Land Suitability Evaluation & Regional Potential Mapping

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

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

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FOREWORD

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

With gratitude to God Almighty for His blessings and grace, we proudly welcome the publication of the book entitled "*Land Suitability Evaluation and Mapping of Regional Potential for the Development of Agricultural Commodities in Liquiçá District, Timor-Leste*". This book is the result of strategic collaboration between the Ministry of Agriculture, Livestock, Fisheries, and Forestry of Timor-Leste and the Faculty of Agriculture, Udayana University, fully supported by the Government of Timor-Leste through Contract No. 24/MAPPF/IV/2024.

As a country rich in natural resource potential, Timor-Leste faces major challenges in optimizing land use under conditions of limited resources and the impacts of climate change. This book responds to the urgent need for land resource management that is oriented toward food security, environmental sustainability, and poverty alleviation. Through a data-driven approach, this study has successfully mapped regional potential for the development of food, plantation, horticultural, and forestry commodities, and formulated relevant strategies to support rural economic growth and create new employment opportunities.

Covering four main sub-districts in Liquiçá District, namely Loes Sub-District, Liquiçá Sub-District, Maubara Sub-District, and Bazartete Sub-District, this book offers strategic guidance for the use of dryland areas that dominate Liquiçá District. The proposed land suitability zoning approach provides solutions to challenges such as land degradation, erosion hazard, and declining soil fertility. Furthermore, the book emphasizes the importance of integrating environmental conservation and modern technology to support sustainable land productivity.

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

Goals (SDGs), especially those related to ending hunger (SDG 2), climate 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 agricultural sector development planning. Through strong synergy and cooperation, it will be possible to ensure that agricultural development in Timor-Leste proceeds in line 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 completion of this book. May this work become an important milestone in Timor-Leste's journey toward robust food security, inclusive economic development, and a sustainable environment.

Respectfully,

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

A. GENERAL OVERVIEW OF THE AREA

This chapter presents an overview of Liquiçá District as an important background for evaluating land suitability and the potential for developing agricultural, plantation, horticultural, and forestry commodities. The information includes demographics, soil types, land use, and existing field conditions, based on a detailed and comprehensive data-driven approach.

1. Demographics

Liquiçá District is one of the districts in Timor-Leste, located on the northern coast of Timor-Leste. It borders Bobonaro District and Ermera District to the south, the Ombai Sea to the north, Dili District to the east, and Bobonaro District to the west. The population of Liquiçá District at the end of 2024 was 96,591 people, with a total area of 548.66 km².

2. Soil Types: Basis for Land Suitability Evaluation

Liquiçá District is dominated by Inceptisols, which have a high capacity to support food crop production due to their adaptability to various environmental conditions. Entisols occupy the next largest area; although they are less developed in terms of morphology and organic matter content, they can still be utilized through intensive management such as fertilization and conservation measures. Alluvial soils cover a smaller area but make an important contribution to local farming systems.

3. Geological Formations

The distribution of geological formations in the study area reflects significant diversity. The most extensive rock lithology in Liquiçá District consists of phyllite, schist, amphibolite, slate, and volcanic rocks. Alluvial formations comprise unconsolidated sediments ranging from clay to boulders, generally found in lowlands and along river courses. Other geological formations consist of conglomerates, sands, and clays, with diverse soil characteristics that require specific management and are suitable for plantation crops tolerant of marginal environmental conditions.

4. Land Use: Ecosystem Dynamics and Human Activities

Land-use patterns in Liquiçá District reflect a complex interaction between ecosystem characteristics and human activities. Agricultural land accounts for 13.18 % of the area, consisting of Loes rice fields and dryland farming. Commercial agriculture in the form of plantation crops occupies 21.47 % of the area and contributes significantly to the local economy, supported by technology and intensive management. Forest areas are distributed across Maubara Sub-District and Loes Sub-District, while rivers and grasslands support irrigation and livestock husbandry. Rural settlements integrated with agricultural land and forest demonstrate an adaptive and multifunctional spatial layout.

5. Slope Gradient: Risks and Potential

Variation in slope classes in Liquiçá District significantly influences land-use potential. Flat slopes (0 to 8 %) are dominant in Maubara Sub-District and are ideal for rice fields. Gentle slopes (8 to 15 %) are suitable for semi-intensive agriculture and plantations. Moderately steep slopes (15 to 25 %) are appropriate for agroforestry and perennial crops, with soil conservation as a key requirement. Steep (25 to 45 %) and very steep slopes (> 45 %) are prioritized for forestry and conservation due to the high erosion risk and the importance of maintaining hydrological functions.

6. Agroclimatic Zones: Grouping of Regional Potential

Agroclimatic zones in Liquiçá District are classified based on elevation and rainfall patterns using the ALGIS system, which refers to Fox (2003). Zone A is suitable for intensive agriculture such as rice cultivation but requires adaptive water management to respond to rainfall fluctuations. Zone B supports food crops and medium-scale livestock production, although it is constrained by limited access to technology. Zone C plays an important role in soil and water conservation and supports coffee-based agroforestry that contributes to both food security and ecological functions.

7. Existing Conditions, Problems, And Potential

Liquiçá District has diverse landforms, including marine, alluvial, fluvial, colluvial, hilly, and denudational mountain landscapes, which influence geomorphological characteristics and spatial utilization potential. Agricultural development still faces constraints, particularly limited access to irrigation water and low labor engagement in land management. High erosion risk on steep slopes leads to the loss of topsoil and declining productivity, especially in areas where soil conservation has not been effectively implemented. Several areas have potential for commodities such as sorghum and tea, but this potential has not yet been utilized optimally.

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

Chromolaena odorata, or siam weed, is an invasive weed that has spread widely in Timor-Leste since the 1980s. This species threatens agriculture by forming dense thickets that compete for nutrients and poses risks to livestock due to its toxic pyrrolizidine alkaloid content. Ecologically, the invasion of this weed hinders the regeneration of native vegetation and increases the risk of land fires. Nevertheless, *C. odorata* has utilization potential, including as a source of traditional medicine, organic fertilizer, and vermicompost. Appropriate management approaches are needed to reduce its negative impacts while optimizing the added value of its biomass.

B. RESEARCH METHODS

This study used a survey approach comprising field observations, interviews, and laboratory analysis to evaluate land suitability comprehensively. It applied Homogeneous Land Units as the basis for delineating areas using thematic map data, including land use, soil type, climate, geology, and slope gradient. Data analysis was supported by Geographic Information System (GIS) technology to produce accurate and informative map visualizations.

Research Procedures

1. Soil Sampling
   - Composite soil samples were collected 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:
   - Soil organic carbon (C-organic, %) using the Walkley and Black method.
   - Total Nitrogen (%) using the Kjeldahl method.
   - Soil texture using the pipette method.
   - Soil pH using a potentiometric method (H_2O 1:2.5).
   - Available Phosphorus and Available Potassium (ppm):
     - Bray-1 method for pH < 7 (with conversion to mg 100 g^{-1})

        - Olsen method for pH > 7 (with conversion to mg 100 g^{-1})
    - Salinity (dS m^{-1}) using a potentiometric method (H_2O 1:2.5)
    - Cation exchange capacity (CEC, cmol (+)) and base saturation (KB, %) using 1 N NH_4OAc at pH 7.
    - Total Phosphorus (mg/100 g) and Total Potassium (mg/100 g) determined using the 25 % HCl method.
    - Total Zinc (ppm) determined using the DTPA extraction method and Available Zinc (ppm) determined using the HNO3-: $HClO_4$ digestion method.
    - Total Sulfur (ppm) and Available Sulfur (ppm) determined using the spectrophotometric method.
    - Soil fertility status based on the PPT (1995) method.
    - Erosion hazard based on field observations and the Universal Soil Loss Equation (USLE)

Stages of Land Suitability Classification

1. Actual Land Suitability
   The initial classification was carried out to evaluate land suitability under existing conditions without any improvement.
2. Land Improvement Recommendations
   Improvement measures were identified to address limiting factors, including management of inputs such as fertilizers and soil and water conservation techniques.
3. Potential Land Suitability
   Suitability evaluation was conducted after considering improvement measures in order to maximize land potential.
4. Zoning of Commodity Development Potential
   Zoning was determined by integrating the Agro-ecological Zones of Liquiçá District, based on land suitability and specific agro-ecosystems.

C. CHARACTERISTICS OF AGRICULTURAL AND FOREST LAND

1. Temperature

Air temperature is a key indicator in land suitability evaluation and was analyzed using a combination of field data and a digital elevation model (SRTM DEM) based on the Braak approach. Liquiçá District has a range of temperatures, with a dominant interval of 21 to 24 °C. With increasing elevation, temperature tends to decrease, affecting evapotranspiration rates and crop water requirements.

2. **Rainfall**

Liquiçá District has annual rainfall ranging from less than 1,000 mm to 2,500 mm, with 1,500 to 2,000 mm dominating in Bazartete Sub-District. The mountainous topography in Bazartete enhances rainfall formation and increases rainfall intensity. This variation in rainfall influences both groundwater and surface water availability, which are key factors in agricultural planning

3. **Dry Months**

The pattern of dry months in Liquiçá District varies across the area, with average durations ranging from 5 to more than 6 dry months. Bazartete Sub-District is dominated by the 5 to 6 dry-month category, although parts of the area experience longer drought periods due to complex landforms and rain-shadow effects. Areas facing moist prevailing winds tend to receive higher rainfall, resulting in shorter dry periods and allowing the cultivation of drought-tolerant crops supported by micro-irrigation. In contrast, areas with prolonged dry months need to apply water conservation measures such as rainwater harvesting and adaptive farming techniques to maintain land productivity.

4. **Drainage**

Most land in Liquiçá District is well drained due to soil textures that support a balanced pattern of water flow and infiltration. These conditions are ideal for intensive agriculture, including annual crops and horticulture. In contrast, poorly drained conditions arise in compact soils that retain excess water, requiring improvement of soil structure and surface drainage systems. In areas with excessively drained conditions, sandy soil textures cause rapid moisture loss, so appropriate irrigation and the addition of organic matter are needed to maintain stable soil moisture.

5. **Coarse Fragments**

Coarse fragments play an important role in determining land suitability because they influence water storage capacity, infiltration, and root development. Analysis in Liquiçá District shows a varied distribution of coarse fragments, with a dominant content of < 3 %, indicating high fertility potential and suitability for agriculture. Conversely, areas with higher coarse fragment contents, particularly on steep land, require soil conservation measures to prevent erosion and sustain productivity.

6. Effective Soil Depth

The distribution of effective soil depth in Liquiçá District shows variation among sub-districts. Effective soil depth determines how far plant roots can develop to optimally absorb water and nutrients. Assessment was carried out by observing root distribution and the presence of hard layers or rock that restrict root penetration (Basir, 2019). In Liquiçá District, most land has an effective depth of 90 to 120 cm, especially in Bazartete Sub-District, which indicates high edaphic potential for sustainable agriculture.

7. Surface Rock

Surface rock content affects ease of tillage, water retention, and root development, and is therefore an important indicator in land evaluation. In Liquiçá District, particularly in Bazartete Sub-District, most land has low surface rock content (<5%), which supports friable soil structure and optimal root growth. Conversely, high surface rock content makes soils denser and more difficult to work mechanically. Such land is more suitable for agroforestry or perennial crops that are tolerant of compact soil conditions.

8. Rock Outcrops

Rock outcrops are an important geological indicator that influences soil physical properties, water-holding capacity, and erosion potential. In Liquiçá District, most areas have varying levels of rock outcrops, with a predominance in the 5 to 15 % category. This indicates that much of the land is relatively free of exposed rock, making it highly suitable for intensive agriculture and infrastructure development. In contrast, areas with high rock outcrop density tend to be difficult to cultivate and are more suitable for forestry, ecotourism, or land conservation.

9. Flood Hazard

In Liquiçá District, most areas, particularly in Bazartete Sub-District, are well drained and have low flood risk, making them suitable for intensive agriculture. Flood-free land has high potential for food crops and horticulture, especially when supported by favorable climate and irrigation. Conversely, areas with high flood risk are better allocated for conservation or agroforestry.

10. Soil Texture

Soil texture in Liquiçá District varies, ranging from clay loam in Bazartete Sub-District to predominantly clay soils in Maubara Sub-District. This variation reflects differences in topography, parent material, and land use that influence soil physical properties. Sandy textures tend to be nutrient-poor and dry out quickly, whereas clay soils retain water but have poorer drainage.

11. Soil pH

Soil pH is an important chemical indicator that affects nutrient availability, microbial activity, and chemical reactions in the soil. In Liquiçá District, pH values range from 5.50 to 5.74, classified as acidic and potentially limiting nutrient uptake. Soil organic matter is a major factor influencing pH, as undecomposed organic materials can lower pH through the production of organic acids.

12. Total Nitrogen

Total Nitrogen is an essential macronutrient for vegetative growth, protein synthesis, and plant metabolism. In Liquiçá District, Total Nitrogen content varies across areas, with moderate levels in Liquiçá and Maubara sub-districts and low levels in Bazartete and Loes sub-districts. Nitrogen is easily lost through volatilization, leaching, and surface runoff, so its availability is often suboptimal.

13. Available Phosphorus

Available Phosphorus in Liquiçá District is very low, with Loes Sub-District having the lowest levels. Low phosphorus availability is caused by strong fixation with clay particles and Al, Fe, or Ca, particularly in acidic soils or soils with high pH. Open grazing further exacerbates this condition through soil compaction and reductions in organic matter

14. Available Potassium

Potassium is an important macronutrient for plants, even though only a small amount is directly involved in metabolism. In Liquiçá District, Available Potassium levels are low across all areas, with Bazartete Sub-District having the highest levels and Loes Sub-District the lowest. These differences are influenced by soil texture, clay content, organic matter, and topographic position. Potassium management needs to be adjusted to soil characteristics and leaching risk in order to maintain land fertility.

15. Electrical Conductivity and Toxicity

Soil electrical conductivity (EC) reflects salinity levels and the amount of dissolved salts, and serves as an indicator of fertility and soluble nutrient content.

In Liquiçá District, EC values range from 1.76 to 2.40 dS m^{-1}, with Bazartete Sub-District classified as moderate and the other areas as low. These differences are influenced by parent material, texture, and land use, and they affect the potential for salt accumulation and osmotic stress in plants

D. SOIL FERTILITY STATUS

The distribution of soil fertility levels in Liquiçá District shows a heterogeneous composition, reflecting agronomic challenges that need to be addressed strategically. Most land has low soil fertility, with this category covering 61.98 % of the total area. Land with very low fertility accounts for 19.31 %, while moderate fertility is found on 10.54 % of the area, and high fertility on 8.16 %. These proportions highlight agronomic constraints that require strategic management to support agricultural productivity in the district.

Spatial distribution among sub-districts shows marked differences. Liquiçá, Bazartete, and Maubara sub-districts each have the largest proportion of land in the low-fertility category. Meanwhile, Loes Sub-District falls predominantly into the very low fertility category (8.55 %).

E. EROSION AND AGROFORESTRY-BASED CONSERVATION

1. Soil Erosion

Soil erosion in Liquiçá District is influenced by a combination of climatic factors, topography, soil characteristics, and suboptimal land management practices. In this area, steep slopes, limited vegetation cover, and low adoption of land conservation techniques accelerate surface runoff that removes the most fertile topsoil layer, which is critical for crop productivity. Bazartete Sub-District shows the most severe erosion levels, driven by extreme slope gradients and the dominance of Inceptisols and Entisols, which have fragile structure, low cohesion, and are easily degraded by water.

The main factors causing erosion in this area include:

- **Topography:** Steep to very steep slopes.
- **Soil orders:** Inceptisols and Entisols.
- **Rainfall:** High rainfall intensity leading to severe to very severe erosion.
- **Low vegetation cover:** Contributing to topsoil loss due to surface runoff.

- **Anthropogenic factors:** Land management that does not follow conservation principles accelerates erosion processes.

2. Agroforestry-Based Conservation

Agroforestry-based conservation is a key and effective approach to addressing soil erosion in Liquiçá District. Agroforestry integrates forest trees, food crops, and livestock to provide ecological benefits and sustainable land productivity. This approach focuses on:

- **Increasing vegetation cover** to reduce surface runoff and maintain soil moisture.
- **Improving soil fertility** through the contribution of organic matter from leaves and roots.
- **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:

1. **Erosion mitigation:** Trees and crops act as natural barriers that protect soil from surface runoff.
2. **Improved water infiltration:** Tree root systems increase the soil's capacity to absorb water.
3. **Enhanced biodiversity:** The combination of food crops and trees creates a more diverse and stable ecosystem.
4. **Increased agricultural productivity:** Through agroforestry components that support diversified crop yields.

3. Implementation of Agroforestry in Liquiçá District

Agroforestry systems implemented in Liquiçá District vary according to agro-ecological zones. Examples of effective agroforestry-based conservation systems include:

- **Alley cropping**: Planting crops between rows of trees on steep slopes to control erosion.
- **Live fences:** Using erosion-resistant species such as Vetiver Root to stabilize slopes.
- **Live stakes:** Using perennial species such as Leucaena as live stakes to control erosion, combined with pepper and other climbing crops.
- **Multi-strata planting:** Combining trees, shrubs, and ground-cover crops to hold soil in place and reduce runoff.

- **Silvopastoral systems:** Integrating forest vegetation with livestock to manage erosion in grazing areas.

4. Conservation Recommendations

   1. **Strengthening agroforestry** practices in erosion-prone zones
   2. **Implementing spatial data based** management to identify priority locations for conservation interventions.
   3. **Increasing farmer capacity** through training and adoption of modern agroforestry techniques.
   4. **Strengthening soil conservation policies** by integrating agroecological approaches into spatial planning.

F. AGRICULTURAL LAND SUITABILITY

1. Land Suitability Evaluation

   a) Bazartete Sub-District

   - Food crops with development potential include soybean and peanut.
   - Horticultural commodities that can be developed include shallot, chili, mango, orange, rose, aster, and sunflower
   - Spice and medicinal crops that can be developed include aromatic ginger and turmeric.
   - Industrial crops that can be developed include Robusta Coffee and tobacco.

   b) Liquiçá Sub-District

   - Lowland food crops such as irrigated rice are classified as highly suitable (S1) for development. Dryland food crops that can be developed include soybean and wheat.
   - Industrial crops that can be developed include Robusta Coffee and sugarcane.
   - Horticultural crops with development potential include tomato vegetable, chili, mango, custard apple, aster, rose, and sunflower.
   - Spice and medicinal crops that can be developed include galangal and lemongrass.

c) Loes Sub-District

- Industrial crops with development potential include Robusta Coffee and cotton.
- Lowland food crops include irrigated rice, which is classified as highly suitable (S1). Dryland food crops with development potential include soybean and sorghum.
- Horticultural crops with development potential include eggplant, caisim, guava, soursop, rose, aster, and sunflower.
- Spice and medicinal commodities such as vanilla and candlenut can be developed.

d) Maubara Sub-District

- Food crops that can be developed include soybean and sorghum.
- Horticultural crops that can be developed include chili, bell pepper, rambutan, durian, rose, aster, and sunflower. Industrial crops with development potential include Robusta Coffee and cotton.
- Spice and medicinal crops that can be developed include galangal and cardamom.

2. Agricultural Commodity Development Zones in Liquiçá District

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

a) **Dryland Agriculture,** This zone covers 95.92 km^2 (17.47 %) at elevations of 0 to 1,000 m above sea level with slope gradients of 0 to 40 %. Commodities include corn, sorghum, cassava, legumes, horticultural crops, as well as industrial and spice crops. Mixed cropping systems, strip cropping, and crop rotation are recommended to maintain productivity and prevent erosion.

b) **Rainfed Rice Fields,** This zone accounts for 13.47 % of the total area and is located at elevations of 50 to 100 m above sea level with slope gradients of 0 to 8 %. Geological conditions are dominated by loose sediment lithology ranging from clay to boulders, under a monomodal agroclimatic regime. Priority commodities that can be cultivated include cassava, corn, legumes, and sorghum.

c) **Grazing Areas,** Grazing land covers 0.10 % of the area and is concentrated mainly in Bazartete Sub-District. Although limited in extent, it is important as a source of livestock feed. Management is directed through rotational grazing and integration with agroforestry. Elephantgrass, Setaria, and legumes are the main feed resources to support sustainable livestock production.

G. FORESTRY POTENTIAL IN LIQUIÇÁ DISTRICT

Forestry potential in Liquiçá District focuses on sustainable land management with a primary emphasis on coffee development within agroforestry systems. Based on the evaluation results, Bazartete Sub-District and Loes Sub-District have land suitability levels ranging from moderately suitable (S2) to marginally suitable (S3), which support the cultivation of Arabica coffee and Robusta Coffee.

The coffee agroforestry systems applied combine coffee plants with shade trees, fruit trees, and soil conservation species to maintain soil fertility, reduce erosion, and increase farmer income. Robusta Coffee is a flagship commodity because it is well adapted to local agroclimatic conditions and has strong competitiveness in both domestic and international markets. In addition to increasing productivity, coffee-based agroforestry management plays an important role in environmental conservation, maintaining biodiversity, and strengthening the economic resilience of communities in Liquiçá through environmentally friendly and sustainable farming practices.

H. LIVESTOCK POTENTIAL IN LIQUIÇÁ DISTRICT

This study aimed to evaluate land suitability for the development of forage feed commodities and the ecological suitability of livestock in Liquiçá District, Timor-Leste. The analysis supports efforts to improve feed availability, strengthen food security, and enhance community livelihoods through the livestock sector. There are three main focus in this assessment:

1. **Land Suitability for Forage Feed Commodities,** The areas of Bazartete, Loes, Maubara, and Liquiçá have potential for developing forage feed commodities such as elephantgrass, Setaria, legumes, and grazing land. However, there are several limiting factors, including Total Nitrogen, Available Phosphorus, Available Potassium, slope gradient, erosion, rock outcrops, and the number of dry months. Technical improvements that

can be implemented include NPK fertilization, addition of organic matter, terracing, sprinkler irrigation, and land clearing. Rock outcrops are a permanent limiting factor and cannot be improved.

2. **Ecological Suitability of Livestock,** an area of 39,341.18 ha is potentially suitable for livestock development (sheep, beef cattle, dairy cattle, pig, buffalo). Maubara Sub-District is the most dominant area for all types of large livestock. Loes Sub-District is suitable for beef cattle, dairy cattle, and pig, but more limited for sheep and buffalo due to temperature conditions. Liquiçá Sub-District and Bazartete Sub-District are suitable for all major livestock types. Poultry has very high ecological suitability across the entire district. The main factors influencing productivity are temperature and annual rainfall, which support forage growth but require careful feed and housing management to reduce heat or cold stress.
3. **Socio-economic Aspects of Community Livestock Farming**, Extensive systems (free grazing) still dominate community livestock management. The advantages of this system include low labor requirements, but its weaknesses include difficulties in controlling nutrition, high risk of disease, livestock theft, and crop damage. Limited capital, low levels of breeding practice (reliance on natural mating and lack of artificial insemination), minimal feed management, and restricted market access (sales mainly in the form of live animals) are key constraints. Proposed solutions include education on breeding and livestock management, including the introduction of artificial insemination technology, provision of credit or loans to increase livestock population and quality, and development of marketing channels for processed livestock products to increase sale value.

I. FISHERIES POTENTIAL IN LIQUIÇÁ DISTRICT

There are two main locations that serve as centers of aquaculture activities, each representing different ecosystem characteristics:

1. **Ulmera Village (Bazartete Sub-District),** Aquaculture is practiced in private earthen ponds measuring approximately 20 × 30 m with a depth of 0.8 m, using tidal water as the main source. The primary commodity is milkfish, with natural seedstock of 5,000 to 10,000 individuals per cycle and harvests ranging from 5,000 to 15,000 individuals, depending on environmental conditions. About five sacks of feed are used per cycle,

without aeration or stocking-density management. Crab fattening is also trialed on a small scale with yields of around 200 individuals per cycle, but simple methods and limited seed availability result in low productivity. Farmers expressed a need for technical training on stocking density management and crab grow-out.

2. **Lissadila Village (Loes Sub-District)**, Aquaculture is managed by 10 community groups using 10 conventional earthen ponds measuring approximately 10 × 20 m. The main commodity is tilapia, with water sourced from groundwater wells. Aeration and irrigation systems are not yet available, and pond management is carried out manually, with 1 to 2 sacks of feed provided per month and no structured aquaculture management.

J. RESEARCH RECOMMENDATIONS

1. Agriculture Recommendations

Liquiçá District has diverse agricultural potential, including irrigated rice fields in Lissadila and Leoteala, sorghum in Gugleur and Guico, and intensive grazing in Fahilebo and Leorema. Food crops (corn, cassava, upland rice, and legumes), horticultural commodities (vegetables, tropical fruits, and strawberry in Leorema), industrial crops (coconut, coffee, cacao), and high-value spices are widely cultivated, supported by forest vegetation such as teak, Albizia, and sandalwood. The main constraints include limited water availability, declining coffee productivity, mortality of fruit trees (apple, mangosteen, avocado), shallow soil layers, weak market access, and low farmer capacity. Improving irrigation, fertilization and crop rejuvenation, enhancing infrastructure access, and providing cultivation training are key to sustainable agricultural development and improved community welfare.

2. Livestock Recommendations

Based on the land suitability evaluation for forage feed and the ecological suitability of livestock, two locations are recommended as pilot projects for livestock development in Liquiçá District. Vatuboro Village in Loes Sub-District has fertile land and a highly favorable climate for pig breeding. These conditions ensure the availability of quality feed, support animal health, and enable the sustainable production of superior pig breeding stock. Meanwhile, Lissadila Village in Loes Sub-District has strong potential to be developed as an integrated livestock farm through the integration of forage species such as Setaria, Calliandra, Gliricidia, and Leucaena to support fattening of cattle and buffalo, combined with food crops such as banana and papaya. Both locations are considered strategic as models for sustainable livestock systems based on local feed resources and crop–livestock integration.

