangan No. 7. Balai Penelitian Perikanan Budidaya Pantai, Maros, 40 Hlm

Ponce-Palafox, J., Martinez-Palacios, C.A., & Ross, L.G. (1997). The Effect Of Salinity And Temperature On The Growth And Survival Rates Of White Shrimp, Penaeus Vannamei, Boone, 1931. Aquaculture, 157: 107-115.

Poxton, M. (2003). Water Quality. In Lucas, J.S. & Southgate, P.C. (Eds.) Aquaculture: Farming Aquatic Animals And Plants. Blackwell Publishing Ltd., Oxford, P. 47-73.

Priyanto, D. (2016). Strategi Pengembalian Wilayah Nusa Tenggara Timur Sebagai Sumber Ternak Sapi Potong. Jurnal Litbang Pertanian, 35(4), 167-178.

Quintarelli, V., Radicetti, E., Allevato, E., Stazi, S. R., Haider, G., Abideen, Z., Bibi, S., Jamal, A., & Mancinelli, R. (2022). Cover Crops For Sustainable Cropping Systems: A Review. Agriculture, 12(12). Https://Doi.Org/10.3390/Agriculture12122076

Rangwala, I., & Miller, J. R. (2012). Climate Change In Mountains: A Review Of Elevation-Dependent Warming And Its Possible Causes. Climatic Change, 114(3), 527-547.

Rayalu, M. B. (2024). Climate Change And Agricultural Productivity: An In-Depth Review Of Impacts, Adaptation Strategies, And Policy Implications. South Asian Journal Of Agricultural Sciences, 4(2), 94–100. Https://Doi.Org/10.22271/27889289.2024.V4.I2b.148

Rejekiningrum, P., Apriyana, Y., Sutardi, Estiningtyas, W., Sosiawan, H., Susilawati, H. L., Hervani, A., & Alifia, A. D. (2022). Optimising Water Management In Drylands To Increase Crop Productivity And Anticipate Climate Change In Indonesia. In Sustainability (Switzerland) (Vol. 14, Issue 18). MDPI. Https://Doi.Org/10.3390/Su141811672

Risma, S., Maryam., Rahayu, A. Y. (2023). Penentuan C-Organik Pada Tanah Untuk Meningkatkan Produktivitas Tanaman Dan Keberlanjutan Umur Tanaman Dengan Metoda SpektrofotometrI UV VIS. Jurnal Teknologi Pertanian 12 (1): 11–19.

Risna, D., Jamili, M. A., & Syam, J. (2022). Sistem Perkandangan Ayam Broiler Di Closed House Chandra Munarda Kabupaten Takalar. Jurnal Sains Dan Teknologi Industri Peternakan, 2(1), 16-22.

Ritung, S., Nugroho, K., Mulyani, A., & Suryani, E. (2011). Petunjuk Teknis Evaluasi Lahan Untuk Komoditas Pertanian. Balai Besar Penelitian Dan Pengembangan Sumberdaya Lahan Pertanian, Puslitbangtanak, Badan Penelitian Dan Pengembangan Pertanian. Bogor. Hlm, 159.

Rokhayati, U. A., & Evadewi, F. D. (2023). Evaluasi Manajemen Pemberian Pakan Terhadap Budi Daya Ternak Sapi Potong Di Kecamatan Bongomeme Kabupaten Gorontalo. Media Peternakan, 24(2).

Rokhayati, U. A., & Evadewi, F. D. (2023). Evaluasi Manajemen Pemberian Pakan Terhadap Budi Daya Ternak Sapi Potong Di Kecamatan Bongomeme Kabupaten Gorontalo. Media Peternakan, 24(2).

Rusdi, M., Roosli, R., & Ahamad, M. S. S. (2015). Land Suitability Evaluation For Settlement Based On Soil Bearing Capacity In Banda Aceh, Indonesia. Advances In Environmental Biology, 53-57.

Salvador, M., Bhujel, R. C., Shrestha, K., Docarmo, A. D., & Pant, J. (2024). Fish Production And Socio-Economic Benefits Of Small-Scale Aquaculture In Timor-Leste After And During Project Implementation. Journal Of Applied Aquaculture, 36(1), 24-46.