3. Fisheries Recommendations

Aquaculture development in Liquiçá District requires integrated strategic actions from both central and local governments. Priority measures include establishing local hatchery units or organizing national seed distribution in Ulmera and Lissadila, providing continuous community training with support from technical institutions, and facilitating access to production inputs through subsidies or microcredit for feed, aerators, and basic infrastructure. Aquaculture development also needs to be integrated into regional development plans while maintaining coastal ecosystem conservation and making use of marginal land. All programs should be accompanied by data-based monitoring and evaluation so they can adapt to climate change and local conditions.

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I. INTRODUCTION

New Context: ASEAN, SDGs, and Food Security Challenges

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 optimizing natural resource management. Population growth demands strategic measures to increase productivity in the agriculture, livestock, and fisheries sectors.

Achievement of the Sustainable Development Goals (SDGs), particularly food security (SDG 2), clean water management (SDG 6), and climate action (SDG 13), has become a primary focus. In this context, Liquiçá District faces both unique challenges and opportunities.

Meaning of the Regional Name: The Origin of Liquiçá

The name Liquiçá originates from the Tokodede language and has several versions of its origin. First, it is derived from the term *Likis Aá*, meaning "change"; second, from the combination of the words *Likiki* (the Makikit bird) and *Sau* (beak); and third, from the term *Likusaen*, which refers to a local ethnic group. Prior to the establishment of Portuguese authority in 1698, this area was governed by traditional authorities. During the colonial period, Liquiçá was designated as the Distrito de Baubau, with the administrative center located in Maubara. Subsequently, during the period of Indonesian administration, the area held district status, and following the restoration of Timor-Leste's independence in 2002, Liquiçá was officially established as one of the Districts.

Focus Area: Population Pressure and Land Potential

Liquiçá District is one of the areas with significant potential to support food security but faces specific challenges, notably high population density, reaching an average of 152 people per km². This figure places strong pressure on land resources and requires optimization of every available area to increase food production.

Topographically, Liquiçá has an asset in the form of flat to gently sloping land (0 to 8 %) covering 18.23 % of the total area. This zone is highly suitable for the development of irrigation-based agriculture, which is critical to support food needs in a densely populated district.

Technical Basis: Challenges of Inceptisols Dominance

Soil (edaphic) characteristics are a key determining factor in Liquiçá. The district is predominantly covered by Inceptisols (80.23 %).

In practical terms, this has two implications:

1. **Potential:** These soils have a moderate degree of development and are suitable for various types of farming, especially vital food crops such as corn, cassava, and rice, provided they are managed properly.
2. **Challenge:** Their main limitation is water-holding capacity, which is generally moderate to low.

Therefore, the key to unlocking Liquiçá's potential lies in water management. Well-designed irrigation systems and water conservation strategies are essential. The use of organic fertilizers is also recommended to continuously improve soil fertility. This potential is complemented by the presence of Entisols (18.52 %) and a small extent of highly fertile Mollisols (1.25 %).

Opportunities for Integrated Sector Development

Development strategies in Liquiçá need to be directed toward optimal and sustainable use of natural resources, with a focus on four pillars:

1. **Agriculture:** Optimizing the 18.23 % flat land for irrigated agriculture to compensate for the tendency of Inceptisols to dry out quickly.
2. **Forestry (Agroforestry):** On sloping land, which constitutes the majority of the area, agroforestry is a strategic solution. This system maintains ecosystem balance, reduces erosion risk, and ensures long-term food production sustainability (Nair, 2011).
3. **Livestock:** Flat coastal areas provide ideal space for grazing land, supporting cattle and goat production as key livestock commodities.
4. **Fisheries (Freshwater and Brackish Water):** The fisheries sector in coastal areas offers strong prospects for brackish-water aquaculture (pond

culture) through the application of modern technology, such as biofloc-based aquaculture systems.

Strengthening infrastructure, particularly irrigation facilities, transport access, and market access, must be prioritized to support this integrated system.

Purpose of the Evaluation in This Book

This study therefore aims to evaluate land suitability in Liquiçá District based on edaphic and agroecological characteristics. The focus is to map regional development potential in the agricultural sector, as well as to explore the livestock and fisheries (freshwater and brackish water) sectors as integrated supporting sectors

Through a comprehensive scientific approach, this book is expected to provide strategic recommendations for government, academia, and other stakeholders in designing sustainable development policies to achieve a resilient and self-sufficient food system in Timor-Leste.

II. GENERAL OVERVIEW OF THE AREA

2.1 DEMOGRAPHY

Liquiçá District is one of the districts in Timor-Leste located on the northern coast of Timor-Leste. It borders Bobonaro and Ermera Districts to the south, the Ombai Strait to the north, Dili District to the east, and Bobonaro District to the west. Liquiçá District lies at latitude 8.340 to 8.440 °N and longitude 125.030 to 125.300 °E. The Administrative Map of Liquiçá District is presented in the figure below (**Figure 2.1**)

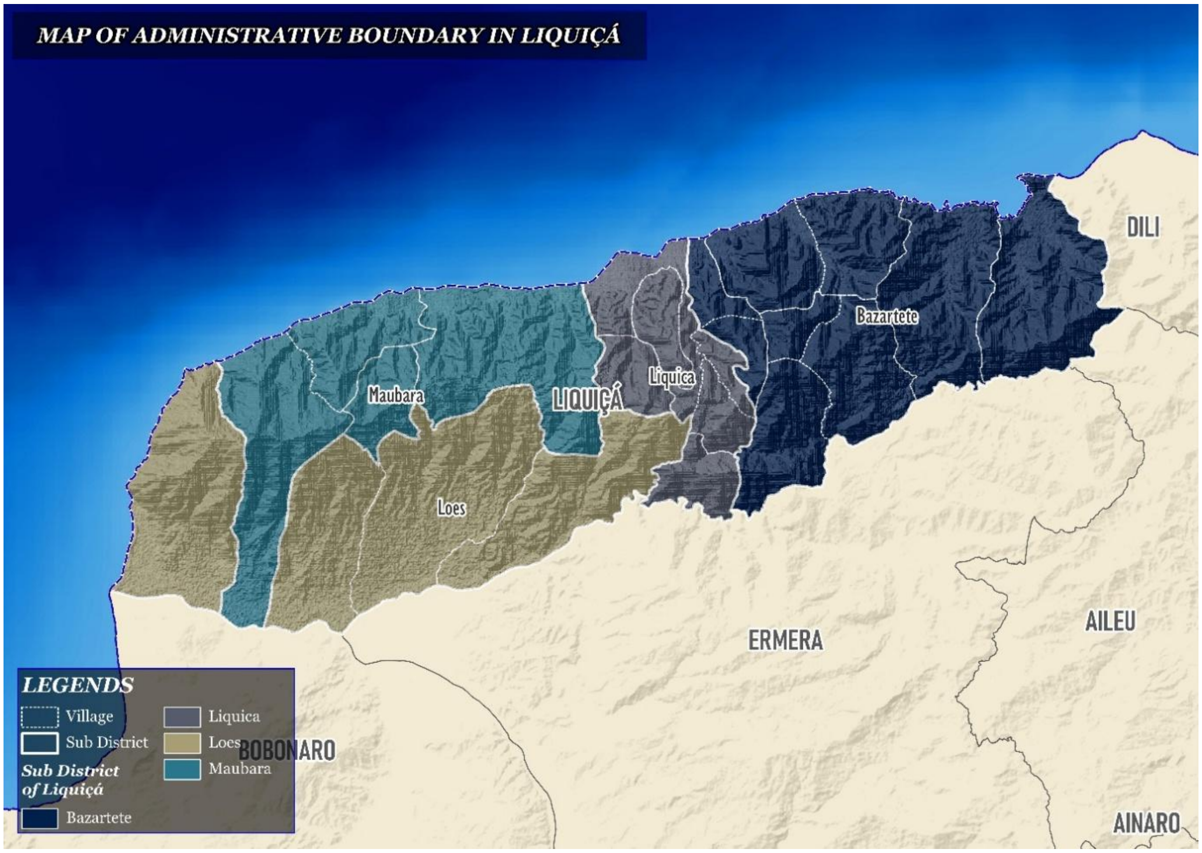


Figure 2.1 Administrative Area of Liquiçá District

Liquiçá District consists of 4 Sub-Districts, namely Bazartete, Liquiçá, Maubara, and Loes, encompassing 23 Villages and 134 hamlets. The population of Liquiçá District at the end of 2024 was 96,591, with a total area of 548.66 km^2 (Administrasaun Munisípiu Liquiçá, 2025). These data are presented in the table below (**Table 2.1**). The name Liquiçá derives from the Tokodede language, with three versions of its origin: first, from the term Likis Aá meaning change; second, from the combination of the words Likiki (Makikit bird) and Sau (beak); third, from the term Likusaen referring to a local ethnic group. Before the Portuguese established their authority in 1698, Liquiçá was governed by traditional authorities; during the colonial period it was designated as Distrito de Baubau with its center in Maubara, during the Indonesian occupation it had district status. After the restoration of Timor-Leste's independence in 2002, Liquiçá was officially designated as one of the districts.

Table 2.1 Area Munisípiu Liquiçá

Sub-district	Area (ha)
Bazartete	18.674,75
Liquiçá	5.903,92
Maubara	12.751,30
Loes	17.535,93

2.2 SOIL TYPES

Information on soil types in Liquiçá District was classified under Soil Taxonomy (using the 1992 Soil Taxonomy keys). The classification was conducted up to the Great Group level. There are 7 soil orders, 16 suborders, and 22 great groups.

Liquiçá District is dominated by the soil order Inceptisols covering 44,017.13 ha (80.23 %), followed by the order Entisols covering 10,163.74 ha (18.52 %), and alluvial soils covering 685.03 ha (1.25 %). The area by soil type and soil type by Sub-District are presented in **Figure 2.2** and **Figure 2.3.**

Inceptisols are the most dominant soil order in Liquiçá District. These soils are characterized by a moderate degree of profile development and are generally fertile for agricultural activities. The extensive presence of Inceptisols indicates considerable potential to support food-crop production, with good adaptation to diverse environmental conditions. Entisols have a very low degree of soil development. This order commonly occurs in newly formed landscapes such as river corridors or mountainous areas experiencing active erosion. Although limited in structure and organic matter content, Entisols can support agriculture with appropriate soil management interventions, such as nutrient additions and soil conservation measures. Alluvial soils occupy a smaller area in Liquiçá District but play an important role in agriculture. These soils form from water-transported deposits and are generally found in lowlands or along riverbanks. Their characteristics include high fertility and varied textures, making them well suited for a wide range of crops.

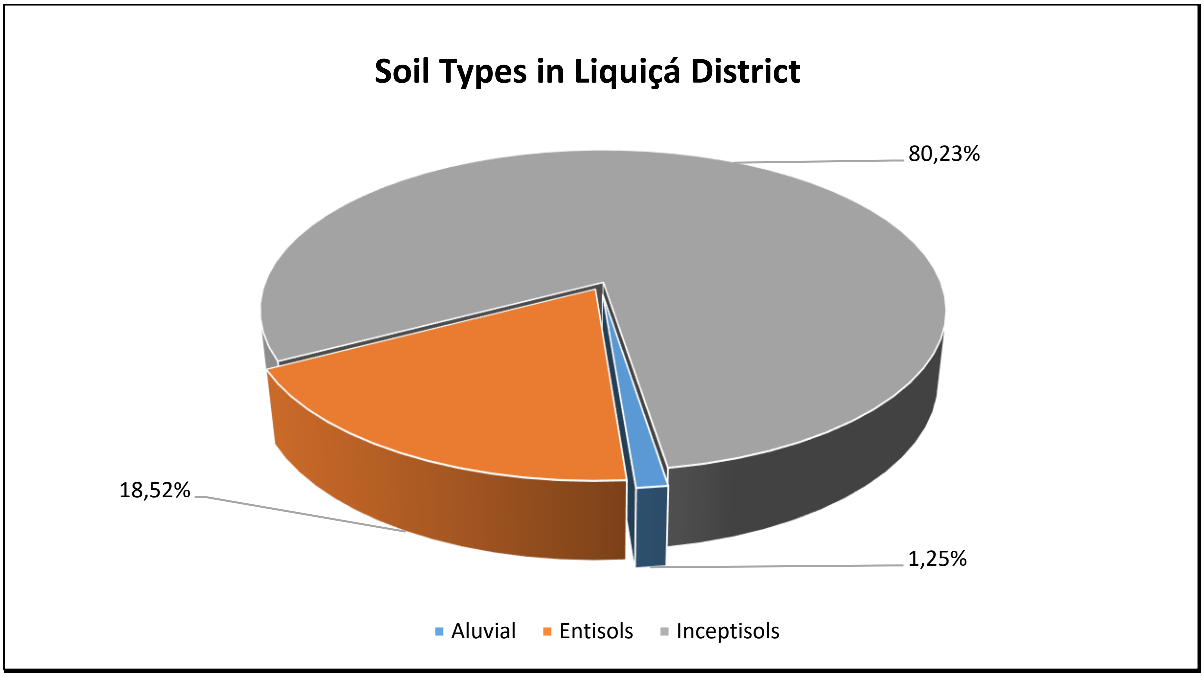
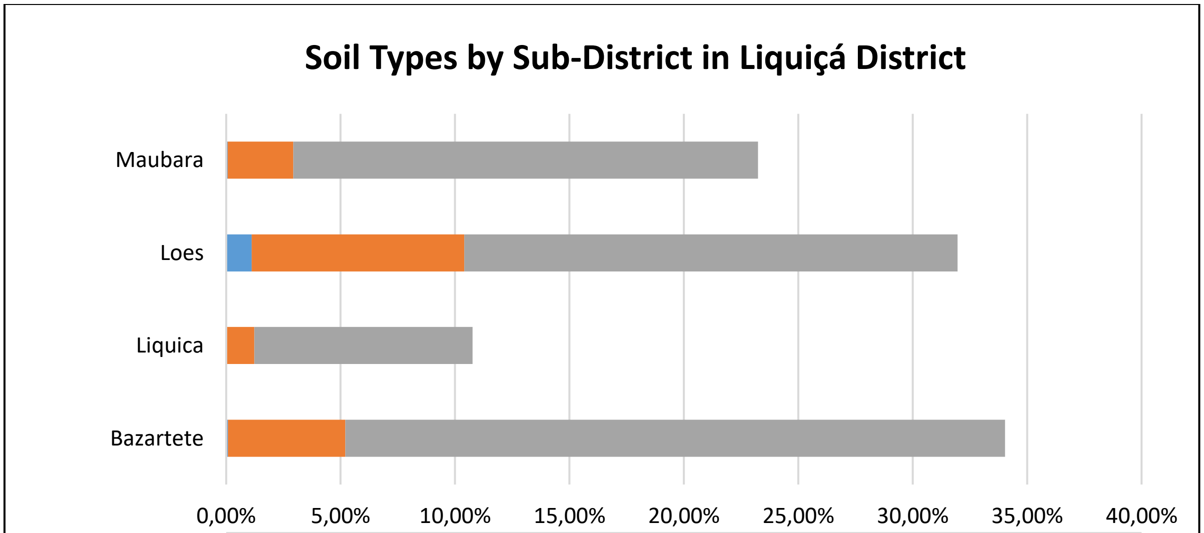


Figure 2.2 Area by Soil Type



	Bazartete	Liquica	Loes	Maubara
Aluvial	0,07%	0,00%	1,11%	0,06%
Entisols	5,13%	1,23%	9,29%	2,88%
Inceptisols	28,83%	9,53%	21,56%	20,31%

Figure 2.3 Distribution of Soil Types by Sub-District in Liquiçá District

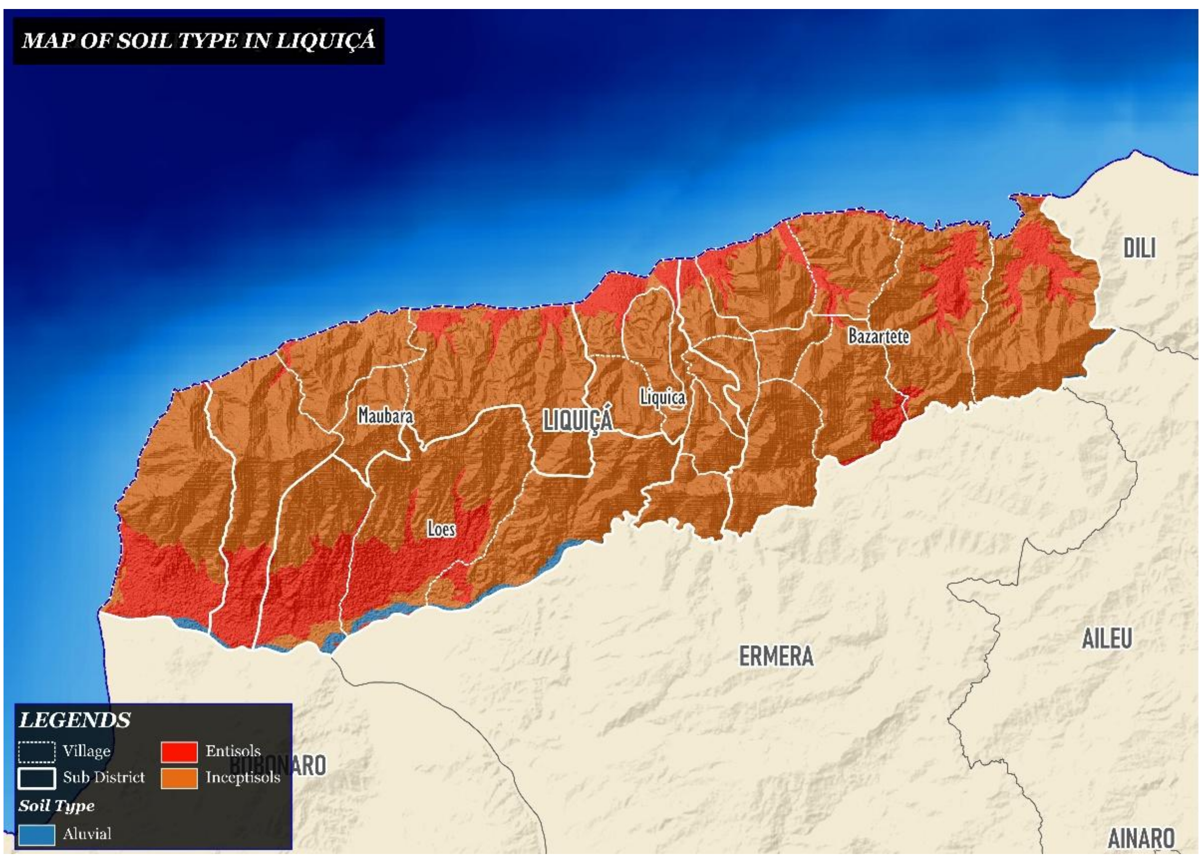


Figure 2.4 Soil Type Map of Liquiçá District

2.3 GEOLOGICAL FORMATIONS

The distribution of geological formations in the study area reflects substantial diversity and represents a complex geological history across the four Sub-Districts of Liquiçá District. Each geological formation contributes distinctively to soil characteristics, which in turn affect land potential and limitations for agricultural development. Based on the analysis, the *Aileu Formation* occupies the largest area at 89.46 %, followed by the *Alluvial Formation* at 10.19 %, and the *Ainaro Formation* at 0.35 %, as presented in **Figure 2.5** and **Figure 2.6**. The distribution map of geological formations in Liquiçá District is presented in **Figure 2.7.**

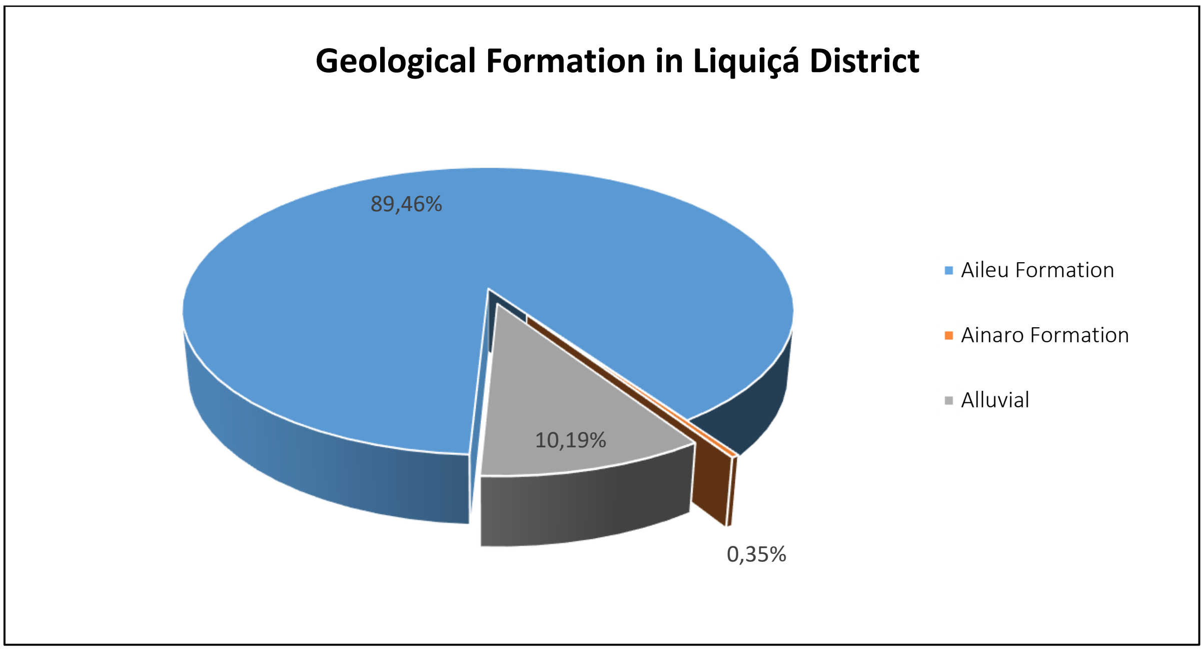
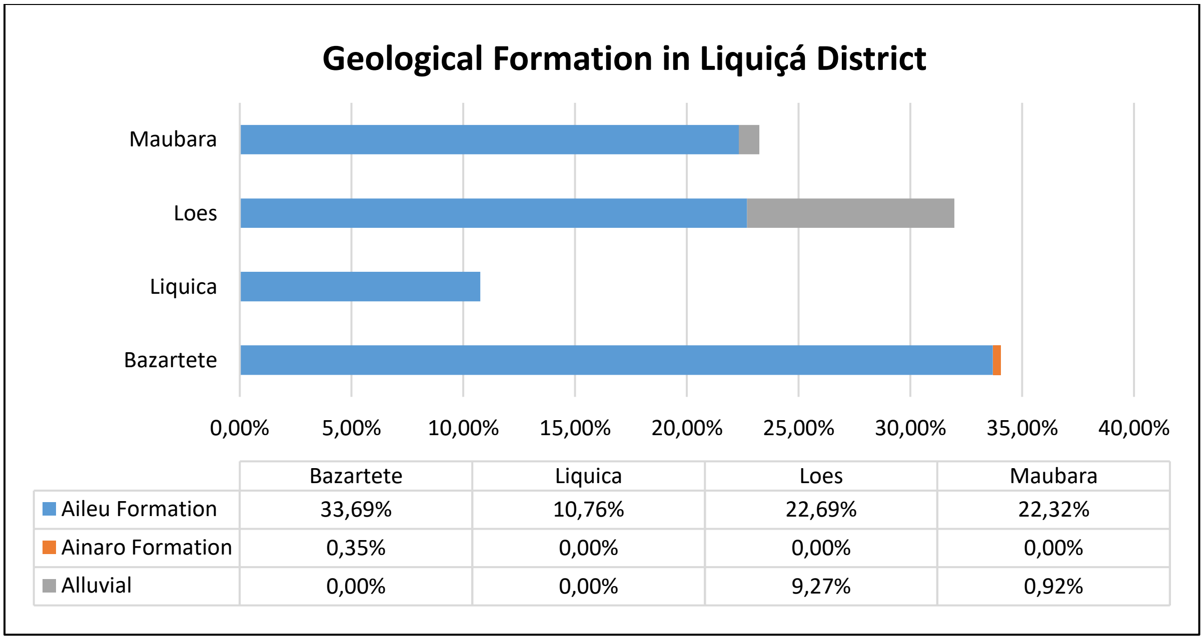


Figure 2.5 Area (%) by Geological Formation



	Bazartete	Liquica	Loes	Maubara
Aileu Formation	33,69%	10,76%	22,69%	22,32%
Ainaro Formation	0,35%	0,00%	0,00%	0,00%
Alluvial	0,00%	0,00%	9,27%	0,92%

Figure 2.6 Distribution of Geological Formations by Sub-District in Liquiçá District

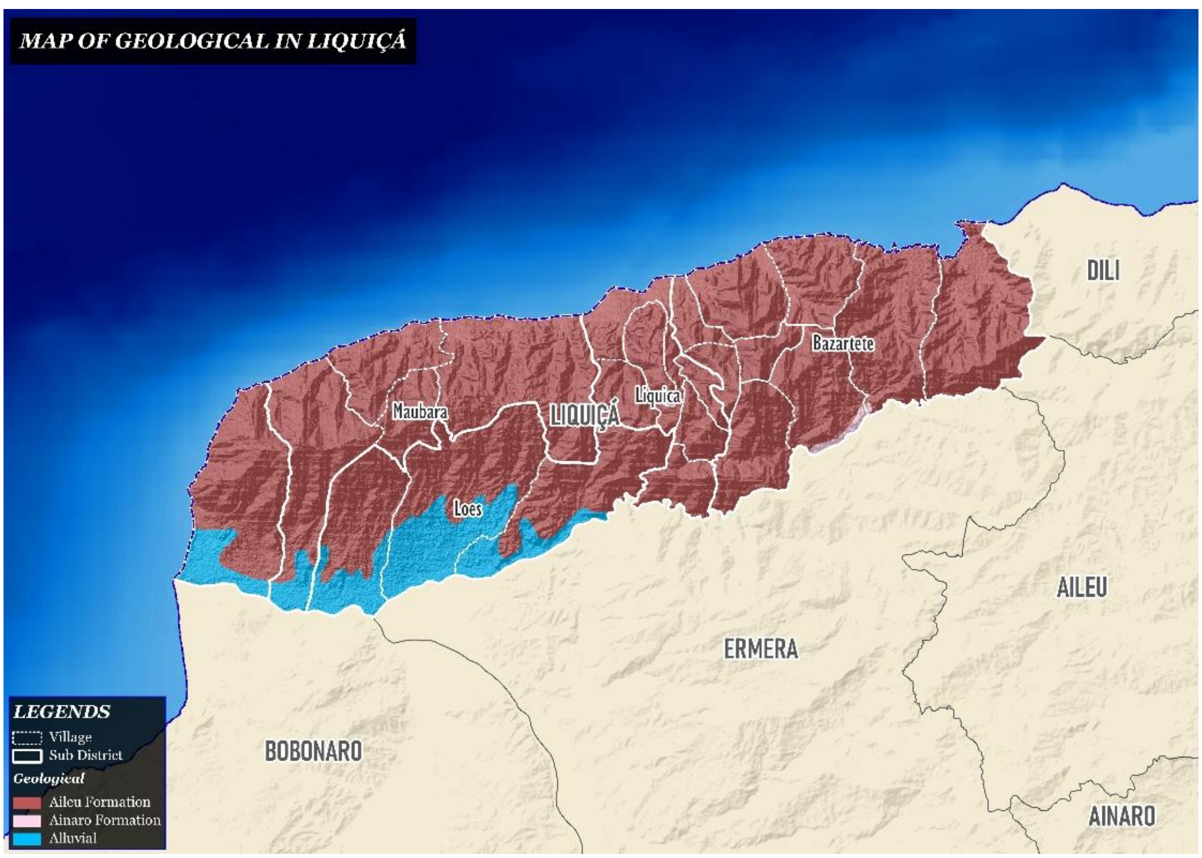


Figure 2.7 Distribution of Geological Formations by Sub-District in Liquiçá District

The *Aileu Formation* is the most dominant formation, covering a total of 49,082.05 ha. Its lithology is dominated by phyllite, schist, amphibolite, slate, and some volcanic rocks. These lithological characteristics indicate high resistance to erosion and soil fertility potential that varies depending on the degree of weathering and land management. The extensive dominance of the *Aileu Formation* indicates its key role in supporting agricultural activities in Liquiçá District.

The Alluvial Formation covers 5,590.7 ha of Liquiçá District. Its lithology consists of unconsolidated sediments ranging from clay to boulders, reflecting soils that tend to be fertile due to deposits rich in nutrients. Alluvial areas are generally concentrated in lowlands or along river courses, offering optimal potential for intensive agricultural development, particularly food and horticultural crops

The Ainaro Formation comprises lithology of conglomerates, sand, and clay, covering an area of 193.16 ha. These materials tend to have variable properties, ranging from susceptibility to erosion to moderate fertility. This area requires specific management strategies to be utilized effectively. These soils are suitable for crops with particular adaptations, such as plantation crops tolerant of challenging environmental conditions.

2.4 LAND USE

The land use pattern in the Sub-Districts of Liquiçá District reflects diversity and complexity, representing the distinctive characteristics of the local ecosystems as well as human activities associated with them. This information serves as a key foundation for the land suitability evaluation process for the development of various agricultural commodities, while maintaining a balance between environmental sustainability and land productivity optimization.

Agricultural land use in Liquiçá District covers 13.18 % of the total area, consisting of rice fields and dryland agriculture for food crops. Rice fields make up 1.06 % of the total area, with the largest coverage found in the Loes Sub-District at 0.96 % of the total area. Dryland agriculture for food crops covers 12.12 % of the total area, with the largest coverage in the Bazartete Sub-District at 9.05 %. Agricultural land use involves utilizing land for activities aimed primarily at producing food, plantation crops, and horticultural products. Agricultural land use can be classified based on the types of crops cultivated, land management systems, and the economic and environmental scale applied.

Commercial agricultural land use in Liquiçá District includes plantation crops. Estate crops account for 21.47 % of the total area, with the largest coverage in the Bazartete Sub-District at 9.42 %. Commercial agriculture refers to large-scale farming systems oriented toward production for commercial or market purposes, both local and export. At this scale, commercial agriculture is usually supported by modern technology, intensive management, and good infrastructure, allowing it to make a significant contribution to the local economy. Commercial agriculture also plays a role in the optimal utilization of land but requires attention to sustainable practices to maintain environmental balance and reduce the risk of land degradation due to agricultural intensification.

Unused dryland areas, such as grasslands are also present. Grasslands cover 0.10 % of the total area and are found only in the Bazartete Sub-District. These areas consist of natural vegetation, primarily grasses, providing significant potential for the development of extensive livestock activities, such as grazing.

Forest land use in Liquiçá District dominates 61.55 % of the total area, reflecting the important ecological functions of these areas in preserving the environment. Forests in this region play a strategic role in biodiversity conservation, soil stabilization, hydrological control, and climate change impact mitigation. **The dry lowland mixed forest** covers 44.40 % of the total area, with the largest coverage in the Maubara Sub-District at 25.50 %. This forest consists of a mixture of various tree species, reflecting high biodiversity and ecological potential. The primary function of this forest is to support conservation efforts. The forest supports the conservation of flora and fauna and provides natural resources such as timber, fuelwood, and medicinal plants for local communities**. Lowland forest- single species**, covers 17.16 % of the total area, with the largest coverage in the Loes Sub-District at 12.54 %. The main characteristic of this forest type is dominance by a single tree species, which is often planted as a monoculture for specific purposes, such as commercial timber production.

Rivers in Liquiçá District cover 1.87 % of the total area. Rivers are distributed across all Sub-Districts, with the largest share in the Loes Sub-District at 0.99 %. The rivers function as the primary source of irrigation for agricultural activities, particularly dryland agriculture and rice fields. In addition, they play a strategic role in maintaining hydrological balance, supporting environmental conservation, and supplying water for domestic needs and small-scale industries.

Rural settlements in Liquiçá District cover 1.83 % of the total area, with the largest coverage in the Bazartete Sub-District at 1.26 %. Village settlements are generally characterized by dispersed, low-density housing, often integrated with agricultural land or forest areas. Area data by land use type are presented in **Figure 2.8** and **Figure 2.9**.

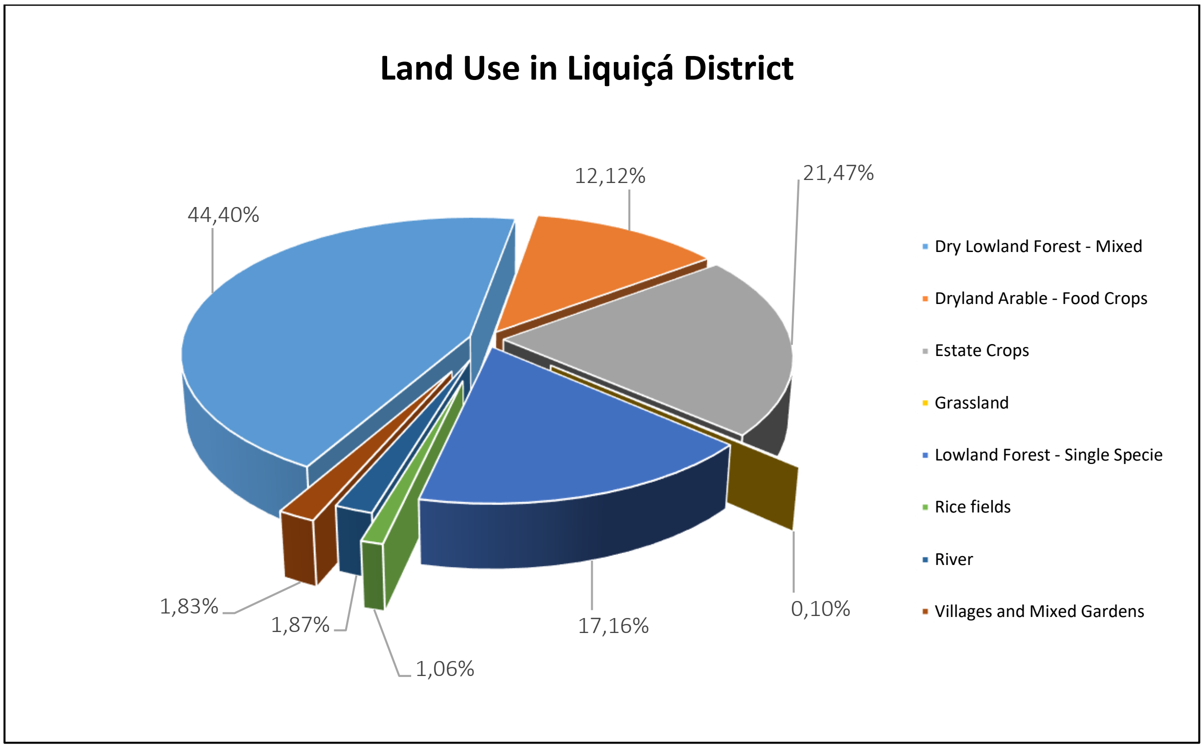
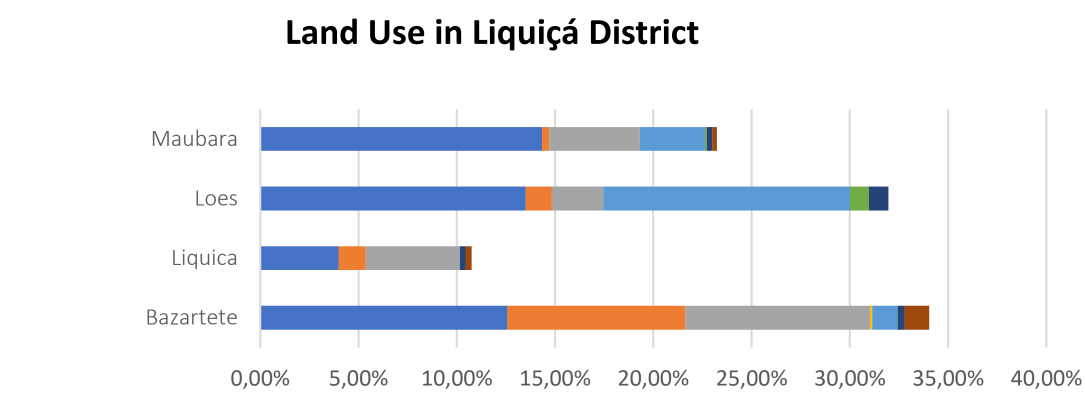


Figure 2.8 Diagram of Land Use Distribution in Liquiçá District



	Bazartete	Liquica	Loes	Maubara
Dry Lowland Forest - Mixed	12,57%	3,98%	13,51%	14,34%
Dryland Arable - Food Crops	9,05%	1,38%	1,32%	0,36%
Estate Crops	9,42%	4,80%	2,63%	4,62%
Grassland	0,10%	0,00%	0,00%	0,00%
Lowland Forest - Single Specie	1,31%	0,00%	12,54%	3,31%
Rice fields	0,00%	0,00%	0,96%	0,09%
River	0,33%	0,28%	0,99%	0,27%
Villages and Mixed Gardens	1,26%	0,32%	0,00%	0,24%

Figure 2.9 Graph of Land Use Distribution in Liquiçá District

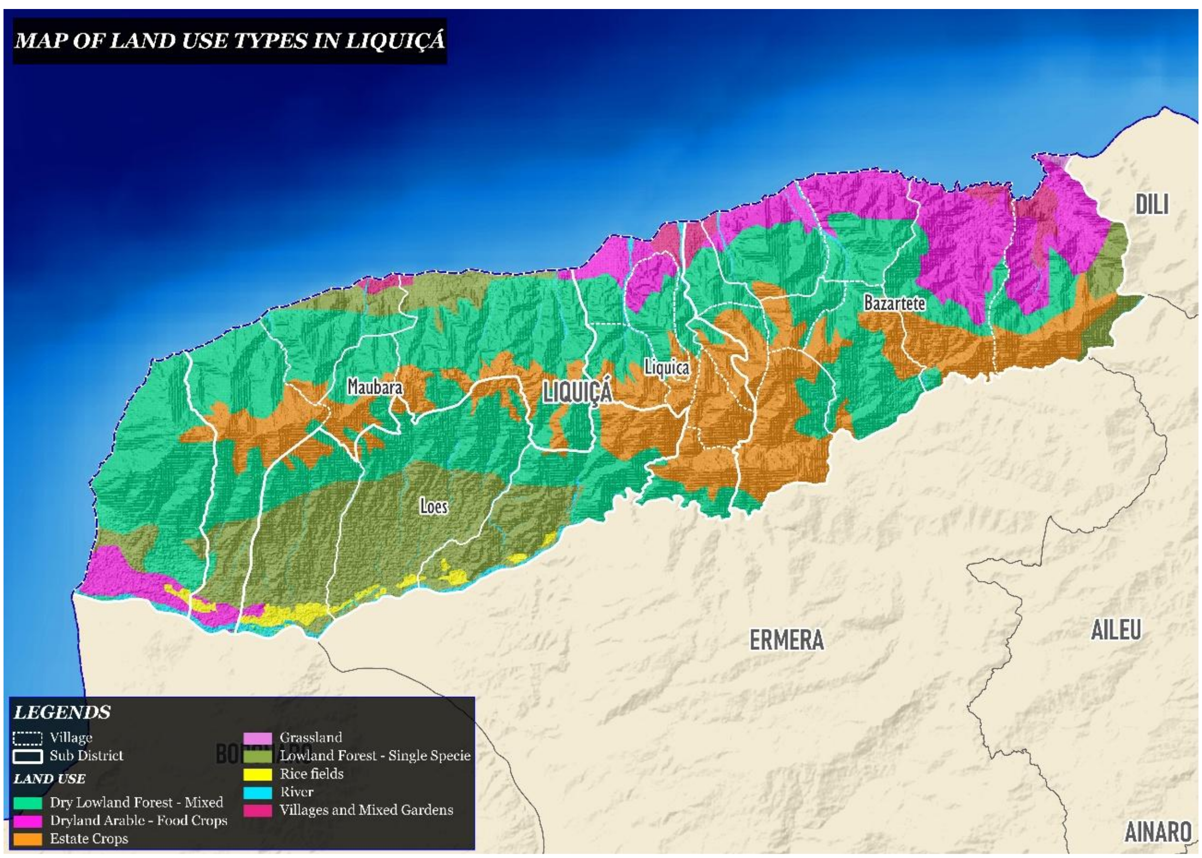


Figure 2.10 Land Use Distribution Map of Liquiçá District

2.5 SLOPE GRADIENT

The distribution of slope gradient classes across the four Sub-Districts of Liquiçá District provides important information on the topography, with implications for land management, soil erosion potential, and natural resource conservation. Slope gradients are grouped into five categories, namely flat (0 to 8 %), gentle (8 to 15 %), moderately steep (15 to 25 %), steep (25 to 45 %), and very steep (>45 %), as presented in **Figure 2.11**. This variation reflects the complexity of the area and influences the potential and challenges of land management for agricultural purposes. The distribution of slope gradient classes by Sub-District in Liquiçá District is presented in **Figure 2.12**. The slope gradient map of Liquiçá District is presented in **Figure 2.13.**

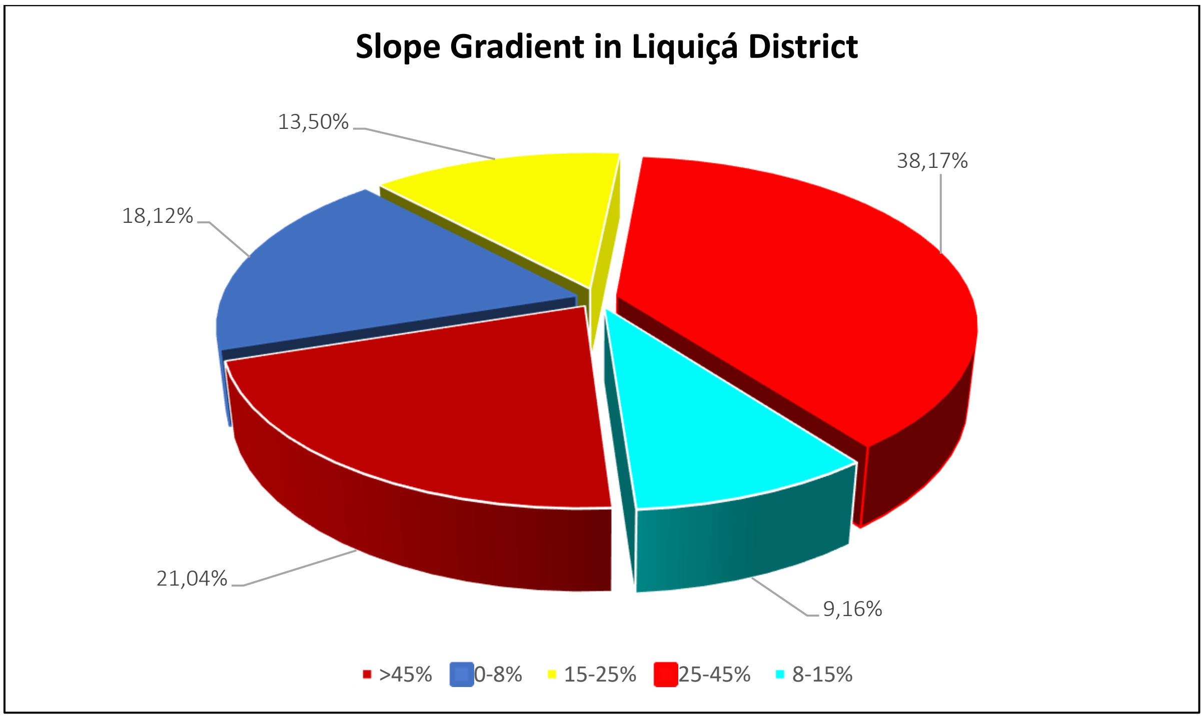
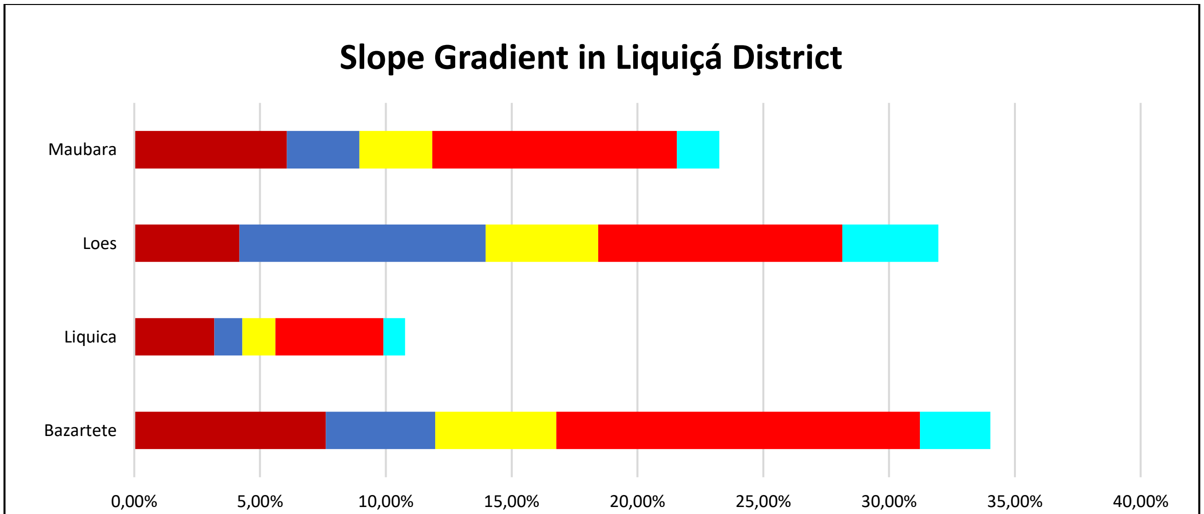


Figure 2.11 Distribution of Area by Slope Gradient in Liquiçá District.



	Bazartete	Liquica	Loes	Maubara
>45%	7,61%	3,18%	4,18%	6,06%
0-8%	4,35%	1,11%	9,78%	2,88%
15-25%	4,81%	1,32%	4,48%	2,90%
25-45%	14,45%	4,29%	9,70%	9,72%
8-15%	2,79%	0,86%	3,83%	1,68%

Figure 2.12 Graph of Distribution of Area by Slope Gradient in Liquiçá District.

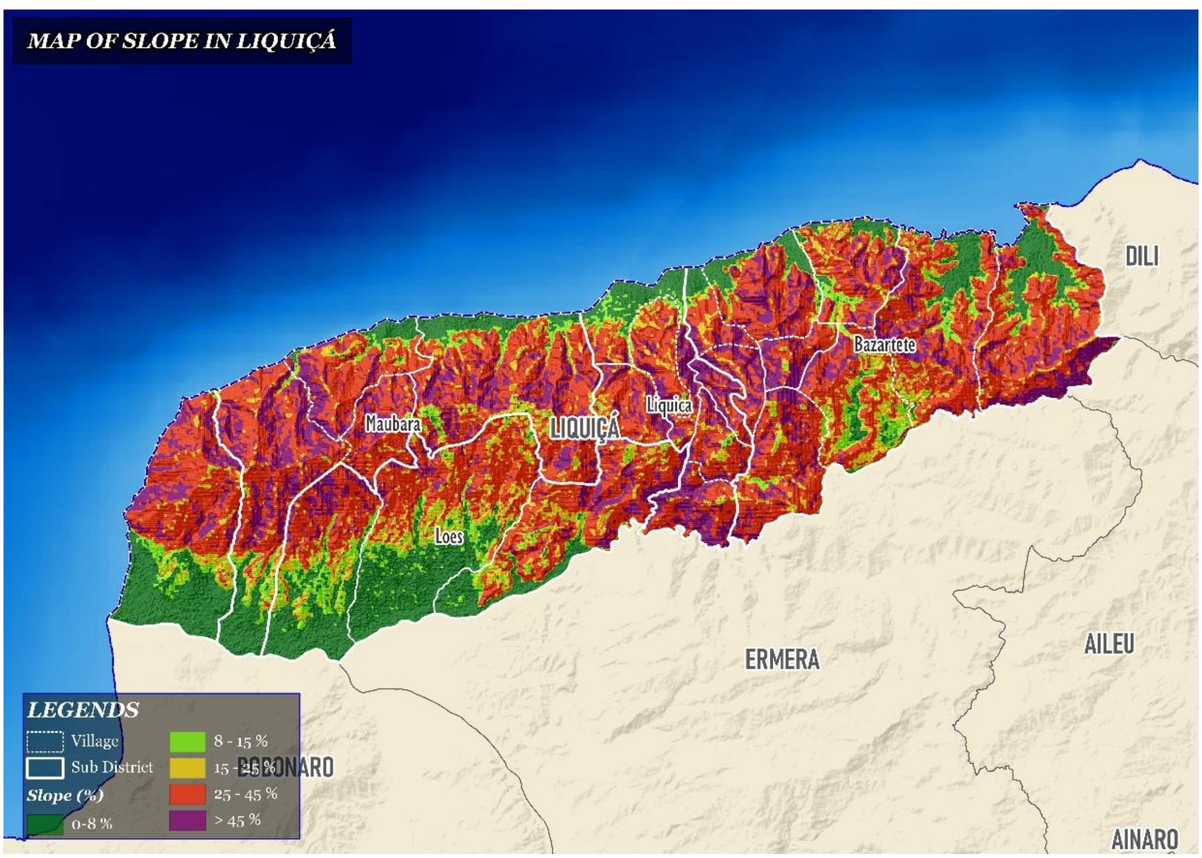


Figure 2.13 Slope Gradient Distribution Map of Liquiçá District.

The flat slope class (0 to 8 %) covers 18.12 % of the total area and is relatively evenly distributed across several Sub-Districts. The Maubara Sub-District has the largest area in this category at 53.62 km^2 or 9.78 %. In the agricultural sector, this class is highly suitable for irrigated rice because irrigation systems can be readily implemented.

The gentle slope class (8 to 15 %) covers 9.16 % of the total area. The Maubara Sub-District has the largest area in this category at 20.97 km^2 or 3.83 %. Areas with slopes of 8 to 15 % have slightly inclined topography, making them suitable for semi-intensive agriculture and plantations. These areas can be used for crops such as corn and soybean, or for plantation crops such as coffee and cacao, depending on soil and climatic conditions.

The moderately steep slope class (15 to 25 %) covers 13.50 % of the total area. The Bazartete Sub-District has the largest area in this category at 26.37 km^2 or 4.81 %. These areas are generally used for perennial crops or agroforestry systems that integrate trees with annual crops. The use of these areas for plantation crops such as coffee, tea, or clove is common because these crops can tolerate steeper slopes. Soil conservation techniques such as contour bunds, cover crops, and micro-irrigation systems are required to prevent erosion and land degradation.

The steep slope class (25 to 45 %) is the most extensive, covering 38.91 % of the total area. The Maubara Sub-District has the largest area in this category at 79.23 km^2 or 14.45 %. Steep slopes are often utilized for forestry, soil and water conservation, or protected areas such as national parks and nature reserves. Planting trees or vegetation with strong root systems is highly recommended to maintain soil stability and prevent landslides.

The very steep slope class (>45 %) covers 21.04 % of the total area. The Maubara Sub-District has the largest area in this category at 41.71 km^2 or 7.61 %. Land use in this class is highly limited due to very high risks of erosion and landslides. These areas are typically maintained as protection forests or conservation areas. In addition to protecting soil from degradation, they are important for maintaining hydrological functions, such as groundwater storage and control of stormwater runoff.