Sawyer, C.N. & Mccarty, P.L. (1978). Chemistry For Environmental Engineering. Third Edition. Mcgraw-Hill Book Company, New York, 532 Pp.

Schmidt, F.H. & Ferguson, J.H.A. (1951). Rainfall Type Based On Wet And Dry Period Ratios For Indonesia With Western New Gurinea. Verhandelingen, 42: 77 Pp. Plus Figures

Setyorini, D., Soeparto dan Sulaeman. (2003). Kadar Logam Berat Dalam Pupuk. Badan Penelitian Tanah. Bogor.

Silva, H. (1954). Panorama Pecuária De Timor. Revista De Ciências Veterinárias, XLIX, 348-349.

Skerman, V. B. D., QUINN, G. R., Sly, L. I., & Hardy, J. V. (1977). Sheath Formation By Strains Of Herpetosiphon Species. International Journal Of Systematic And Evolutionary Microbiology, 27(3), 274-278.

Stickney, R.R. (2000). Tilapia Culture. In Stickney, R.R. (Ed.) Encyclopedia Of Aquaculture. John Wiley & Sons, Inc., New York, P. 934-941.

Sukarman, Mulyani, A., & Purwanto, S. (2018). Modifikasi Metode Evaluasi Kesesuaian Lahan Berorientasi Perubahan Iklim. Jurnal Sumberdaya Lahan, 12(1), 1–1.

Tatipikalawan, J. M. (2017). Karakteristik Sosial Ekonomi Dan Kendala Produksi Dan Pemasaran Ternak Kambing Lakor Di Pulau Lakor Provinsi Maluku. Jurnal Budidaya Pertanian, 13(2), 68-73.

Tatoli. (2022). MAP Memberikan Pelatihan Tentang Cara Memelihara Ikan Kepada Kelompok Petani Di Covalima. Diakses Dari Https://Tatoli.Tl/2022/07/25/Map-Fo-Formasaun-Oinsa-Hakiak-Ikan-Ba-Grupu-Agrikultor-Iha-Covalima/?Form=MG0AV3

Toban, E. W., Sunarta, I., & Trigunasih, N. (2016). Analisis Kinerja Daerah Aliran Sungai Berdasarkan Indikator Penggunaan Lahan Dan Debit Air Pada Das Unda. J. Trop. Agroecotechnol, 5, 394-404.

TOMAK. Chicken & Egg: The Hard Choices. Diakses Pada 13 Maret 2025, Dari Https://Tomak.Org/Chicken-Egg-The-Hard-Choices/?Form=MG0AV3

Universitas Gadjah Mada. (2016). Produktivitas tanaman pangan di Lautem, Timor Leste belum optimal. UGM News.

Vong, E. A. (2016). Studi karakteristik tanah lempung Bobonaro di Maliana, Timor Leste. Jurnal Rekayasa Infrastruktur, 1(4)

Westaway, J., Quintao, V., & De Jesus Marcal, S. (2018). Preliminary Checklist Of The Naturalised And Pest Plants Of Timor-Leste. Blumea-Biodiversity, Evolution And Biogeography Of Plants, 63(2), 157-166.

Widarti & Sukaesih. (2015). Keragaman Jenis Pakan Ternak Dan Ketersediaannya Di Wilayah Sekitar Taman Nasional Gunung Halimun Salak. 1(7): 1565-1569.

Williams, R. L., Bacon, S., Ferreira, A., & Erskine, W. (2018). An Approach To Characterise Agricultural Livelihoods And Livelihood Zones Using National Census Data In Timor-Leste. Experimental Agriculture, 54(6), 857-873. Doi:10.1017/S0014479717000436

Williamson, G. (1993). Pengantar Peternakan Di Daerah Tropis.

Wiryanta, B.T.W., Sunaryo, Astuti, & Kurniawan, M.B. (2010). Budi Daya & Bisnis Ikan Nila. PT Agromedia Pustaka, Jakarta, 210 Hlm.