2.6 AGROCLIMATE ZONES

The agroclimate zones in Liquiçá District were classified based on elevation and rainfall patterns, as integrated in the Agriculture Land Use Information System (ALGIS), following Fox (2003). This classification system divides the area into six principal agroclimate zones, each with specific characteristics that include rainfall pattern, elevation, types of agricultural commodities that can be cultivated, and livestock development potential. The total area allocated to each agroclimate zone in Liquiçá District is shown in **Figure 2.14**, while the distribution of agroclimate zones by Sub-District is illustrated in **Figure 2.15**.

This classification approach not only serves as a method to understand climatic and topographic variability but also provides an essential scientific basis for natural resource management in Liquiçá District. It offers a framework for land suitability evaluation that supports sustainable land-use practices. This evaluation is relevant for minimizing the risk of land degradation and for maximizing productivity and ecosystem resilience (Molyneux *et al*., 2013; Williams *et al*., 2017). The zoning structure strengthens the integration between land-use planning and climate change adaptation practices, thereby supporting more integrated agricultural and livestock development.

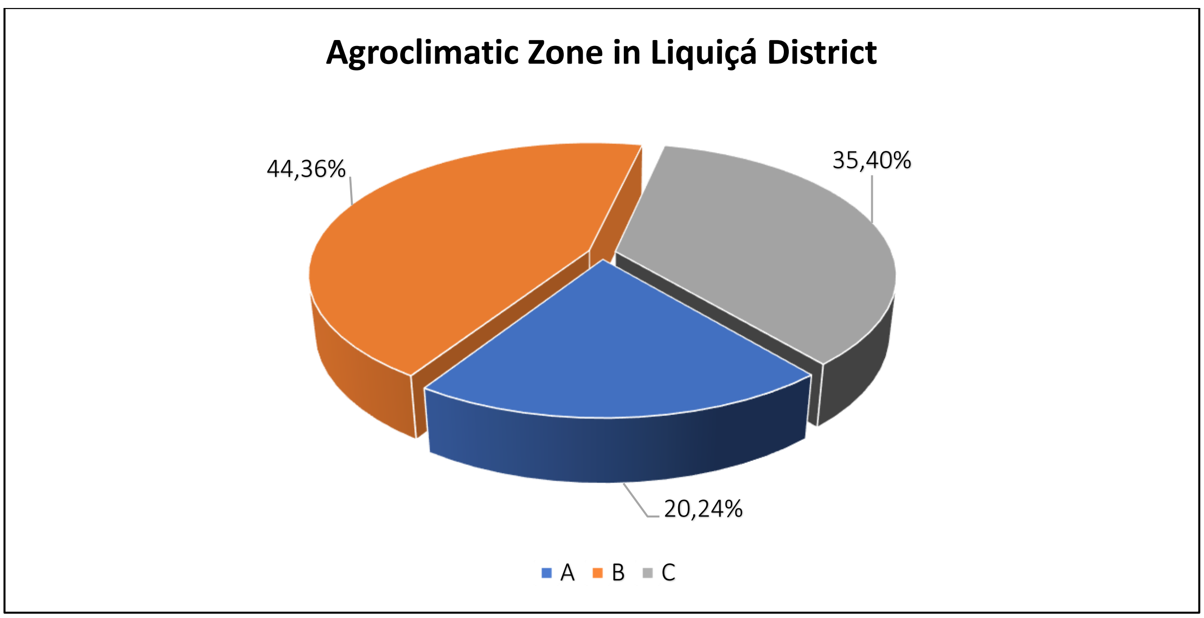


Figure 2.14 Distribution of Agroclimate Zones in Liquiçá District

Figure 2.14 depicts an agroclimate that supports crops with relatively highwater requirements and adaptation to a monomodal rainfall pattern influenced by northwesterly monsoon winds, with the rainy season lasting 4 to 5 months from November to March. This area is often used for specific agricultural commodities such as rice and other seasonal crops that require controlled irrigation. The zone shows potential for intensive agricultural development, although it requires optimal water-resource management.

Zone A is distributed across all Sub-Districts in Liquiçá District. The Maubara Sub-District has the largest area classified as Zone A at 44.30 km^2 or 8.08 % of the total area, followed by the Bazartete Sub-District at 34.89 km^2 or 6.36 % of the total area, and the Maubara Sub-District at 24.15 km^2 or 4.4 % of the total area. Previous research by Molyneux *et al*. (2013) identified that one of the main challenges in this zone is fluctuation in rainfall patterns, which affects crop productivity. Therefore, the application of water management technologies and agronomic practices that can adapt to this variability is essential.

Zone B is characterized by high flexibility for various types of agriculture. It has a monomodal rainfall pattern and a rainy season lasting 5 to 6 months (October to March). The agroclimatic characteristics of this zone allow for a diversity of crops, including food crops. In addition, the area often has significant potential for medium-scale livestock development. Zone B is distributed across all Sub-Districts in Liquiçá District. The Loes Sub-District has the largest area classified as Zone B at 95.84 km^2 or 17.48 % of the total area, followed by the Bazartete Sub-District at 75.94 km^2 or 13.84 % of the total area, and the Maubara Sub-District at 54.08 km^2 or 9.86 % of the total area. Williams *et al*. (2017) noted that farming systems in this zone combine food-commodity production with livestock activities. However, the main constraint is limited access to modern agricultural technology, which affects efficiency and productivity.

Zone C has important ecological functions, particularly in supporting soil and water conservation, which makes it a strategic zone for natural resource sustainability. It has a monomodal rainfall pattern and a longer rainy season of 6 to 7 months (October to April). Zone C is distributed across all Sub-Districts in Liquiçá District. The Bazartete Sub-District has the largest area classified as Zone C at 76.00 km^2 or 13.83 % of the total area, followed by the Maubara Sub-District at 49.27 km^2

or 8.98 % of the total area. According to Molyneux *et al*. (2013), this zone has significant opportunities for the implementation of coffee-based agroforestry systems, which contribute to environmental conservation while supporting food security.

This agroclimate zoning classification provides a systematic scientific framework for identifying land potential in Liquiçá District, particularly for the development of agriculture, livestock, and fisheries. The overview of agroclimate zones serves as an essential basis for the research team to conduct an in-depth land suitability evaluation. The evaluation process integrates various thematic maps, such as soil type, rainfall, geology, and land use, together with data from field observations and laboratory analyses. In addition, this approach involves matching crop growth requirements for food, horticultural, plantation, industrial, forestry commodities, and grazing areas. By applying this strategy, land management can be directed to strengthen food security and ensure the sustainability of natural resources in an integrated manner.

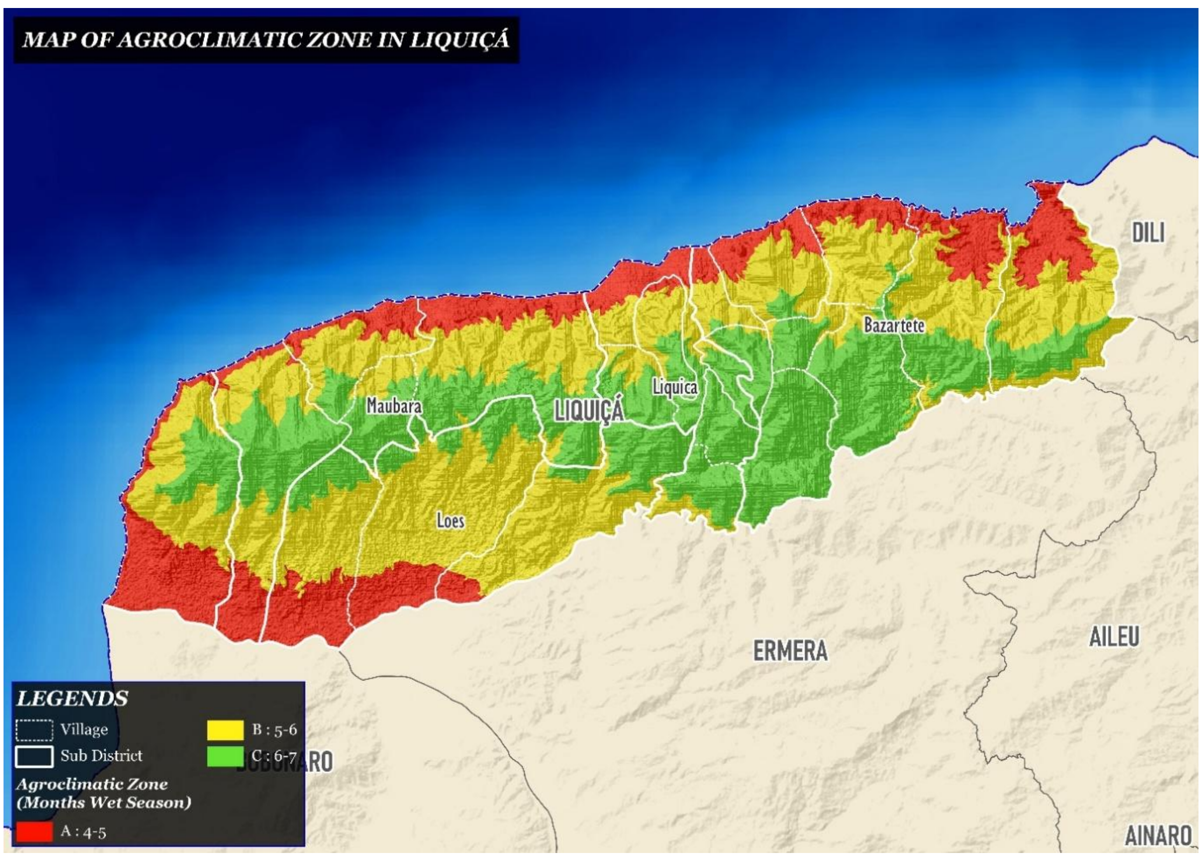


Figure 2.15 Agroclimate Zone Map of Liquiçá District.

2.7 EXISTING CONDITIONS

Liquiçá District has a variety of landforms, including Marine, Alluvial, Fluvial, Colluvial, Denudational Hills, and Denudational Mountains, which influence geomorphological characteristics and potential land use. However, agricultural development in the area faces significant challenges. One key constraint is the limited availability of irrigation water, with sources located at considerable distances. In addition, land use and maintenance remain suboptimal, particularly due to limited human-resource engagement in effective management (**Figure 2.16**).

Figure 2.16 Mixed-garden Land Conditions in the Field
(Source: Researcher documentation, 2025)

In areas with steep slopes, both on agricultural land and in forests, the risk of soil erosion is very high. Erosion can cause loss of topsoil, reduced soil fertility, and diminished land capacity to support agricultural productivity and forest ecosystems. Erosion intensity increases where vegetation is inadequate or where effective soil conservation techniques have not been implemented.

Figure 2.17 Site with Tea Plants.
(Source: Field Documentation, 2025)

The Loes Sub-District has substantial potential for the development of sorghum as an alternative source of food and industrial raw material; however, it has not been developed optimally. In Leotela Village, Loes Sub-District, agroclimatic conditions are highly suitable for tea cultivation, but management has not been well structured. Existing tea plants are left to grow wild without optimal maintenance systems (**Figure 2.17**). To realize greater economic benefits, reorganization of cultivation systems and more intensive estate management are required to increase yields and market competitiveness.

In Loidahar Village and Leoteala Village, the development of rambutan has experienced a decline in productivity due to dieback, characterized by drying that begins at the shoot tips and progresses until the entire plant dies. This condition occurred after a heavy fruiting phase, indicating physiological disturbance or environmental factors that have not been adequately addressed. Meanwhile, in Hatuquessi Village, many coffee plants have died as a result of the loss of Albizia trees serving as shade. The death of these shade trees altered the surrounding microclimate, such as increased temperature and direct light intensity, which triggered environmental stress for the coffee plants.

2.8 *Chromolaena odorata*

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

Figure 2.18 *C. odorata* plant
(Source: Researcher documentation, 2025)

In tropical Asia, *C. odorata* is commonly found from lowlands up to elevations of 500 m a.s.l, especially in open areas such as coconut and rubber plantations, household yards, and grazing lands (Peniwiratri and Arbiwati, 2021). The plant has distinctive morphology, with a cylindrical, pubescent stem; simple, serrate leaves; and compound inflorescences that are bluish when young and turn brown with age. In terms of phytochemical constituents, *C. odorata* contains active compounds such as flavonoids, tannins, alkaloids, saponins, and essential oils (Jamatia *et al*., 2024). The presence of these compounds indicates considerable potential for use as raw material in traditional medicines to treat various ailments, including diabetes, burns, hypertension, and skin infections (Jamatia *et al*., 2024).

In Timor-Leste, *C. odorata* was first recorded in the 1980s and spread rapidly as a result of slash-and-burn practices and a dry tropical climate conducive to its growth (Day *et al*., 2013). The species can grow on various soil types, including nutrient-poor marginal lands, with an optimal elevation range of 500 to 2,000 m a.s.l. (Westaway *et al*., 2018). Its rapid invasive growth reflects exceptional adaptive capacity to new environments and poses a serious threat to the sustainability of productive land.

Figure 2.19 Leaf and flower structure of *Chromolaena odorata*
(**Source**: *Ashasathees*)

The threats posed by *Chromolaena odorata* to multiple sectors, including agriculture, livestock, and ecosystems, are substantial and require serious attention. In agriculture, *C. odorata* is known to form dense thickets that impede the growth of cultivated crops such as maize, coffee, and various horticultural species. This weed aggressively invades newly cleared land for subsistence farming, which is a primary livelihood for rural communities. Its capacity to absorb soil nutrients more rapidly than cultivated plants, due to a deep and highly branched root system, creates detrimental nutrient competition. As a result, agricultural productivity declines sharply, with implications for local food security.

Negative impacts are also evident in the livestock sector. The leaves of *C. odorata* contain hepatotoxic pyrrolizidine alkaloids, which can cause liver damage in cattle and goats if consumed in large quantities. In addition, the spread of this weed in grazing areas reduces the availability of forage grasses, lowers carrying capacity, and adversely affects the livestock economy, particularly in regions such as Timor-Leste.

From an ecological perspective, invasion by *C. odorata* disrupts ecosystem balance by dominating native vegetation and hindering the regeneration of trees and local plants important for biodiversity. Its biomass dries readily and increases the risk of land fires during the dry season, which is a serious threat in tropical regions. Recurrent fires not only accelerate land degradation but also reduce environmental quality, including declines in soil microbial communities that help maintain soil fertility. Thus, the presence of *C. odorata* threatens both agriculture and livestock and contributes to broader ecological problems.

With respect to soil fertility, *Chromolaena odorata* can increase nutrient content, particularly phosphorus, in sandy soils when its biomass is mixed with farmyard manure. Studies indicate that this combination can support the growth of cultivated crops such as shallot. In addition, the high organic matter content of *C. odorata* makes it a potential feedstock for environmentally friendly organic fertilizers. In traditional medicine, this plant has long been used for treating burns, diabetes, hypertension, and skin infections. Its flavonoids and phenolic compounds provide strong antioxidant, anti-inflammatory, and antibacterial properties. Uses vary across countries; in Vietnam, leaves of *C. odorata* are applied to soft-tissue wounds and to address leech bites, while in Africa the plant is used as a natural antiseptic.

Furthermore, *C. odorata* biomass can be processed into high-quality vermicompost through biodegradation with the earthworm *Eisenia fetida*. Research shows that the resulting vermicompost contains significant levels of macronutrients such as nitrogen, phosphorus, and potassium. This makes *C. odorata* a promising alternative material to support sustainable agricultural practices through more efficient production of organic fertilizers.

III. RESEARCH METHODS

This study was conducted in Liquiçá 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 research was carried out from May to June 2025 and comprised direct field observations, soil sampling, interviews with local farmers, and geographic information system (GIS)-based mapping. All stages were organized systematically to generate accurate information that can serve as a basis for planning sustainable land management.

3.1 RESEARCH DESIGN

A. Methodological Approach

This study employed 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 included field observations and laboratory analyses, encompassing soil sampling and interviews with local communities.

B. Determination od Sampling Points

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

C. Soil Morphological Observations

During soil sampling, environmental conditions were observed and recorded using a soil observation form. Parameters observed included soil color, texture, structure, consistency, and drainage condition. For more detailed analysis, ring samples of undisturbed soil were collected to measure bulk density (BD) and soil porosity, which are important for determining land fertility and water-retention capacity (Sukarman *et al*., 2017)

D. Interviews and Questionnaires

In parallel with the field survey, systematic interviews and questionnaires were administered to farming communities using purposive sampling, or judgmental sampling, which considered respondents' experience and expertise in agriculture (Sekaran and Bougie, 2013). The data collected included cropping patterns, agricultural challenges, and prevailing land-use systems in the study area.

E. Land Suitability Evaluation

Field survey results, climate data, and laboratory results were tabulated and evaluated using the agroecosystem land suitability assessment system based on the criteria of Ritung *et al*. (2011). The classification method referred to the FAO (1976) system with a matching approach, namely matching land characteristics with the growth requirements of the evaluated crops. The agricultural commodities evaluated in this study included food crops, horticultural crops, industrial crops, forestry species, spices and medicinal plants, forage feed, and grazing.

3.2 RESEARCH PROCEDURES

A. Literature Review

The literature review stage was conducted to collect relevant secondary data to support this study. The data collected included administrative maps of the study area, geographic conditions, agricultural land area, and agricultural commodity production. The climate data examined included temperature, rainfall, dry months, and humidity. In addition, previous research relevant to land suitability evaluation was reviewed to strengthen the study's theoretical foundation.

B. Land Unit Analysis

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

a. Interpretation of the Digital Elevation Model (DEM) map to assist in the analysis and delineation of land units based on landforms and slope gradients.
b. Satellite Image Analysis to verify actual land use, particularly for developed areas such as rice fields, settlements, and other infrastructures.
c. Use of Supporting Data such as slope gradient maps, geological maps, and soil type maps to obtain additional information for determining land units.
d. Overlay process of various thematic maps to generate homogeneous land units that will serve as the basis for soil sampling.

C. Field Survey

Field surveys were conducted to verify the suitability of sampling points with actual field conditions. If discrepancies were found between land-use interpretations from satellite imagery and field reality, adjustments were made by establishing new sampling points. Sampling points were determined based on satellite image analysis and current field conditions.

Interviews with local farmers were also conducted to obtain additional information on agricultural practices and challenges in land management. Observations covered environmental factors affecting agricultural productivity, such as soil drainage, effective soil depth, erosion risk, flood risk, and surface rock outcrops (Ritung *et al*., 2011).

Soil sampling was performed using the boring method to depths of 0 to 30 cm for annual crops and 30 to 60 cm for perennial crops. The collected soil samples were then analyzed in the laboratory to identify soil physical and chemical properties that influence land fertility. Climate data, such as temperature, rainfall, and humidity, were obtained from local climate observation stations and presented in tabulated form. The results of the land suitability evaluation and the characteristics of each land unit are presented in **Table 3.1**, while the map of land suitability distribution is 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 of Timor-Leste
2	Rainfall		√	Remote Sensing/ Climatology of Timor-Leste
3	Dry Months		√	Remote Sensing/ Climatology of Timor-Leste
4	Humidity		√	Remote Sensing/ Climatology of 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. Soil Analysis in the Laboratory

The parameters used to determine the soil properties or characteristics of the samples analyzed in the laboratory are as follows:

a. Organic Carbon using the Walkley and Black method (%).
b. Total Nitrogen using the Kjeldahl method (%).
c. Soil Texture using the pipette method.
d. Soil pH using the potentiometer method (H2O 1:2.5).
e. Available Phosphorus (P) (ppm) and Available Potassium (K) (ppm) using the Bray-1 method if soil pH is below 7, and the Olsen method if soil pH is above 7, with unit conversion (mg/100 g).
f. Salinity (dS/m) using the potentiometer method (H2O 1:2.5).

g. Cation Exchange Capacity (CEC) (cmol) and Base Saturation (BS) (%) using NH4OAc 1N pH 7 as the extraction.
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 Determination based on the method by PPT (1995).
l. Erosion Risk using the Universal Soil Loss Equation (USLE)

E. Land Suitability Evaluation

The results from field observations and laboratory analyses are then tabulated into agroecosystem land characteristics/quality data. The land suitability evaluation for agroecosystems is carried out by matching land characteristics/quality data with plant growth requirements to determine the land suitability class based on the criteria of Ritung *et al*. (2011). The land suitability classification is analyzed down to the land unit level.

Land suitability classes are determined as actual and potential suitability. The actual land suitability for each homogeneous land unit is determined by matching the land characteristics/quality with the plant growth requirements without improvement for limiting factors. Potential land suitability is determined by considering inputs and management actions applied to each homogeneous land unit with the assumption that improvements to limiting factors will be made.

F. Agricultural Commodity Development Planning

Commodity planning is based on the evaluation of potential land suitability for the agricultural commodities being developed, specifically the highest suitability class for each crop as the main parameter. Other parameters include the primary land use in each homogeneous land unit and the feasibility of farming activities.

G. Land Use Direction

Land use direction is made at the land unit level, based on the results of the highest land suitability evaluation followed by lower suitability classes, addressing limiting factors and implementing corrective actions for each homogeneous land unit across the 14 Districts in Timor-Leste. The creation of digital maps using geographic information systems (GIS) greatly facilitates the interpretation of information. The information includes agroecosystem land suitability, land use direction, and agricultural commodity zoning. Land suitability maps are created based on homogeneous land units and the results of agroecosystem land suitability classification.

The land suitability classification results are mapped for each evaluated crop group. The land suitability for crop commodities is presented in agricultural commodity zoning maps, while land use planning is presented in land use direction maps. The systematic flow diagram of the research is 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). Combining these components produced an information system using QGIS 3.10. The outputs comprised land suitability classes for food crops, horticultural crops, industrial crops, forestry species, spices and medicinal plants, forage feed, and grazing, based on the evaluation results. The land suitability maps, together with databases and land resource information, were compiled using land suitability data and criteria, in line with evolving uses such as varieties, cultivation technology, and land management.

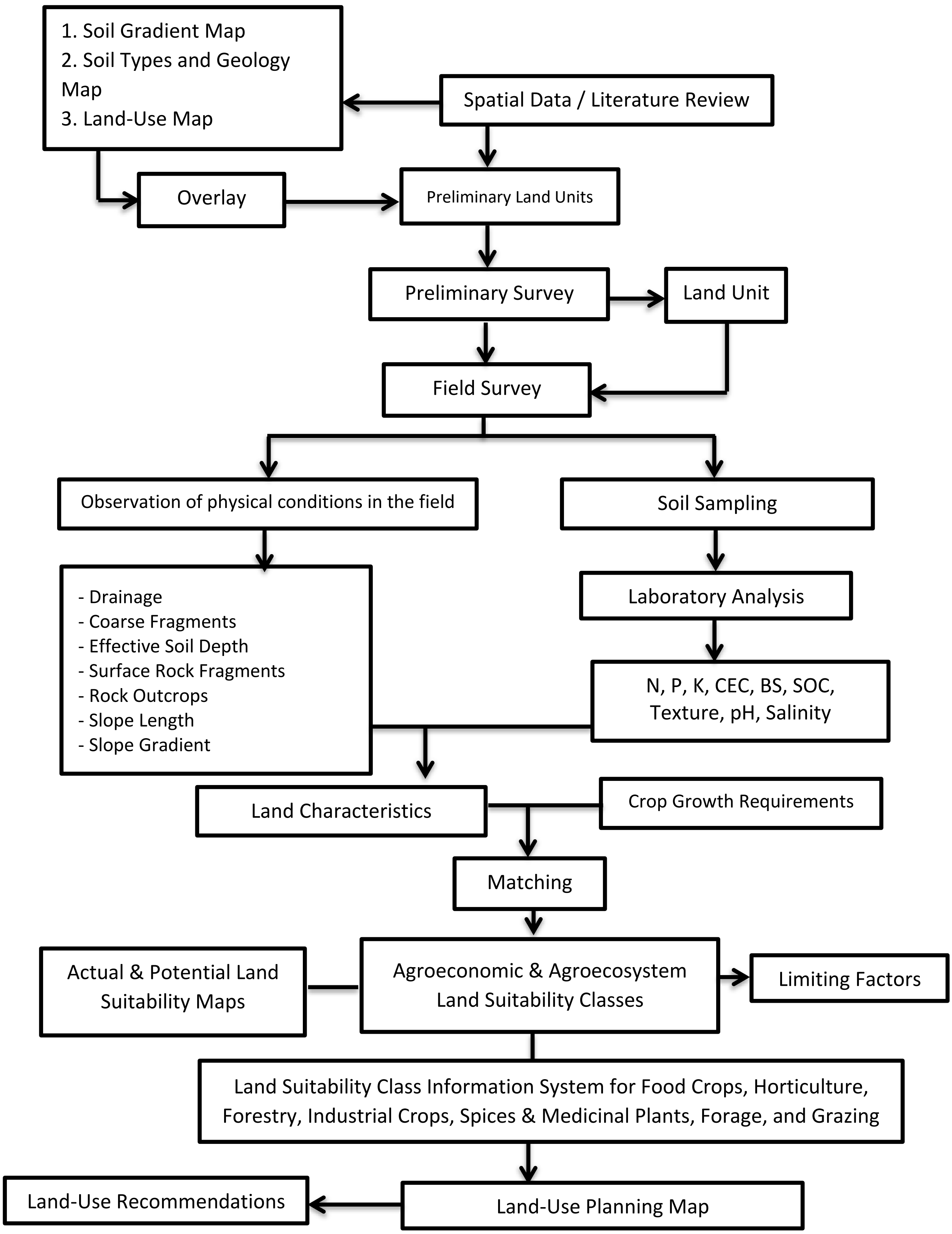


Figure 3.1 Flowchart of the Research Process

The land-use planning map was derived from land suitability classification and commodity zoning. The land-use planning map is a thematic digital map that provides guidance on land use for various commodities, including food crops, horticultural crops, industrial crops, forestry species, spices and medicinal plants, forage feed, and grazing. The digital map is the result of converting primary and secondary data and information from raster and analog forms into digital data. Advantages of digital map data include ease of correcting errors, ease of copying, long-term storage, and the ability to measure distance and area on the screen without field measurements, which would require considerable time and cost (Nugroho and Yarianto SBS, 2010). The outputs include digital maps in analog or hard-copy form in *.jpeg format that can be printed, and digital maps in *.dbf or shapefile *.shp formats that are integrated, easy to copy, and informative. Map marginal information presents the map title, followed in order by the map author's name, a scale bar, and a legend box displaying homogeneous land units, the study area, soil types, slope gradients, and land use, as well as the data source, latitude and longitude coordinates, and the datum system used.

3.3 GEOGRAPHI INFORMATION SYSTEM (GIS) TECHNOLOGY

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

1. Collect, store, and retrieve information based on spatial locations.
2. Identify locations within a specific area that meet pre-established criteria.
3. Explore relationships between various datasets within a specific region.
4. Facilitate the selection and distribution of data for specific analytical application models, which can predict the impact of alternatives on the conditions of a particular region.
5. Present a specific area both graphically and numerically, both before and after analysis (Murai, 2006).

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

The term geographic is part of spatial. These two terms are often used interchangeably, giving rise to a third term, geospatial. In the context of GIS, all three carry the same meaning. Use of the word geographic conveys issues concerning the Earth: two- or three-dimensional surfaces (Prahasta, 2005).

The term geographic information refers to information about places located on the Earth's surface, knowledge of the position where an object is situated on the Earth's surface, and information about attributes on the Earth's surface whose positions are given or known (Prahasta, 2005).

GIS is a formal entity composed of various physical resources related to objects on the Earth's surface. Thus, GIS is also a type of software that can be used for input, storage, manipulation, visualization, and output of geographic information together with its attributes (Prahasta, 2005). Figure 3.2 shows the components that constitute GIS.

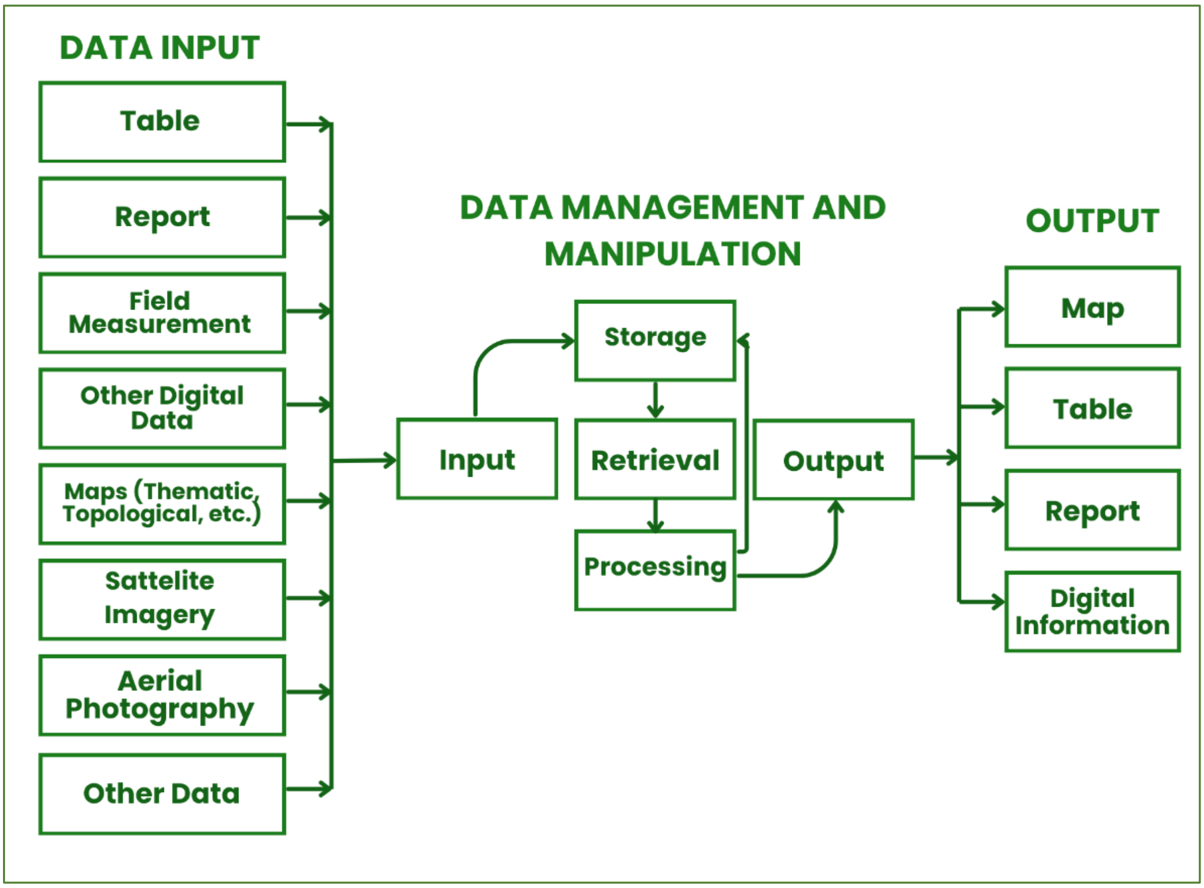


Figure 3.2 Components of GIS
(Source: Prahasta, 2005)

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

1. **Cartographic Capabilities**

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

2. **Data Management Capabilities**

   GIS has the ability to store, process, and manipulate geographically referenced data. This management capability also includes the ability to process attribute data, meaning it can store and manage detailed information related to geographical features.

3. **Analytical Capabilities**

   Analytical capability is the ability to interpret and study collected data and information for specific purposes. These capabilities include engineering function analysis, prediction/forecasting, computational operations, demographic analysis, socio-cultural analysis, analysis of various types of regions, graphical and tabular presentation, overlay analysis, logical analysis, and selection analysis.

4. **Integration of GIS and Multimedia**

   The ability to integrate GIS and multimedia is an innovation developed by local practitioners in Bali. Through the integration of multimedia with GIS, the final presentation of GIS analysis results becomes more engaging and easier to read and understand.

A. GIS Processes and Components

GIS essentially performs six processes (Prahasta, 2005):

1. **Data Input**

   Before geographic data are used in GIS, they must be converted into digital format. This process is called digitization. In this project, the digitization performed is on-screen digitizing, in which data conversion can be carried out using scanning technology.

2. **Data Transformation**

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

3. **Editing**

   The editing stage is the digital correction stage. Corrections may involve adding or removing arcs or features by editing arcs (graphic data) that are excessive (overshoot) or by adding missing arcs (undershoot). Editing is also performed to add arcs manually, such as creating polygons, lines, or points.

4. **Data Management**

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

5. **Queries and Analysis**

   Queries in GIS are essentially an analytical process carried out in tabular form. Fundamentally, GIS analysis uses spatial analysis. GIS has many advantages in spatial analysis, but two of the most important are:

   a. Proximity Analysis

      A geographic analysis based on distance between layers. Questions include, for example, how many houses are located within a river basin. In proximity analysis, GIS uses a process called buffering, that is, creating a supporting layer around a layer at a specified distance to determine the closeness of relationships among spatial features.

   b. Overlay Analysis

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

6. **Visualization**

   For several types of geographic operations, the best final output is expressed as a map or graph. Maps are highly effective for storing and conveying geographic information.

B. GIS Components

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

1. Hardware

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

2. Software

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

a. Tools for data input and manipulation.
b. Database management system (DBMS).
c. Tools that support geographic query, analysis, and visualization.
d. Graphical User Interface (GUI) untuk pengaksesan *tools*.

3. Data

Data are a critical component in GIS. Fundamentally, GIS works with two geographic data models, namely the vector data model and the raster data model. The vector model displays, positions, and stores spatial data using points, lines or curves, or polygons along with their attributes. The raster model displays, positions, and stores spatial data using a matrix structure or pixels forming a grid. Each pixel or cell has its own attributes, including its unique coordinates at a grid corner, at the grid center, or elsewhere. The accuracy of this data model depends heavily on the resolution or pixel size of the grid cells on the Earth's surface.

4. Human

GIS technology is not useful without people who manage the system and develop plans that can be applied under real-world conditions. As with other information systems, GIS users have varying levels of technical specialization, ranging from specialists who design and maintain the system to end users who apply GIS to support their daily work

5. Methods

A robust GIS aligns a sound design plan with real-world rules, and its modeling methods and implementations vary for each problem.

C. Data Processing in GIS

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

1. Base Map Digitization

Digitization is performed on the *Rupabumi Indonesia* map at a scale of 1:25,000, which serves as the basis for conducting surveys and for map digitization, including data updating. Data are converted into digital format layer by layer with topology.

2. Data Import

Data import is carried out for satellite imagery that uses formats different from the processing software. This format conversion is an initial step commonly performed in image processing tasks.

3. Geometric Correction of Imagery

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

4. Digital Image Processing

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

5. Satellite Image Classification

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

6. Updating Spatial Information

Spatial information updates are performed using raster–vector overlay with the light table effect to interpret and analyze spatial land-use information. Planimetric spatial information is updated with raster–vector overlay. This integration model combines digital image classification with visual image interpretation to obtain accurate spatial data from the updates. Specific objects deemed important but unclear in the imagery are mapped using GPS during field surveys. The final output of the updating work is digital spatial land-use data in GIS.

7. Field Survey

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

8. Re-interpretation dan Editing

This work corrects inaccurate image-interpretation results based on fieldwork findings. It is conducted digitally in the laboratory to obtain final, up-to-date spatial information.

9. Edge Matching

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

10. Digital Cartography and Map Production

Cartographic processing is performed fully digitally to produce standard map layouts in accordance with established cartographic principles. The cartographic design follows the thematic map cartography model issued by *Badan Informasi Geospasial*.

11. Database Compilation and Modeling

Database compilation is conducted for all GIS-format outputs, consisting of digital spatial land-use data, attribute data, and the thematic maps produced.

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. The air temperature analysis showed that Liquiçá District has a range of temperatures. The 21 to 24 °C range was the most extensive category, with a significant dominance in the Bazartete Sub-District. In addition, the >26 °C, 24 to 26 °C, and 18 to 21 °C categories were also most extensive in the Bazartete Sub-District. This pattern is associated with undulating to hilly terrain and varied elevations. With increasing elevation, air pressure decreases and temperature declines. Air temperature decreases by approximately 0.6 °C for each 100 m increase in elevation (Braak, 1977).

Temperature variation can affect evaporation rates and water requirements in agricultural systems. According to Iek *et al*. (2014), areas with temperatures above 20 °C are categorized as hot. Relatively high temperatures indicate increased evapotranspiration, which implies a higher risk of drought compared with cool to warm conditions. Consequently, water management strategies, the selection of heat-tolerant crop varieties, and soil and water conservation are important factors for improving agricultural productivity in Liquiçá District. Temperature data for Liquiçá District are presented in **Figure 4.1**.

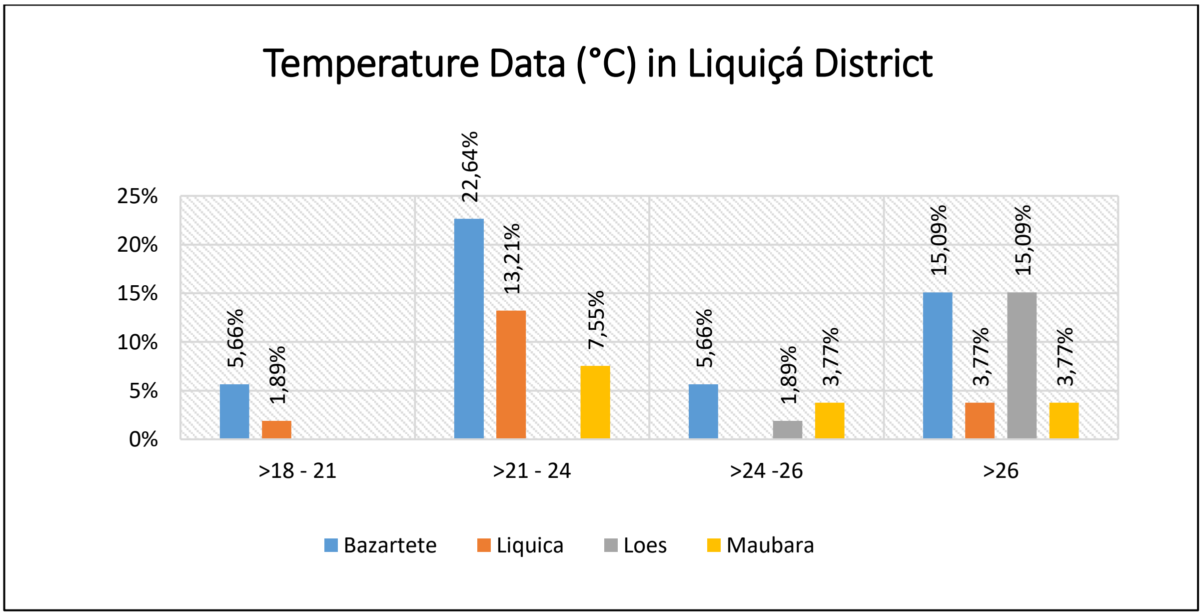


Figure 4.1 Temperature Data (°C) in Liquiçá District

4.2 RAINFALL

Based on field observations of rainfall, the area exhibits varied annual rainfall from <1,000 to 2,500 mm/year (**Figure 4.2**). Liquiçá District is generally dominated by annual rainfall of 1,500 to 2,000 mm/year, with the largest extent in the Bazartete Sub-District. This condition is influenced by the geographic setting of Bazartete, which has mountainous terrain that promotes uplift of moist air masses blowing from the south and southwest, particularly from the Timor Sea. This uplift triggers condensation and produces intense orographic rainfall. In addition, Bazartete is more exposed to northwesterly monsoon winds and seasonal winds from the Indian Ocean, which carry substantial moisture and further increase rainfall intensity in the area.

According to Wijaya *et al*. (2024), rainfall is the principal factor determining water availability in a region. When rainfall is insufficient, irrigation systems can be developed as an anticipatory measure. Conversely, when rainfall is excessive, improvements to drainage systems can be implemented. This is consistent with Siregar *et al.* (2019), who stated that rainfall-related limiting factors can be mitigated by improving irrigation or water management systems. Spatial variation in rainfall directly influences groundwater and surface-water availability, which are fundamental elements in planning and implementing agricultural activities. Each area should apply adaptive strategies to optimize available water resources through agroclimate zoning and water conservation techniques, such as rainwater harvesting and season-based planting schedules, so that agricultural systems can be developed more efficiently and sustainably.

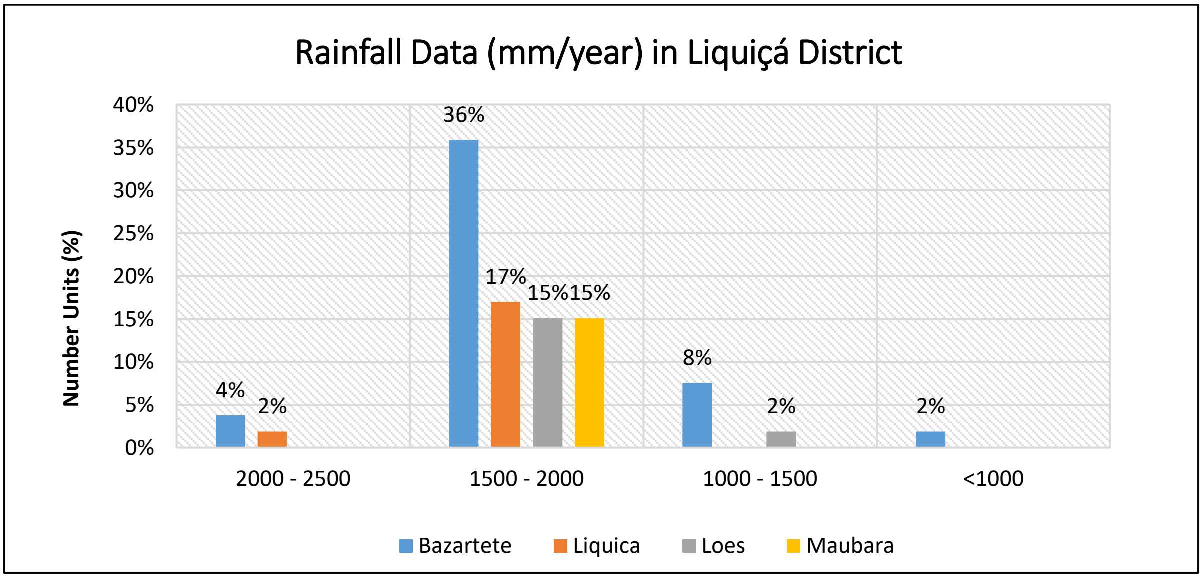


Figure 4.2 Rainfall Data (mm/year) in Liquiçá District

4.3 ELEVATION

The elevation distribution in Liquiçá District shows a dominance of low-elevation areas, particularly within the range of 0 to 400 masl (Figure 4.3). The largest extent of this elevation category occurs in Bazartete Sub-District, followed by Loes Sub-District. These physiographic conditions reflect the characteristics of coastal plains and lowlands, which generally experience relatively high and stable air temperatures. With rainfall concentrated in coastal areas, lowlands are more suitable for intensive land use, particularly due to easier accessibility and climatic conditions that support productive activities. However, the potential for waterlogging resulting from rainfall intensity remains a factor that must be anticipated through proper water management.

In contrast, the 400 to 700 masl elevation category represents the smallest spatial extent in Liquiçá District. The largest distribution within this category is found in Bazartete Sub-District and Maubara Sub-District. At intermediate elevations, air temperatures tend to be cooler than in lowland areas, while rainfall is relatively higher due to orographic effects. These conditions make mid-elevation areas more suitable for conservation functions and water resource management, while also offering potential for land uses adapted to cooler climatic conditions. Nevertheless, limited accessibility and erosion risk constitute limiting factors for intensive land use.

Thus, the elevation distribution pattern in Liquiçá District demonstrates differences in land suitability that are closely associated with variations in temperature and rainfall. Lowland areas support more intensive land use, whereas mid-elevation areas are more appropriate for ecological and conservation functions. This pattern underscores the importance of land use planning that takes physiographic and climatic conditions into account, in order to achieve a balance between productivity and sustainability.

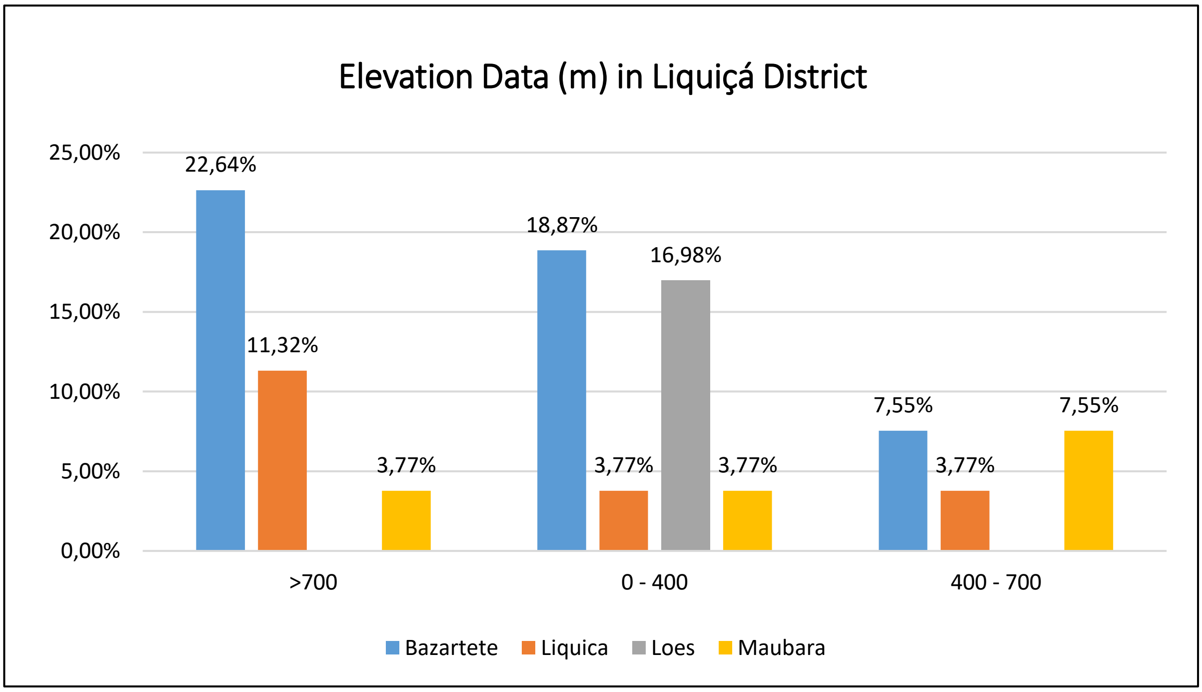


Figure 4.3 Elevation Data (m) in Liquiçá District

4.4 DRY MONTH

Land characteristics based on dry-month duration also vary across the area. Dry months are an important component in determining land suitability, particularly in relation to groundwater availability and potential declines in crop productivity. On average, Sub-Districts in Liquiçá District experience 5 months to more than 6 months of dry conditions (**Figure 4.4**). A dry-month duration of 5 to 6 months is most dominant in the Bazartete Sub-District; however, parts of Bazartete are also dominated by >6 dry months. This pattern occurs because Bazartete has complex terrain with significant variation in elevation and landforms. Areas on steep slopes or in the rain shadow behind hills tend to receive less rainfall and therefore have a longer dry period (>6 months) (Ralph *et al.*, 2003; Grujic *et al.*, 2018).

Conversely, zones that face directly toward incoming moist winds receive rainfall more frequently, resulting in a shorter dry period (5 to 6 months). Areas with a shorter dry period still allow the use of cropping strategies with drought-tolerant species or supported by micro-irrigation systems and water conservation. In contrast, a prolonged dry period can limit land use for agricultural commodities that require a stable year-round water supply, and thus should be prioritized for water-conservation techniques such as rainwater harvesting and conservative agricultural practices such as agroforestry and rotations with highly resilient crops.

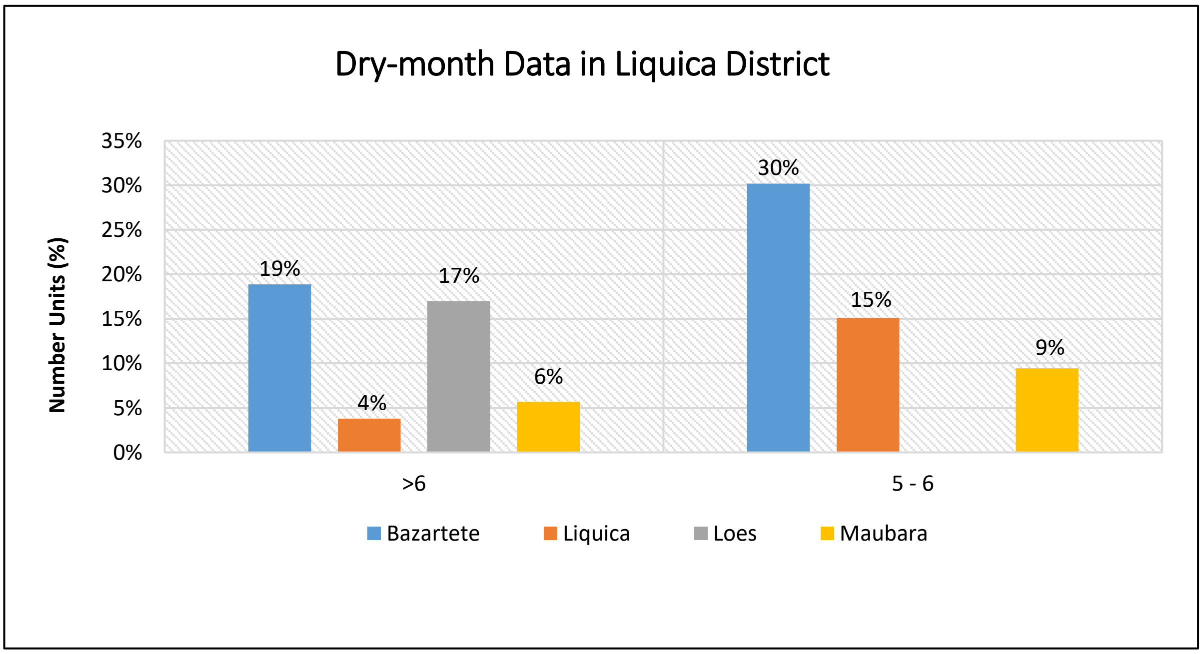


Figure 4.4 Dry-month duration in Liquiçá District.

4.5 DRAINAGE

Based on observations, land drainage conditions in Liquiçá District are dominated by well-drained classes, with the largest extent in the Bazartete Sub-District (**Figure 4.5**). Land with optimal drainage typically has soil texture that supports aeration and balanced water movement, allowing efficient water uptake by plant roots without creating anaerobic conditions. These characteristics are suitable for intensive agricultural systems, including both annual crops and horticultural commodities. In contrast, areas with somewhat poorly drained conditions, such as parts of the Loes Sub-District, commonly have fine-textured or compacted soils that impede infiltration and tend to retain water longer. Although agriculture remains feasible, technical interventions are required, such as improving soil structure through more intensive tillage and applying surface drainage systems to avoid detrimental water accumulation. Meanwhile, excessively drained conditions, as observed in parts of Loes and Maubara Sub-Districts, are often associated with coarse-textured soils and high porosity, for example sandy soils that lose moisture rapidly. These situations require appropriate irrigation scheduling and the addition of organic matter to increase water-holding capacity and support optimal plant growth. In areas with suboptimal drainage, adaptive strategies are essential to maintain production efficiency and the sustainability of agricultural systems.