RESEARCHER BIOGRAPHIES

A. Researchers from Udayana University

Prof. Dr. Ir. Ni Made Trigunasih, M.P. (Team Leader)

Education: B.Eng./B.Sc. in Agricultural Engineering (Udayana University); M.Sc. in Soil Science (Padjadjaran University); Ph.D. in Agricultural Science (Udayana University).
Academic Rank: Full Professor.
Teaching Experience: 1986–present.
Areas of Expertise: Land resource development grounded in environmental conservation; land suitability evaluation; soil and water conservation; sustainable land-use planning and management.
Collaboration Contact: trigunasih@unud.ac.id |+62 819-3311-8689

Ir. I Dewa Made Arthagama, M.P.

Education: B.Eng./B.Sc. in Agricultural Engineering (Udayana University); M.Sc. in Soil Science (Brawijaya University/ Gadjah Mada University).
Teaching Experience: 1986–present.
Areas of Expertise: Applied soil science and agricultural land management; soil fertility and soil quality improvement; soil–water management for sustainable production systems.

Prof. Dr. Ir. I Made Mega, M.S.

Education: B.Sc. in Soil Science (Udayana University); M.Sc. in Soil Science (Gadjah Mada University); Ph.D. in Agricultural Science (Udayana University).
Academic Rank: Full Professor.
Teaching Experience: 1985–present.
Areas of Expertise: Industrial crop production; crop management and productivity enhancement; management of growth factors and crop production systems.

Ir. I Nyoman Dibia, M.Si

Education: B.Sc. in Soil Science (Udayana University); M.Sc. in Geomorphology (Gadjah Mada University).
Areas of Expertise: Geomorphology and landscape analysis; landform interpretation for land-resource planning; mapping and zoning support based on regional physical characteristics.

Ir. Moh Saifulloh, S.P., M.Sc.

Education: B.Sc. in Soil and Environmental Science, Faculty of Agriculture (Udayana University); M.Sc. in Geography and Remote Sensing (Gadjah Mada University).
Professional Engineer (Insinyur): Geodesy / Regional Mapping.
Areas of Expertise: GIS and remote sensing; thematic mapping and spatial analysis; integration of field data and satellite imagery; geodetic and mapping support for research and territorial management.

Dr. Ir. Ni Luh Gde Sumardani, S.Pt., M.Si., IPM.

Education: B.Sc. in Animal Science (Udayana University); M.Sc. in Reproductive Biology, Graduate School (IPB University); Ph.D. in Animal Science (Udayana University).
Teaching Experience: 2002–present.
Professional Engineer (Insinyur): Animal Husbandry.
Areas of Expertise: Livestock reproductive biology; reproductive and production management; science-based strengthening of livestock systems; improvement of livestock production performance.

I Wayan Darya Kartika, S.Pi., M.Si.

Education: B.Sc. in Fisheries Product Technology (IPB University); M.Sc. in Fisheries Product Technology, Graduate Program (IPB University).
Teaching Experience: 2018–present.
Areas of Expertise: Fisheries product technology (processing and quality assurance); post-harvest handling; product development; value addition for fisheries commodities.

B. Researchers from MAPPF, Timor-Leste

Eng. Celestino Luis Moreira, MP
Areas of Expertise: Land suitability assessment; soil classification; regional potential mapping.
Role/Responsibilities: Technical coordinator for field operations and program development for regional potential mapping and land suitability evaluation in Timor-Leste (2024/2025).

Eng. Cesar Jose da Cruz, PG-GSRNA
Areas of Expertise: Research management; field supervision; monitoring and quality assurance of field observations.
Role/Responsibilities: Research Director responsible for strategic guidance and for ensuring that field observations are implemented in accordance with the work plan and methodological standards.

Eng. Nilton J.A. de Carvalho Ribeiro, M.Sc
Areas of Expertise: Geographic Information Systems (GIS); spatial database management; integration of spatial and attribute datasets.
Role/Responsibilities: GIS and database technician responsible for database preparation, updating, and management, and for providing technical support for analysis, mapping, and reporting.

RESEARCH ASSISTANTS

1. Hagai Bryant Silalahi, S.P.
2. Gieselle E. Immaculata Siahaan, S.P.
3. Santisima Fransiska, S.P.
4. Nindya Oktaviani, S.P.
5. Ni Putu Sindy Wahani Putri, S.P.
6. Ni Made Elyariani, S.P.
7. I Komang Putra Astika, S.P.
8. Ni Luh Manik Sugiantini, S.Pt.
9. Faisal Peru Sihombing, S.Pi.