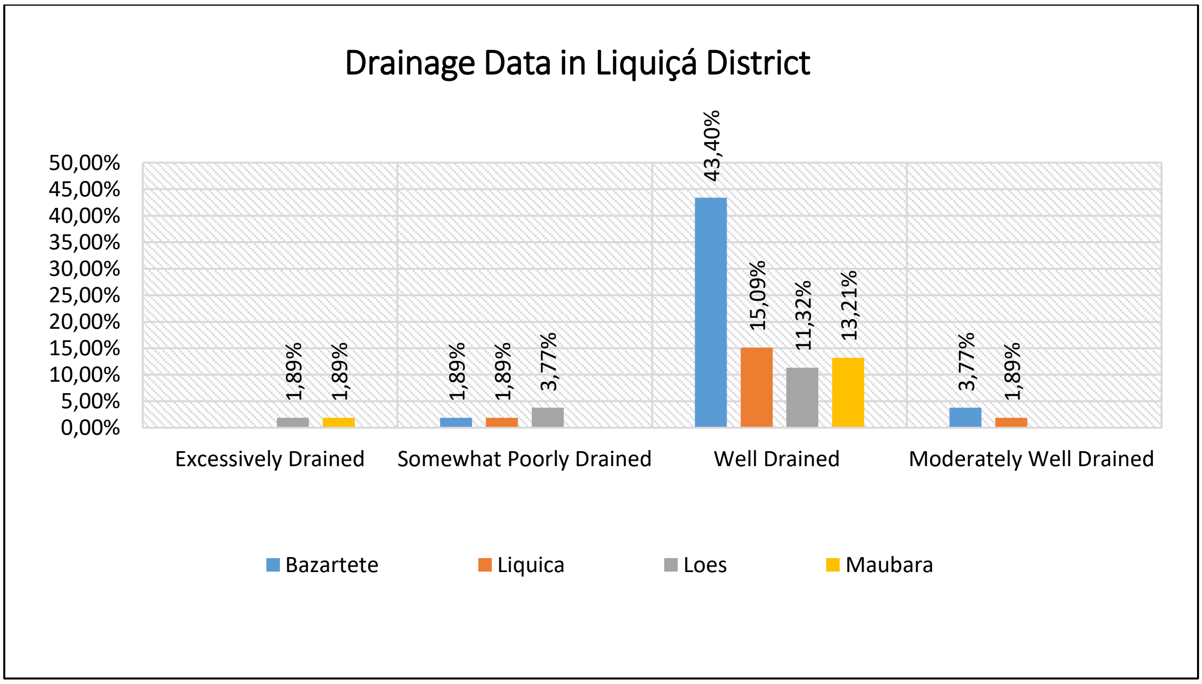


Figure 4.5 Land Drainage Condition in Liquiçá District

4.6 COARSE FRAGMENT

The coarse fragment content of soil is an important factor in determining land suitability for agriculture because it affects the soil's ability to store water, regulate infiltration, and support root systems. The percentage of coarse fragments in Liquiçá District showed diverse distributions (**Figure 4.6**). According to Tetegan *et al*. (2011), differences in the content and types of coarse fragments produce different effects on soil water-holding capacity and therefore influence soil moisture.

The largest coarse-fragment category in Liquiçá District is <3 %, most extensive in the Bazartete Sub-District, indicating soils with low coarse-fragment content that are potentially more fertile and suitable for agriculture. Conversely, areas with higher coarse-fragment content require appropriate soil conservation techniques to maintain fertility and avoid erosion, particularly on land with steep slopes. High coarse-fragment content restricts root exploration and the uptake of nutrients and water; thus, as coarse fragments increase, root growth space becomes more limited. Therefore, sound land management strategies, such as selecting suitable crops and implementing efficient irrigation methods, are needed to improve agricultural productivity in the area.

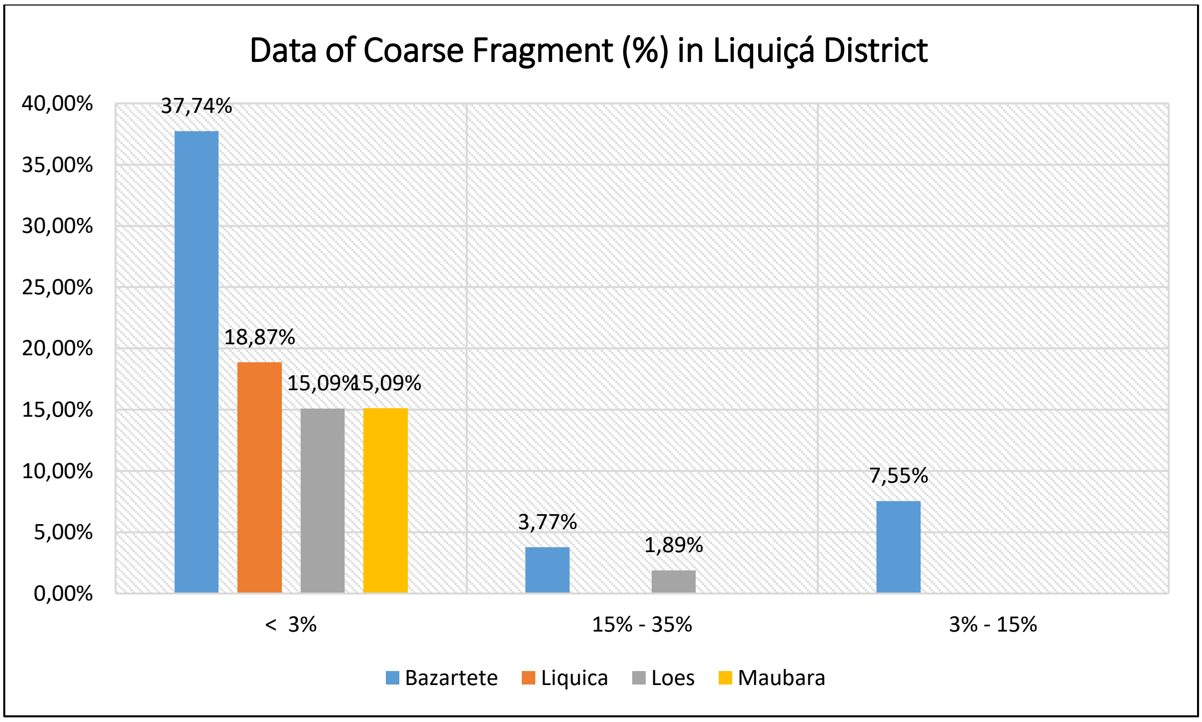


Figure 4.6 Data of Coarse Fragments (%) in Liquiçá District.

4.7 EFFECTIVE SOIL DEPTH

Effective soil depth relates to the ability of plant roots to penetrate the soil profile, absorb nutrients and water, and support optimal vegetative growth. Effective depth can be determined in the field by observing the distribution of fine and coarse roots and their penetration depth. In addition, effective depth is determined by the presence or absence of hardpans, gravel layers, or rock fragments that roots cannot penetrate (Basir, 2019).

Analysis of effective depth parameters in Liquiçá District showed that the area is generally dominated by an effective depth of 90 to 120 cm, with the greatest extent in the Bazartete Sub-District, indicating edaphic potential that strongly supports sustainable agricultural development in the area (**Figure 4.7**). This depth allows substantial water storage and provides adequate physical space for both lateral and vertical root development. According to Ritung *et al*. (2007), an effective depth ≥90 cm indicates land that is highly suitable for food and horticultural crops because it can store larger volumes of water and provides ample space for maximum root development.

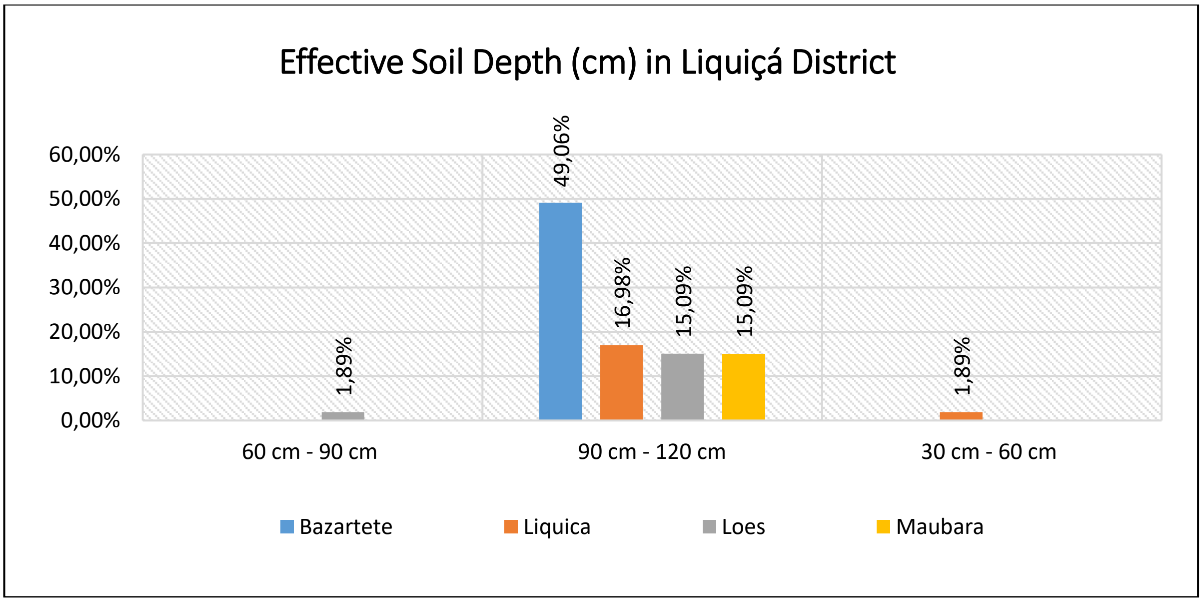


Figure 4.7 Effective Soil Depth (cm) in Liquiçá District.

4.8 SURFACE ROCK

Surface rock is an important indicator in land suitability evaluation because they affect tillage feasibility, water retention, and root development. In Liquiçá District, the analysis showed that most areas, especially the Bazartete Sub-District, have a low percentage of surface rock (<5 %). The proportion of surface rock determines how easily land can be tilled. The varied distribution in Liquiçá District has strategic implications for land-use planning. Land with low surface rock generally has friable soil structure, which facilitates good aggregate formation and optimal root growth. In contrast, areas with high outcrop cover tend to have dense soils with limited porosity, which impedes infiltration and aeration and complicates mechanical tillage. As the percentage of surface rock increases, greater inputs are required for land preparation because the soil becomes hard and difficult to work. Such areas are less suitable for annual crops and are better used for agroforestry or perennial species that tolerate compact growth media. Surface rock in Liquiçá District is presented in **Figure 4.8**.

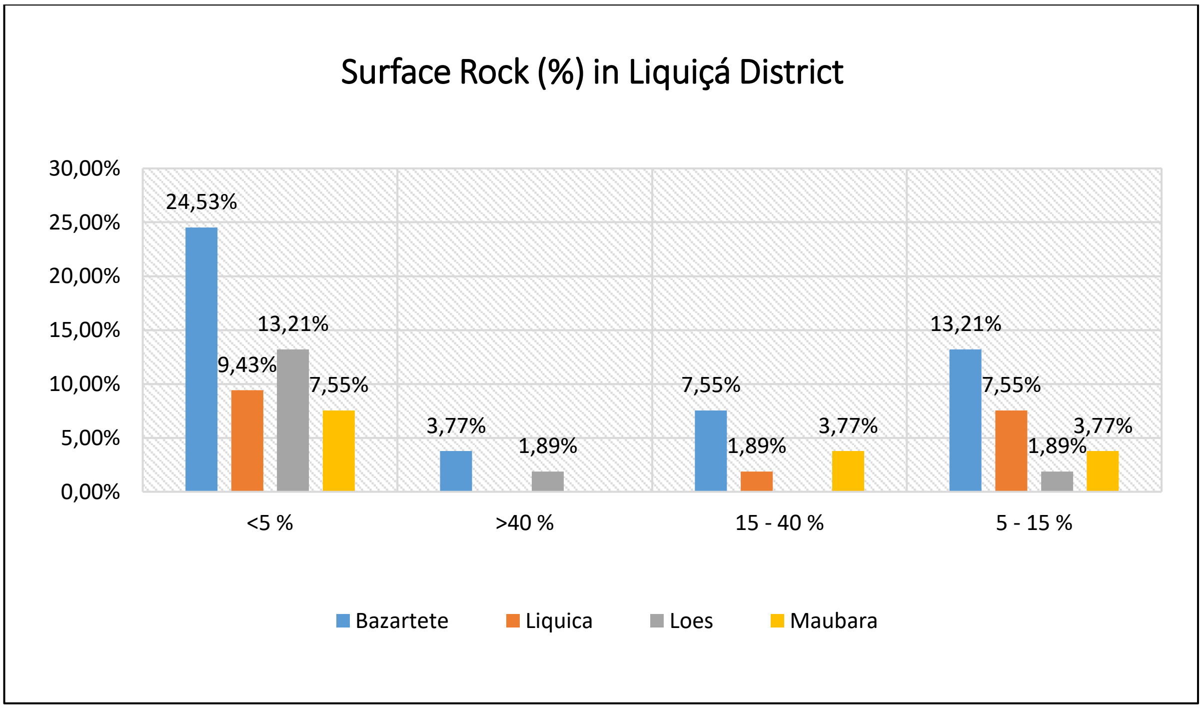


Figure 4.8 Surface Rock (%) in Liquiçá District.

4.9 ROCK OUTCROPS

Rock outcrops are an important indicator in assessing geological conditions and land suitability. Their presence can influence soil physical properties, water-storage capacity, and erosion rates. The percentage analysis of rock outcrops in Liquiçá District showed that most areas have varying levels of outcrops (**Figure 4.9**).

The 5 to 15 % outcrop category has the largest proportion, with the greatest extent in the Bazartete Sub-District, indicating that much of the area has ground surfaces relatively free of exposed rock, which supports agricultural activities and infrastructure development. Areas with low outcrop cover have high potential for intensive agriculture, especially for food and horticultural crops that require fertile, easily worked soils. Conversely, as the abundance of surface stones and rock outcrops increases, the land surface becomes covered and tillage and planting become more difficult (Rusdiana *et al.*, 2012). Areas with high outcrop cover are more suitable for forestry, ecotourism, or soil-conservation projects to reduce erosion risk. Appropriate land management strategies are required to ensure optimal and sustainable land use.

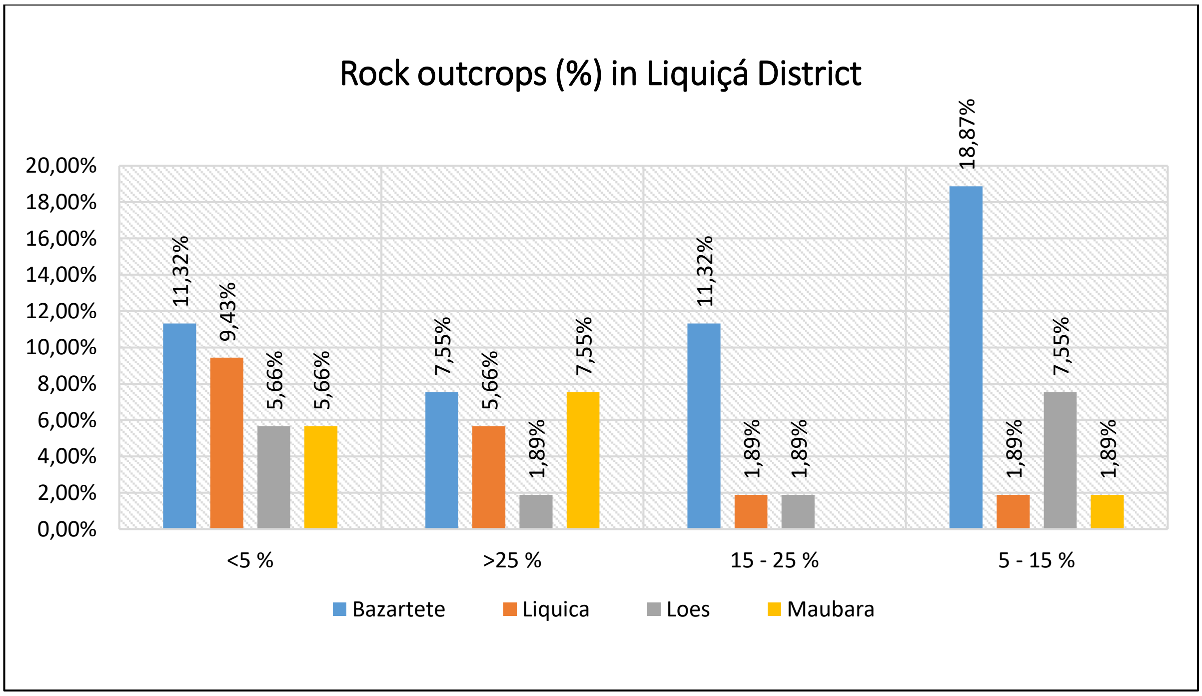


Figure 4.9 Rock Outcrops (%) in Liquiçá District.

4.10 FLOOD HAZARD

Flood hazard is a major limiting factor in land suitability evaluation, and a site's response to inundation is strongly influenced by edaphic characteristics such as texture, structure, and infiltration capacity. Based on flood hazard potential data for Liquiçá District (**Figure 4.10**), most areas fall in the no-flood class, indicating relatively low flood vulnerability. The Bazartete Sub-District is predominantly in the no-flood class, consistent with its well-drained conditions shown in **Figure 4.5.** Well-drained land reduces flood hazard because rainfall infiltrates effectively.

Areas free from flood hazard have high potential for developing food and horticultural crops because the risk of waterlogging damage is minimal. These lands can be prioritized for agricultural intensification, especially where agroclimatic suitability and irrigation water availability are favorable. In contrast, areas with high flood risk commonly coincide with poorly drained soils that have high ponding potential and slow drying. Such areas are better allocated to non-productive or conservation functions, or developed through agroforestry and adaptive agriculture. Sustainable conservation measures are required in high-hazard areas, including forest rehabilitation, revegetation in catchments, and construction of infiltration and drainage infrastructure.

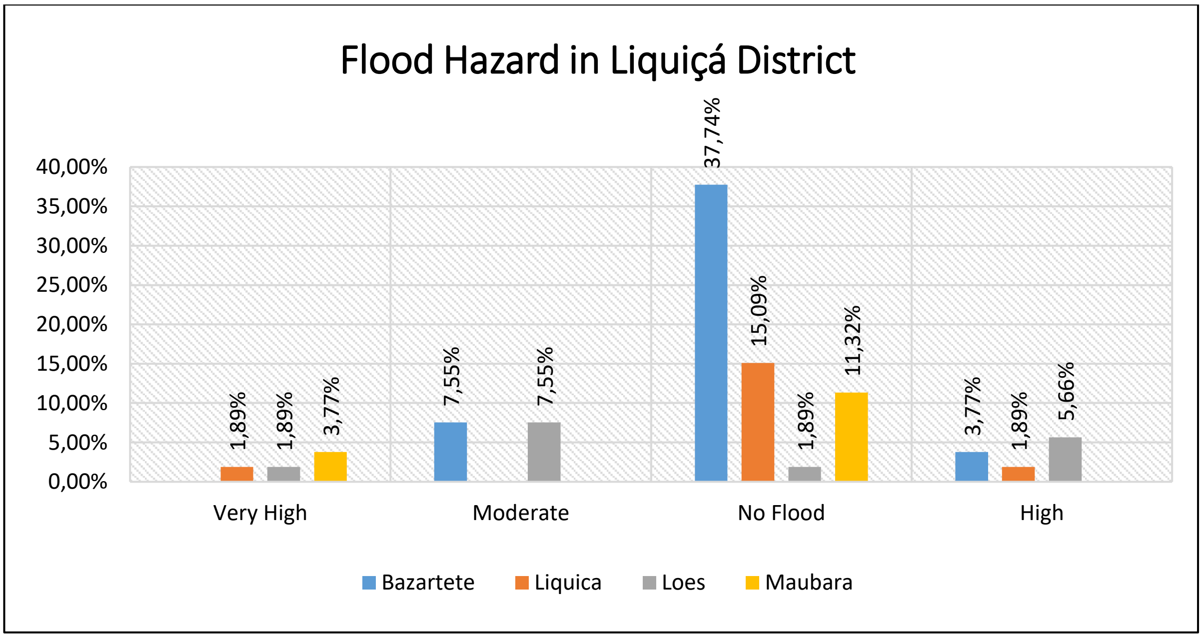
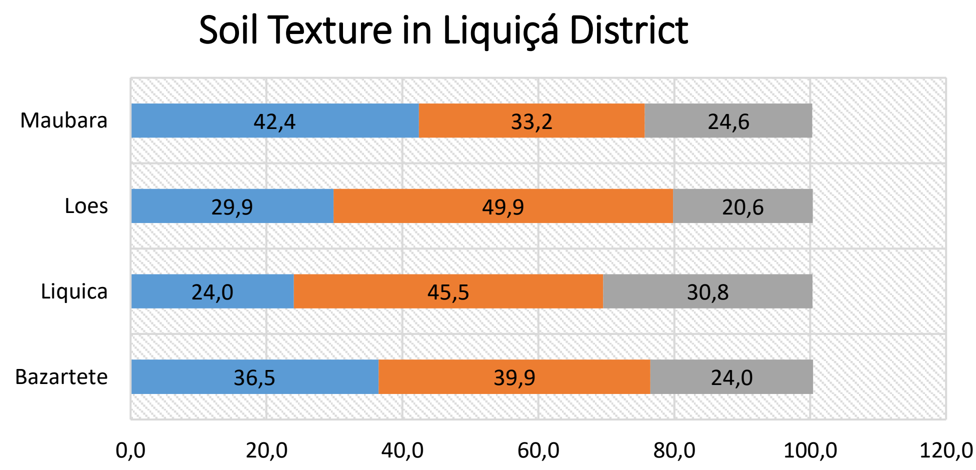


Figure 4.10 Flood Hazard in Liquiçá District.

4.11 SOIL TEXTURE

Soil texture refers to the relative proportions of mineral particle-size fractions, namely sand, silt, and clay. Indirectly, texture also determines soil structure, which is important for air, water, and nutrient movement in soil, and influences macro and microorganism activity (Arifin, 2011). The results indicate that soil texture in Liquiçá District varies among areas. The Bazartete Sub-District is dominated by clay loam textures, indicating a relatively high clay content. In the Liquiçá and Loes Sub-Districts, soils are generally loam, whereas the Maubara Sub-District is dominated by clay textures. These differences reflect environmental variation and soil-forming processes influenced by topography, land use, and parent material.

Textural diversity presents challenges for land management, particularly in agriculture, conservation, and sustainable use. Coarse-textured soils, such as sandy soils, have low water-holding capacity and nutrient retention, increasing the risk of nutrient deficiency and drought stress. Conversely, clayey soils retain water and nutrients but often have poor drainage and aeration, which can restrict root growth and soil biota activity. Addressing these challenges requires solutions tailored to each texture class, such as improving soil structure, managing irrigation and drainage, and planting cover crops. The soil texture distribution in Liquiçá District is presented in **Figure 4.11.**



	Bazartete	Liquica	Loes	Maubara
Clay (%)	36,5	24,0	29,9	42,4
Silt (%)	39,9	45,5	49,9	33,2
Sand (%)	24,0	30,8	20,6	24,6

Figure 4.11 Soil texture distribution in Liquiçá District

4.12 SOIL pH

Soil pH is a principal chemical parameter in land suitability evaluation, indicating soil acidity or alkalinity and directly affecting nutrient availability, microbial activity, and chemical reaction dynamics. pH values outside the optimal range can cause plant physiological disorders and reduce nutrient-use efficiency. Soil analyses in Liquiçá District showed variation among areas (**Figure 5.1 in Chapter 5**): Bazartete Sub-District pH 5.74, Liquiçá 5.68, Loes 5.65, and Maubara 5.50. All values fall within the acidic category, indicating potential limitations in macro and micronutrient availability. These conditions require data-driven management, such as liming and increasing organic matter inputs, to improve soil reaction and support optimal crop growth.

One of the main factors influencing soil pH is organic matter content. As noted by Afandi *et al*. (2015), applying organic matter can increase soil pH depending on the maturity of the amendment. Partially decomposed organic materials tend to produce organic acids during decomposition, which can lower soil pH. This aligns with Fahmi *et al*. (2009), who stated that organic acids produced during decomposition can decrease soil pH. Measures to address and stabilize soil pH in Liquiçá District include using well-matured organic amendments and managing soil drainage and aeration.

4.13 TOTAL NITROGEN

Total nitrogen (N-total) is a macronutrient essential for vegetative growth, protein synthesis, and metabolic activity. N-total comprises all forms of nitrogen stored in soil, both organic and inorganic, including humic compounds, ammonium ($NH4^+$) and nitrate ($NO3^-$), which play roles in the nitrogen cycle and nutrient availability to plants (Sari *et al*., 2020; Sutanto, 2012). Based on soil analyses in Liquiçá District, N-total content varied among areas (**Figure 4.12**). The Liquiçá and Maubara Sub-Districts had values of 0.25 % and 0.20 %, respectively, categorized as moderate, whereas the Bazartete and Loes Sub-Districts showed 0.18 % and 0.13 %, categorized as low. Adequate nitrogen availability is important to maintain land productivity. Low N-total can cause nutrient deficiency, whereas moderate levels indicate fertility that can still be enhanced through appropriate nutrient management.

Soil N-total commonly declines due to natural processes, including gaseous losses through volatilization, leaching of nitrogen from surface horizons by rainfall, and removal by surface runoff. These factors make nitrogen prone to loss, hindering its optimal availability to crops. This aligns with Ann (2015), who noted that nitrogen is mobile, contributing to its loss from the soil system. Overall, spatial variation in N-total in Liquiçá District is influenced by differences in soil characteristics, land management practices, and local environmental conditions, necessitating appropriate nutrient management strategies to keep soil nitrogen availability optimal for crop growth.

4.14 AVAILABLE PHOSPHORUS

Available phosphorus (P) in Liquiçá District was very low, ranging from 1.25 to 2.54 ppm. The Liquiçá Sub-District recorded the highest value at 2.54 ppm, followed by Maubara (2.04 ppm), Bazartete (1.76 ppm), and Loes with the lowest at 1.25 ppm. This distribution indicates widespread limitations in plant-available phosphorus across the district.

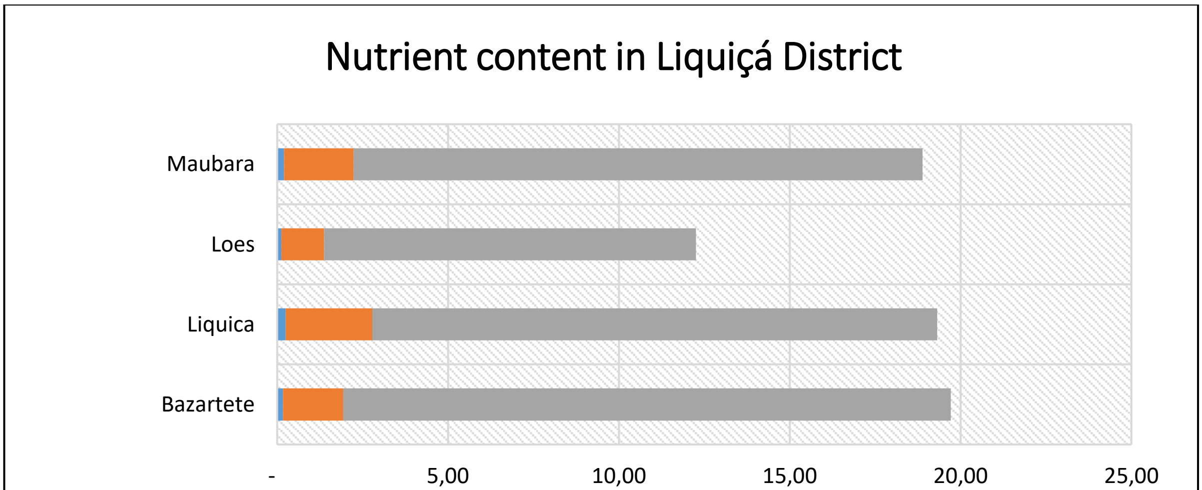
Phosphorus is a macronutrient critical for root growth, cell division, and reproductive development. Although total soil P may be adequate, the available fraction is often highly limited. This is due to phosphate fixation by clay particles, aluminum (Al), iron (Fe), and allophane, particularly in Andosols (Sari *et al*., 2017). In acidic soils, soluble Al and Fe increase, strengthening phosphate bonding and reducing availability (Tan, 1995). Conversely, in high-pH soils, phosphorus tends to bind with calcium (Ca) and magnesium (Mg), forming poorly soluble phosphates (Alwi *et al*., 2023). Beyond soil chemistry, land management also affects P dynamics. Da Costa (2023) in Luro, Timor-Leste, reported variation in available P associated with free grazing during the dry season. Such activity causes soil compaction, reduces organic matter, and degrades soil structure, thereby lowering land productivity. Matima *et al*. (2010) reported that overgrazing can increase soil pH and accelerate the loss of macronutrients, including phosphorus, through declines in organic matter and disruption of nutrient cycling. Available P in Liquiçá District is presented in **Figure 4.12.**

4.15 AVAILABLE POTASSIUM

Potassium (K) is an essential macronutrient; although only a small proportion is directly involved in metabolism, available K in soil includes the dissolved fraction and exchangeable K. In Timor-Leste, fluctuations in surface-soil K in the Dili area have demonstrably influenced local fertility and productivity (Santos and Barreto, 2024). This underscores the importance of adaptive management of available K, especially in humid tropical regions where leaching risk is high.

In Liquiçá District, the status of available K was low across all administrative areas. The Bazartete Sub-District showed the highest value at 17.78 cmolc kg^{-1}, followed by Liquiçá (17.28 cmolc kg^{-1}), Maubara (16.64 cmolc kg^{-1}), and Loes with the lowest at 16.36 cmolc kg^{-1}. These differences reflect variation in soil capacity to retain and supply potassium, influenced by physical and chemical properties such as texture, clay mineralogy, and degree of weathering.

Batubara *et al.* (2024) emphasized that soil potassium status is strongly affected by soil physical and chemical characteristics, particularly texture, CEC, and organic matter content. Clayey soils with adequate organic matter tend to have better K retention. Punuindoong *et al*. (2022) showed that K distribution is also influenced by topographic position and soil depth. On flat land, K levels may be lower due to leaching and erosion, whereas localized nutrient accumulation can occur on slopes. Available K in Liquiçá District is presented in **Figure 4.12**.



	Bazartete	Liquica	Loes	Maubara
N-total	0,18	0,25	0,13	0,20
Available phosphorus	1,76	2,54	1,25	2,04
Available Potassium	17,78	16,53	10,88	16,64

Figure 4.12 Nutrient content in Liquiçá District

4.16 EC/TOXICITY

Soil electrical conductivity (EC) is an important parameter in soil quality evaluation because it reflects the total dissolved salts in the soil solution. In soils, EC indicates salinity and the degree of mineralization, and can therefore serve as an indicator of soluble nutrient content and soil fertility status.

Soil analyses in Liquiçá District showed that EC values varied among areas, within the moderate to low categories. The Bazartete Sub-District recorded the highest value at 2.40 dS/m, classified as moderate, whereas the Liquiçá, Loes, and Maubara Sub-Districts showed 1.85 dS/m, 1.82 dS/m, and 1.76 dS/m, respectively, classified as low (**Figure 5.1** in **Chapter 5**). These differences reflect variation in soil characteristics and the influence of environmental factors such as parent material, texture, and land use.

High EC values generally indicate high concentrations of dissolved ions, while low values indicate low salt content or soils with low electrical conductivity (Swardana *et al.*, 2022). With respect to soil toxicity, high EC is often associated with excessive salt concentrations (high salinity), which can cause osmotic stress in plants and affect water and nutrient uptake. Environmental factors such as high rainfall and erosion also influence toxicity by accelerating the loss of organic matter and increasing the mobility of toxic ions in soil. In addition, poor drainage leads to the accumulation of toxic ions and anaerobic conditions that are unfavorable for soil microorganisms (Delsiyanti *et al.,* 2016).

V. SOIL FERTILITY

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

5.1 CATION EXCHANGE CAPACITY (CEC)

Cation exchange capacity (CEC) is a key indicator of soil fertility because it reflects the soil's ability to adsorb and retain nutrient cations such as K^+, Ca^{2+}, and Mg^{2+}. In tropical regions such as Liquiçá District, CEC is influenced by clay mineral composition, organic matter content, and soil acidity. Soils with higher clay and organic matter contents have greater negative charge, enabling them to bind more cations and increase CEC (Costa *et al*., 2020). Effective strategies to increase CEC include additions of organic materials such as compost, farmyard manure, and biochar, as well as conservation practices such as terracing and minimum tillage. Biochar in particular has high exchange capacity and can improve soil structure, making it effective for increasing CEC in tropical soils (Domingues *et al*., 2020).

Analysis of soil chemical properties in Liquiçá District showed that most locations had low CEC. Spatially, the lowest value was recorded in the Loes Sub-District at 11.80 cmolc kg^{-1}. The Bazartete and Maubara Sub-Districts were slightly higher but remained in the low category. In contrast, the Liquiçá Sub-District had the highest value at 15.47 cmolc kg^{-1}. CEC data for Liquiçá District are presented in **Figure 5.1**.

5.2 BASE SATURATION (BS)

Base saturation (BS) indicates the percentage of the CEC occupied by base cations such as Ca^{2+}, Mg^{2+}, K^+, and Na^+. It is an important indicator of soil fertility. In tropical regions, CEC tends to be low due to the dominance of kaolinitic minerals, but BS can remain high if base cations dominate soil charge (Costa *et al*., 2020; McLaren and Cameron, 1996). High BS reflects fertile soil with a relatively neutral pH and good nutrient availability, whereas low BS indicates dominance by acidic ions (H^+ or Al^{3+}) that can inhibit plant growth. Factors influencing BS include organic matter content, clay mineralogy, and soil pH.

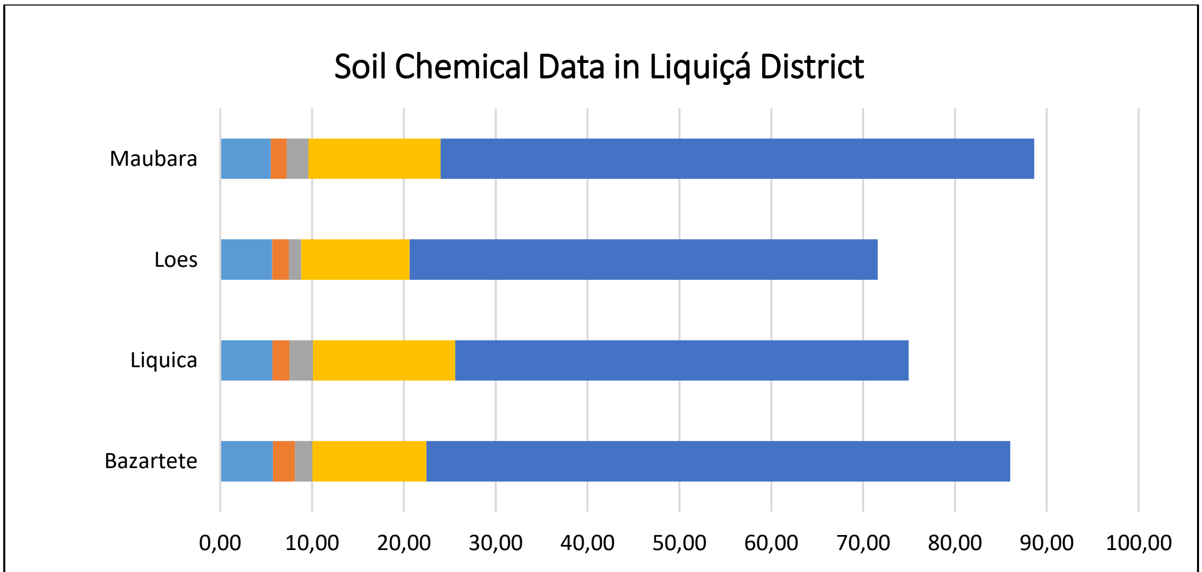
Soil analyses in Liquiçá District showed BS values in the moderate to high range. The Liquiçá Sub-District recorded the lowest BS at 49.39 %, while the highest value was found in the Maubara Sub-District at 64.64 %. This range indicates that most soils have a reasonably good capacity to retain base cations, supporting efficient nutrient uptake by crops. To maintain optimal BS, soil management should include organic matter additions, liming to stabilize pH, and the use of fertilizers containing base cations. Conservation practices and crop rotation are also important for sustaining soil chemical balance. BS data for Liquiçá District are presented in **Figure 5.1.**

5.3 SOIL ORGANIC CARBON (SOC)

Soil organic carbon (SOC) is a key indicator of soil fertility and ecosystem health because it improves soil structure, increases CEC, and supports moisture retention and microbial activity.

Laboratory analyses showed that soils in Liquiçá District had low to moderate SOC, ranging from 1.35 % to 2.58 %. The Loes Sub-District had 1.35 % (low), whereas the Liquiçá Sub-District had the highest value at 2.58 %. This range remains below the ideal threshold for productive tropical soils, indicating the need for interventions to improve soil organic matter quality.

Factors contributing to low SOC in Liquiçá include a tropical climate that accelerates organic matter decomposition, limited organic inputs from farming activities, and the dominance of low-CEC clays such as kaolinite. Management strategies should include the addition of organic materials (compost, farmyard manure, biochar), liming to neutralize acidity, and conservation agriculture practices such as crop rotation and cover cropping. These steps can gradually increase SOC, improve soil physical and chemical properties, and support sustainable agricultural productivity in Liquiçá District. SOC data are presented in **Figure 5.1.**



	Bazartete	Liquica	Loes	Maubara
pH	5,74	5,68	5,65	5,50
Salinity	2,40	1,85	1,82	1,76
C-Organic (%)	1,91	2,58	1,35	2,34
CEC	12,40	15,47	11,80	14,39
BS	63,57	49,39	50,96	64,64

Figure 5. 1 Soil Chemical Data in Liquiçá District.

5.4 TOTAL PHOSPHORUS

Total phosphorus is a soil fertility indicator that supports energy formation, root growth, and the synthesis of organic compounds. Its availability is influenced by soil texture, organic matter, and the contents of iron and aluminum oxides, which bind phosphorus in insoluble forms (Sanchez, 2019).

Laboratory analyses showed that soils in Liquiçá District had moderate to very high total P, ranging from 38.90 to 61.30 mg 100 g^{-1}. The Liquiçá Sub-District had the lowest value at 38.90 mg 100 g^{-1}, categorized as moderate. The Bazartete and Loes Sub-Districts were in the high category, while the Maubara Sub-District had the highest value at 61.30 mg 100 g^{-1}, categorized as very high. According to Sulastri *et al*. (2019), soils with total P above 50 mg 100 g^{-1} are categorized as high to very high. Although high phosphorus can enhance plant growth, its effectiveness still depends on soluble P availability and soil environmental conditions.

The very high total P in the Maubara Sub-District may be associated with organic matter accumulation, limited leaching, and possible phosphate inputs from farming activities or weathering of phosphate-bearing rocks. In contrast, moderate values such as in the Liquiçá Sub-District may reflect lighter textures or stronger weathering. Optimization of phosphorus can be achieved through soil pH adjustment via liming, additions of organic matter, and selection of phosphate fertilizers suited to soil characteristics (Tiessen *et al*., 2014). Total P content for Liquiçá District is presented in **Figure 5.2.**

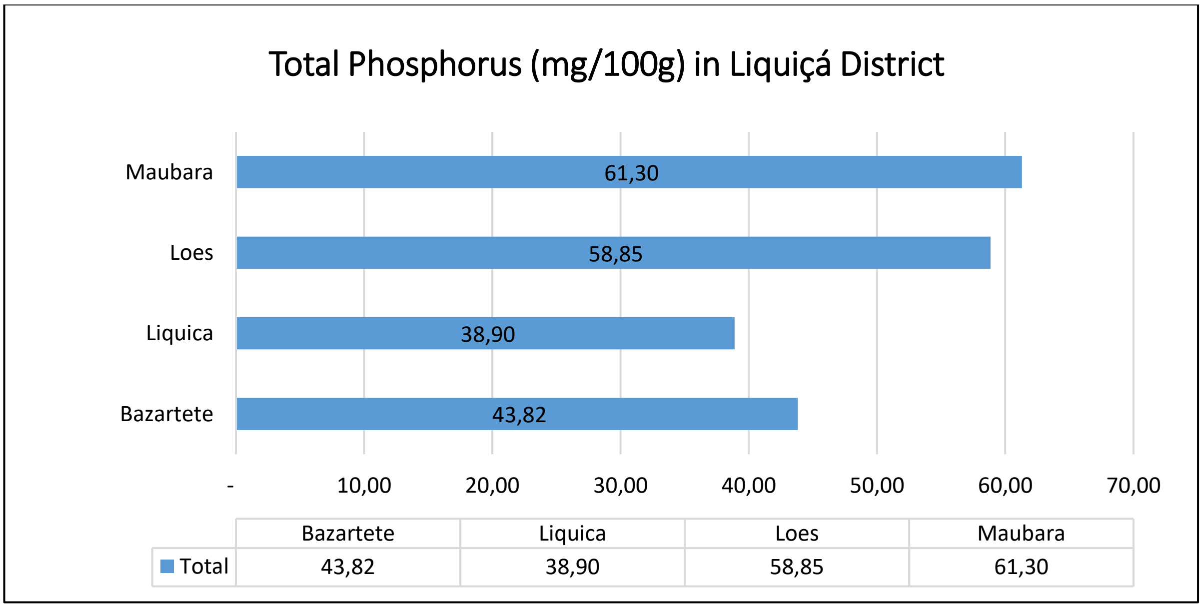


Figure 5.2 Total Phosphorus Content Data in Liquiçá District.

5.5 TOTAL POTASSIUM

Total potassium reflects the overall quantity of potassium in soil, including dissolved forms and K bound to clay minerals and organic matter. It is influenced by weathering of parent material, land use, and biological activity. In Timor-Leste, soil potassium levels are generally moderate due to the dry tropical climate and traditional farming practices with limited K fertilization (Soares *et al*., 2019).

Soil analyses in Liquiçá District showed very high total K, ranging from 75.53 to 187.83 mg 100 g^{-1}. The Liquiçá Sub-District had the lowest value at 75.53 mg 100 g^{-1}, followed by Bazartete and Loes. The Maubara Sub-District had the highest value at 187.83 mg 100 g^{-1}. According to Sari *et al*. (2020), soils with total K above 60 mg 100 g^{-1} are categorized as high to very high. High potassium content in the Maubara Sub-District is likely associated with the dominance of primary minerals and limited leaching, whereas lower values in the Liquiçá Sub-District may be influenced by intensive weathering and lighter soil textures.

Optimization of total K can be supported through organic fertilization (compost and farmyard manure), appropriate application of mineral K fertilizers, and soil-conservation techniques such as cover cropping and mulching. Adding organic matter also improves the soils capacity to retain potassium through associations with clay colloids (Lima *et al.*, 2020). Total K content in Liquiçá District is presented in **Figure 5.3.**

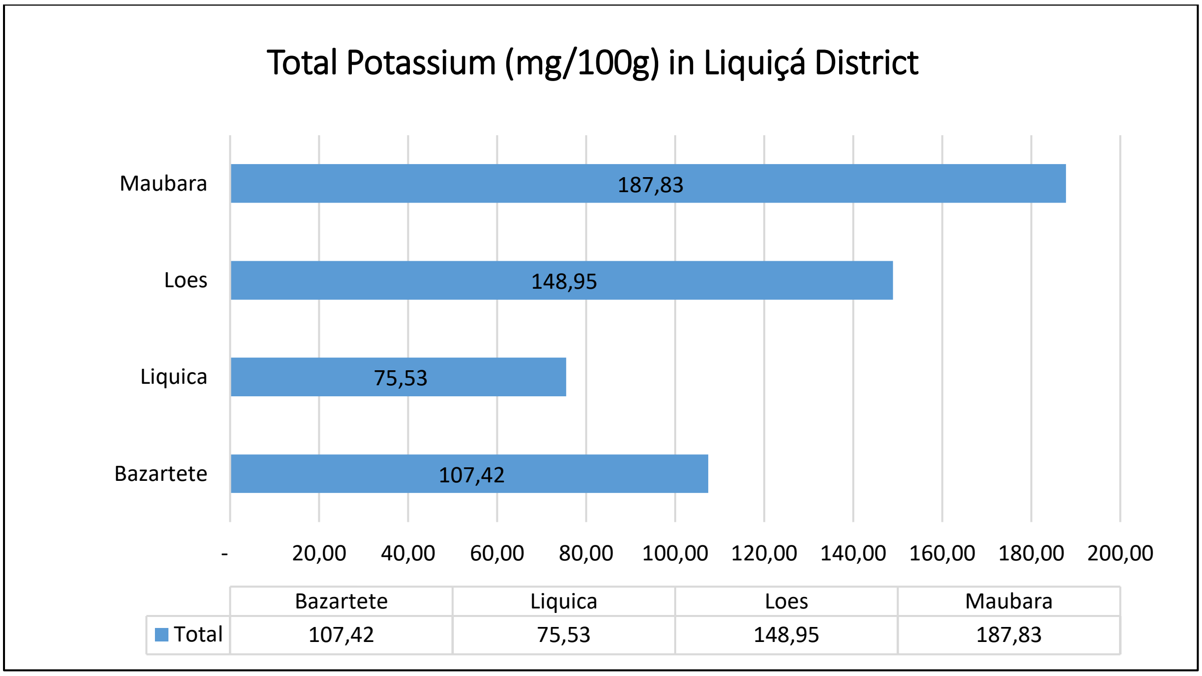


Figure 5.3 Total Potassium Content Data in Liquiçá District.

5.6 TOTAL ZINC

Total Zn reflects the overall amount of zinc in soil, including both available and chemically bound forms. In Liquiçá District, soils derived from limestone and clay commonly exhibit advanced weathering and low organic matter, so most zinc is bound to clay minerals and iron and aluminum oxides, limiting plant availability. In highly weathered tropical soils such as in Timor, approximately 65 to 80 % of zinc occurs in insoluble forms due to associations with oxide and silicate fractions (Ferreira *et al.*, 2023). Costa *et al*. (2022) reported in sloping agricultural landscapes of Timor-Leste that shifting cultivation (slash and burn) contributes to soil degradation and declines in total Zn, particularly on sloping and rocky positions, which are widespread in Liquiçá.

Laboratory analyses showed that soils in Liquiçá District had total Zn ranging from 82.86 to 164.46 ppm. The Maubara Sub-District recorded the lowest reported value at 120.42 ppm, followed by Loes and Bazartete, while the highest value was observed in the Liquiçá Sub-District at 432.96 ppm, indicating spatial variation within a single administrative area. Increasing zinc availability can be achieved through applications of organic amendments (compost, farmyard manure, biochar), Zn fertilizers such as $ZnSO_4$, and mycorrhizal inoculation. Managing soil pH toward neutral to slightly acidic conditions is also important to prevent zinc precipitation into insoluble forms. Total Zn content in Liquiçá District is presented in **Figure 5.4**.

5.7 AVAILABLE ZINC

Available Zn is the fraction of zinc in soil that is water soluble or exchangeable and can be directly taken up by plant roots. This micronutrient is essential in multiple metabolic processes, including auxin formation, protein synthesis, and enzyme activity. Even where total Zn is high, available Zn may remain low because Zn bound to clay minerals or organic matter is poorly soluble and unavailable to plants.

Laboratory analyses showed that available Zn in Liquiçá District ranged from 0.79 to 2.72 ppm. The Loes Sub-District recorded the lowest value at 0.79 ppm, whereas the Liquiçá Sub-District had the highest at 2.72 ppm. This range reflects spatial variation influenced by soil characteristics, land use, and the degree of weathering.

High Zn can reduce phosphorus availability through formation of insoluble Zn–P complexes, particularly in soils with high pH, light textures, and excess phosphorus (Barber, 1995). Conversely, available Zn can increase due to excessive Zn fertilization, heavy metal contamination, or acidic soil conditions that accelerate metal dissolution. Available Zn content in Liquiçá District is presented in **Figure 5.4**

5.8 TOTAL SULFUR

Sulfur is a secondary macronutrient involved in amino acid synthesis and supports plant enzymatic activity. In soils, sulfur occurs in organic and inorganic forms, with the organic fraction typically dominant (Brady and Weil, 2008). Total S encompasses both forms.

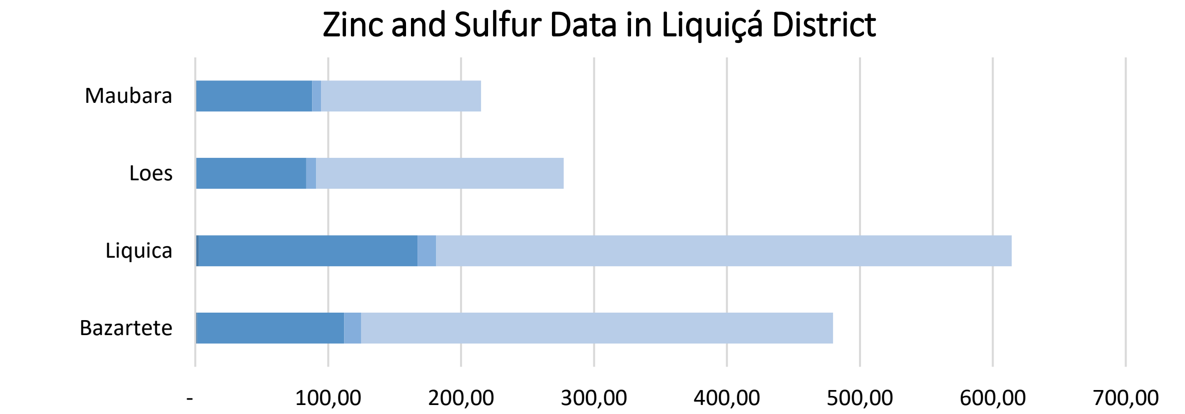
Analyses showed that soils in Liquiçá District had total S ranging from 120.42 to 432.96 ppm. The Maubara Sub-District recorded the lowest value, where as the Liquiçá Sub-District showed the highest. These differences reflect variation in soil conditions such as organic matter accumulation, weathering intensity, and microbial activity.

Low sulfur levels commonly occur in soils with poor organic matter inputs and repeated mineral fertilization without organic additions. High levels are often found in soils with high organic matter accumulation, such as peat or poorly drained land. However, excess sulfate can disrupt uptake of other nutrients and increase soil acidity. Total S in Liquiçá District is presented in **Figure 5.4**.

5.9 AVAILABLE SULFUR

Available sulfur (available S) is the portion of total sulfur that has mineralized from organic matter and is present as sulfate (SO_4^{2-}), which plants can absorb. It serves as a direct indicator of soil fertility with respect to sulfur, which is important for protein synthesis and plant enzyme formation. The mineralization process is influenced by soil organic matter content. Higher organic matter increases the potential release of sulfur in plant-available forms. According to Widijanto *et al*. (2011), decomposition of organic matter produces organic sulfur compounds that are subsequently converted to inorganic forms through soil microbial activity.