FIELD SURVEYORS (MAPPF, TIMOR-LESTE)

1. Eng. Deolindo de Oliveira
2. Eng. Armandina Marcal, M.Sc
3. Eng. Julio Correia, MP
4. Eng. Marcos C. Vidal, M.Sc
5. Eng. Juliberto dos Santos, MP
6. Eng. Ida Pereira dos Santos, MP
7. Eng. Leandro C. R. Pereira, M.Sc
8. Eng. Jose da Costa R. Freygen, M.Sc
9. Eng. Julieta Lidia
10. Eng. Pedro Bere
11. Eng. Telesforo F. Moniz
12. Eng. Florindo M. Neto
13. Eng. Inacio Savio Pereira
14. Mario D. Dos Santos Vinhas, L.Ed
15. Eng. Mario Tavares Goncalves
16. Eng. Paulo da Costa

17. Eng. Zito Aquino
18. Eng. Apolinario Ximenes
19. Jacinto Boavida, S.Pt
20. Eng. Francisco Gusmao
21. Eng. Adelia C. G. dos Santos, M.Pt
22. Edson V. X. Da Luz
23. Eng. Antonio Vicente
24. Jorge Amaral
25. Tinoco Vicente
26. Hermenegildo A. da Silva
27. Gilberto Rogerio

Manatuto Municipality

Manatuto Municipality is a strategic area for comprehensive agricultural development, characterized by a diverse land-use composition that includes irrigated rice fields (7.77 %), rainfed rice fields (9.38 %), dryland farming (19.89 %), grazing areas (0.96 %), and forestry zoning consisting of agroforestry systems (31.81 %), protected forests (29.96 %), and mangrove forest (0.23 %). The main food commodity potential includes irrigated rice and rainfed rice, upland rice, corn, sweet potato, sorghum, and mung beans, with Barique/Natarbora Administrative Posts functioning as major food production areas as well as mangrove ecosystem zones. In addition, fruit horticultural commodities (orange, melon, watermelon), vegetable commodities (bell pepper, eggplant, cucumber, cabbage), spices and medicinal plants (vanilla, cinnamon, turmeric, aromatic ginger), and industrial crops (Robusta coffee, tea, cacao, tobacco, kapok) exhibit high land suitability. Forestry potential includes sandalwood, mahogany, Melaleuca, and teak, supported by the Afoco marginal land reforestation program implemented by MAPPF.

In addition to the crop sector, Manatuto Municipality has substantial opportunities for livestock development, including buffalo, cattle, goats, pigs, and sheep, supported by the availability of forage feed commodities such as elephantgrass, Gliricidia sepium, and corn. Two core locations of the Cattle Production Area (KTS), namely Natarbora and Aiteas, serve as centers of milk production in Timor-Leste. The fisheries sector also shows development potential in Lacumesak Village (Laclo Administrative Post), Ma'abat Village (Manatuto Administrative Post), and Aubeon Village (Barique and Natarbora Administrative Posts), with leading commodities including Nile tilapia, common carp, and giant freshwater prawn. Nevertheless, technical challenges remain, particularly soil conditions with high base status that require integrated management measures, including the application of elemental sulfur at approximately 0.5 to 4 ton/ha depending on soil texture, gypsum at 2 to 8 ton/ha on sodic soils, ammonium-based fertilizers, and organic amendments in the form of compost at 10 to 20 ton/ha and biochar at 2 to 5 ton/ha to balance soil fertility and enhance productivity.

To support food security and sustainable development, multisector development in Manatuto Municipality is directed through an integrated farming system based on the five key farming practices, livestock integration, and aquaculture intensification. Soibada Administrative Post is designated as a development area for high-value economic crops such as vanilla and coffee, with a need for improved land management and farmer training to optimize production. Furthermore, three Villages, namely Aubeon (Barique/Natarbora Administrative Posts), Umacaduac (Laclo Administrative Post), and Ma'abat (Manatuto Administrative Post), are recommended as pilot projects for integrated agriculture, which are expected to support national food security while strengthening Timor-Leste's position in responding to regional dynamics, including the country's accession to ASEAN.