In Liquiçá District, available S showed substantial spatial variation, ranging from 6.63 to 14.15 ppm. The Maubara Sub-District recorded the lowest concentration, whereas the Liquiçá Sub-District had the highest. These differences reflect variation in soil conditions and land management practices at each location. High available S is commonly a result of excessive and repeated sulfur fertilization without prior soil analysis. Conversely, low levels are often associated with limited organic matter, restricted sulfur fertilization, and topographic conditions such as steep slopes that accelerate erosion and nutrient leaching. These factors collectively influence sulfur availability to plants. Data on available S in Liquiçá District are presented in **Figure 5.4.**



	Bazartete	Liquica	Loes	Maubara
Zn Available	1,47	2,72	0,79	1,01
Zn total	110,58	164,46	82,86	86,97
S-Available	12,80	14,15	7,31	6,63
S-total	354,90	432,96	186,18	120,42

Figure 5.4 Zn and S content data in Liquiçá District.

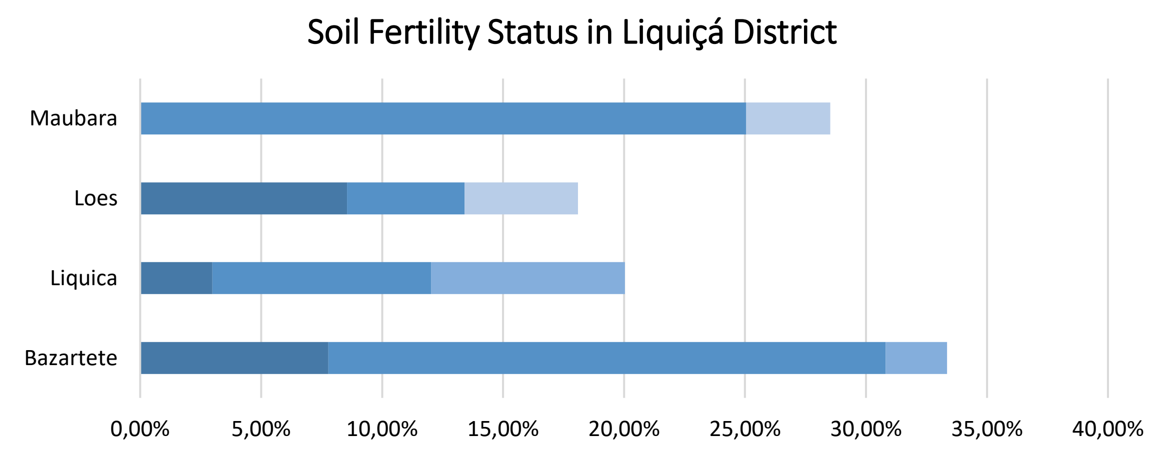
5.10 SOIL FERTILITY STATUS

Laboratory analyses of soils in Liquiçá District showed that most land had low fertility (**Figure 5.5**), and the map is presented in **Figure 5.6.** The area in this category covered 330.00 km², or about 61.98 % of the total area. Very low fertility covered 102.82 km² (19.31 %), medium fertility 56.12 km² (10.54 %), and high fertility 43.36 km² (8.16 %). These proportions indicate agronomic challenges that require strategic measures to support agricultural productivity.

Spatially, soil fertility distribution among Sub-Districts showed differing characteristics. The Liquiçá, Bazartete, and Maubara Sub-Districts each had the largest proportions in the low-fertility category, with areas of 48.10 km² (9.03 %), 122.67 km² (23.04 %), and 133.34 km² (25.05 %), respectively. The Loes Sub-District fell in the very low fertility category, with 24.97 km² (8.55 %).

Assessment of soil fertility status was based on chemical parameters indicating the soil's capacity to supply nutrients to plants. These parameters included soil pH, cation exchange capacity (CEC), base saturation (BS), soil organic carbon, and the contents of phosphate (P_2O_5) and potassium (K_2O). In addition to chemical factors, steep topography accelerates erosion and nutrient leaching, especially on land not managed conservatively. Agricultural practices that are not based on soil analysis also contribute to soil quality degradation, as fertilization is applied inappropriately and without balance. This condition reinforces the urgency of implementing data-based approaches for more effective land management.

To increase land productivity sustainably, an agroecological zoning approach is needed that considers soil characteristics and local environmental conditions. This strategy includes systematic soil fertility mapping, application of soil conservation techniques, and the use of fertilizers tailored to site-specific needs. Such an approach is effective for supporting adaptive and sustainable agricultural systems in Liquiçá District.



	Bazartete	Liquica	Loes	Maubara
Very Low	7,78%	2,99%	8,55%	0,00%
Low	23,04%	9,03%	4,86%	25,05%
Moderate	2,53%	8,01%	0,00%	0,00%
High	0,00%	0,00%	4,69%	3,47%

Figure 5.5 Soil Fertility Status in Liquiçá District.

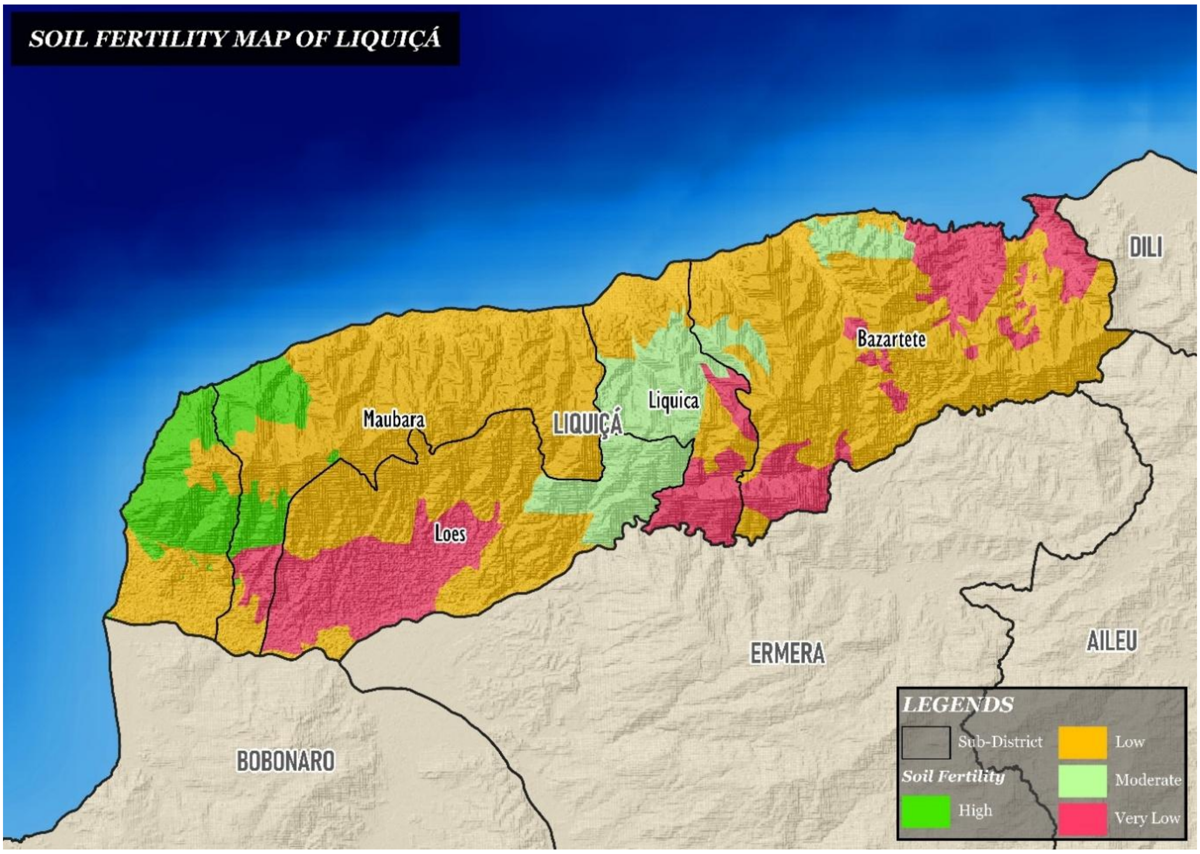


Figure 5.6 Soil Fertility Status Map of Liquiçá District

VI. EROSION AND CONSERVATION

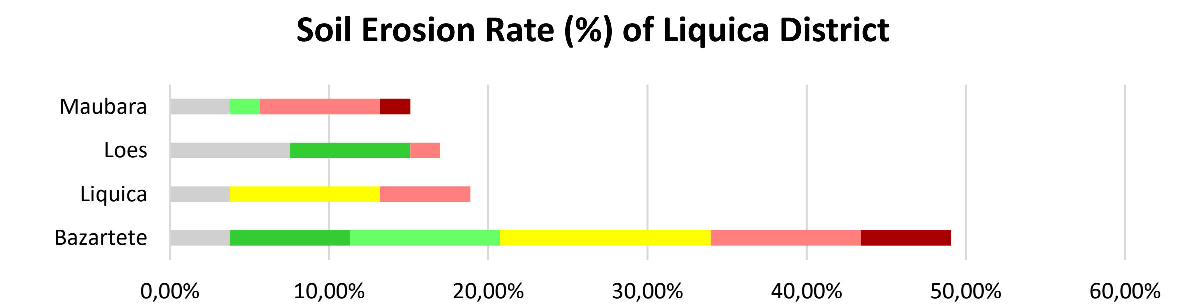
6.1 SOIL EROSION

Soil erosion analysis plays an important role in land suitability evaluation, particularly for the development of agricultural commodities. 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 provides the basis for designing appropriate 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, soil erosion is influenced by several main factors, rainfall erosivity, soil erodibility, slope length and slope gradient, vegetation cover, and land management practices. In Timor-Leste, many of these factors tend to elevate erosion risk. Topography dominated by steep slopes, limited conservation measures, soil structures that are unstable due to geological influences, and sparse vegetative cover are major drivers that accelerate erosion. As noted by Morgan (2005), uncontrolled soil erosion can remove the topsoil, the most fertile soil layer, thereby limiting productive capacity.

Liquiçá District has erosion severities ranging from very slight to very severe, particularly in the Bazartete Sub-District, as shown in **Figure 6.1**. One of the main causes is variation in slope gradient, as described in Chapter 2. Steep to very steep slopes tend to increase surface runoff, which can strip the fertile soil layer (Yuliani *et al*., 2015). The steeper the slope, the greater the erosion potential, as described by Zhang *et al*. (2025), Duhita *et al*. (2021), Zheng *et al.* (2019), and Anthony (2001). Slope position also determines erosion intensity lower slope positions are more easily eroded than upper positions because runoff gains momentum and velocity as it moves downslope.

In addition to slope, soil type also strongly influences erosion. Bazartete is dominated by Inceptisols and Entisols, as presented in **Chapter 2**. Both are known to be erosion-prone. Inceptisols often have blocky, granular, or massive structures that are easily disrupted by water, and clay properties that limit infiltration, thereby increasing erosion risk. Entisols are weakly developed soils with sandy-dominated textures and low aggregation, making them highly susceptible to scouring, as explained by Andrieni *et al*. (2022) and Chapparo *et al*. (2020). Erosion data for Liquiçá District are presented in **Figure 6.1**. The map of soil erosion distribution in Liquiçá District is presented in **Figure 6.2**.



	Bazartete	Liquica	Loes	Maubara
No Erosion	3,77%	3,77%	7,55%	3,77%
Very Light	7,55%	0,00%	7,55%	0,00%
Light	9,43%	0,00%	0,00%	1,89%
Moderate	13,21%	9,43%	0,00%	0,00%
Heavy	9,43%	5,66%	1,89%	7,55%
Very Heavy	5,66%	0,00%	0,00%	1,89%

Figure 6.1 Soil Erosion Rate in Liquiçá District.

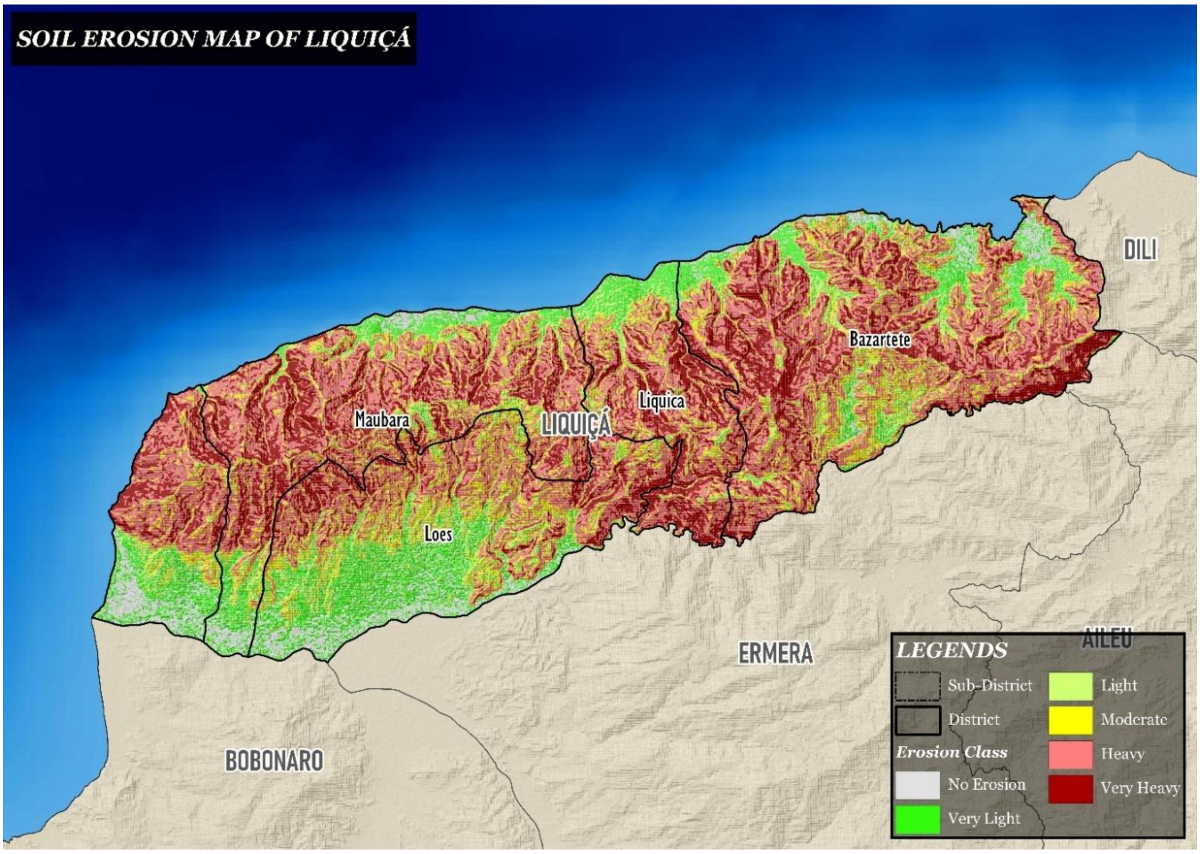


Figure 6.2 Map of Soil Erosion Distribution in Liquiçá District.

6.2 SOIL AND WATER CONSERVATION

Conservation is a long-term natural resource management effort aimed at maintaining land quality and productivity. Conservation protects soil from degradation, rehabilitates degraded land, increases infiltration, and maintains fertility.

Conservation recommendations in Liquiçá District are based on slope classes ranging from flat to very steep (0 to >45 %). On flat to gentle slopes (0 to 8 %), food crops, pulses, and horticultural crops are recommended. These commodities can also be grown on land with slopes up to 40 % when terraces are constructed to increase rainfall infiltration, thereby reducing erosion and surface runoff. Where slopes exceed 45 %, land should be used for perennial crops (tree species such as banyan, mahogany, albizia, teak, Gliricidia, *lamtoro*, and others), because terracing would produce very narrow planting strips and the land is susceptible to erosion and landslides during rainfall events. Slope-gradient data for Liquiçá District are presented in **Table 6.1**, and the slope map is shown in **Figure 6.3.**

Table 6.1 Slope-gradient Data in Liquiçá District

Sub-District	Slope (%)	Potensial Class	Area(ha)	Area (%)
Liquica	25-45%	Agroforestry	2352,95	4,29
Liquica	>45%	Agroforestry	1745,45	3,18
Liquica	0-8%	Highly Suitable	606,33	1,11
Liquica	8-15%	Suitable	471,14	0,86
Liquica	15-25%	Moderately Suitable	722,39	1,32
Bazartete	25-45%	Agroforestry	7923,09	14,45
Bazartete	>45%	Agroforestry	4171,44	7,61
Bazartete	0-8%	Highly Suitable	2386,29	4,35
Bazartete	8-15%	Suitable	1531,47	2,79
Bazartete	15-25%	Moderately Suitable	2637,55	4,81
Loes	25-45%	Agroforestry	5316,01	9,7
Loes	>45%	Agroforestry	2291,45	4,18
Loes	0-8%	Highly Suitable	5361,97	9,78
Loes	8-15%	Suitable	2097,02	3,83
Loes	15-25%	Moderately Suitable	2454,31	4,48
Maubara	25-45%	Agroforestry	5328,21	9,72
Maubara	>45%	Agroforestry	3324,07	6,06
Maubara	0-8%	Highly Suitable	1579,82	2,88
Maubara	8-15%	Suitable	923,51	1,68
Maubara	15-25%	Moderately Suitable	1587,92	2,9

Liquiçá District has similar slope classes across all Sub-Districts but with different areal extents. The Sub-District with the largest area of very steep slopes (>45 %) is Bazartete at 4,171.44 ha or 7.61 %, indicating that land with very steep slopes is suitable only for perennial crops or agroforestry. Gentle slopes (0 to 8 %) are most extensive in the Loes Sub-District at 5,361.97 ha or 9.78 %. Loes has potential for the development of food crops, horticulture, and plantation crops. Land with high potential use at gentle slopes (0 to 8 %) covers 9,934.41 ha (18.12 %), land with potential use at 8 to 15 % covers 5,023.14 ha (9.16 %), land with moderate potential use at 15 to 25 % covers 7,402.17 ha (13.05 %), and land with moderate potential use at 25 to 45 % covers 20,920.26 ha (38.17 %).

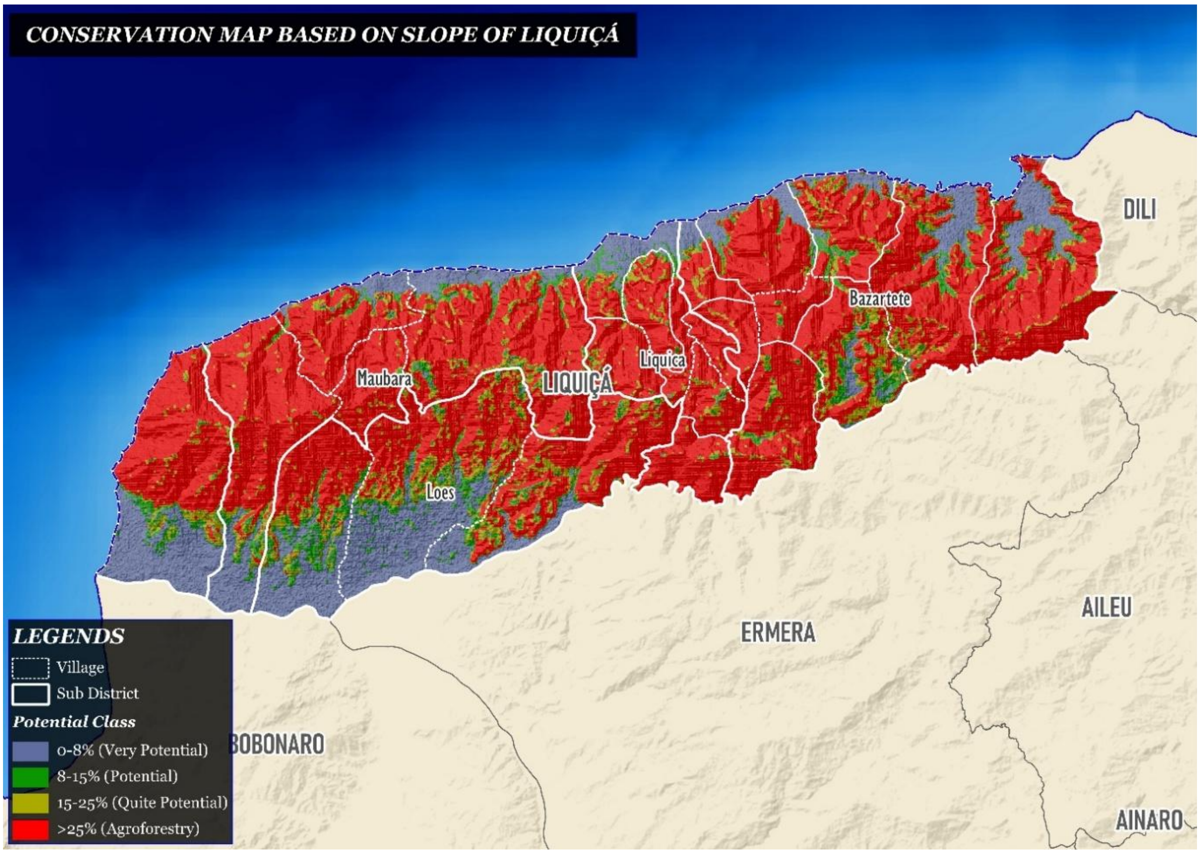


Figure 6.3 Conservation Zoning Based on Slope in Liquiçá District.

Based on the slope map in **Figure 6.3**, areas with gentle (0 to 8 %) to moderate (8 to 25 %) slopes are suitable for developing food crops, pulses, plantation crops, and horticulture. In areas with moderate to moderately steep slopes, terracing methods are required to reduce erosion risk. Areas indicated in red represent very steep slopes (>45 %) that allow only the development of perennial or timber species. Such areas are more appropriately used in agroforestry systems, which integrate trees, agricultural crops, and/or livestock within one area to create diverse ecological interactions.

Interactions among agroforestry components (trees, crops, and livestock) provide benefits that include improved soil fertility; enhanced soil physical, biological, and chemical properties, provision of specific habitats, increased biodiversity, reduced runoff, dissipation of rainfall kinetic energy, binding of soil particles, greater soil water storage, and erosion control. Based on its component, agroforesty is classified into several systems:

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

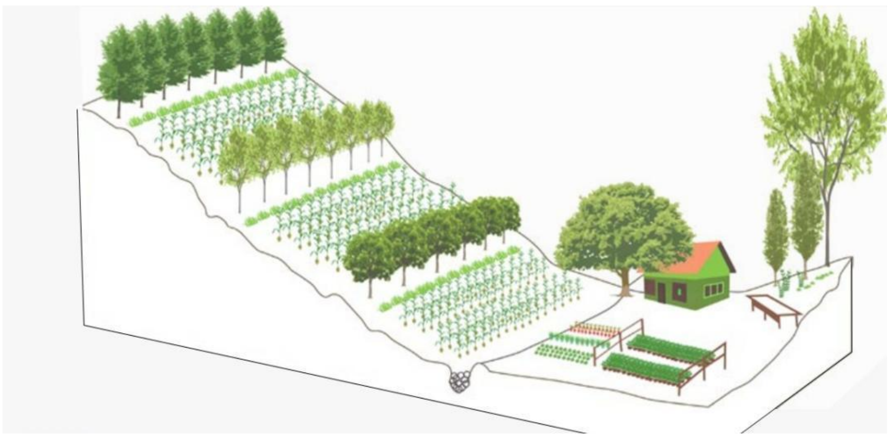


Figure 6.4 Agroforesty Conservation Model.
Source: La *et al.,* 2016

A. IMPORTANCE OF THE AGROFORESTRY CONCEPT

Agroforestry plays an important role in producing local commodities (fuelwood, timber, fruit, and livestock feed) as well as global commodities (coffee, tea, cocoa, rubber, and latex). It has strategic roles in poverty alleviation, food security, and environmental sustainability. Agroforestry enhances farmer resilience and household income through staggered harvests of diverse products throughout the year. Combinations of trees, crops, and livestock help reduce environmental risks, create permanent ground cover that counters erosion, minimize flood damage, and increase water storage beneficial for crops and pasture. Agroforestry provides multiple benefits, including:

1. **Improved food security and nutritional enrichment.**

Agroforestry supplies diverse plant species that generate a variety of foods contributing to food security. Integrating agroforestry components can increase agricultural productivity and broaden nutritional diversity for consumers.

2. **Resilient livelihoods.**

Integrating trees, crops, and livestock reduces production vulnerability to climatic hazards and market shocks. Agroforestry can also suppress pest outbreaks common in monocultures by creating a more favorable microclimate, thereby supporting resilient livelihoods.

3. **Climate-change mitigation and adaptation.**

Integrating diverse crops aids mitigation of climate-change impacts on agriculture. Trees in agroforestry systems sequester carbon and regulate the microclimate, which helps moderate climate-change rates and influences plant growth.

4. **Environmental protection.**

Agroforestry systems regulate climatic and environmental services. Perennial plants help improve air and water quality. Tree litter can be used as organic matter to reduce reliance on chemical fertilizers. Deep root systems support nutrient cycling. Agroforestry components also support biodiversity by creating suitable habitats for flora and fauna within agricultural landscapes.

5. **Poverty alleviation.**

Agroforestry can diversify income through commercial crops, timber sales, and livestock-derived income. Such diversification can sustainably increase agricultural productivity by raising farmers’ incomes and creating employment opportunities, thereby contributing to poverty alleviation and improved community welfare.

B. AGROFORESTRY AND AGRO-ECOLOGY IN LIQUIÇÁ DISTRICT

The most successful agroforestry systems in Timor-Leste typically involve mixed cultivation of fruit trees and timber trees with spices. Principal fruit species include jackfruit, mango, and pineapple. Timber trees commonly planted together with fruit trees include mahogany and teak. Agroforestry has adopted modern, technique-oriented approaches focused on crop rotation, intercropping, and agro-silvopasture.

Paudel *et al*. (2022) describe agroforestry models commonly implemented in Liquiçá District.

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

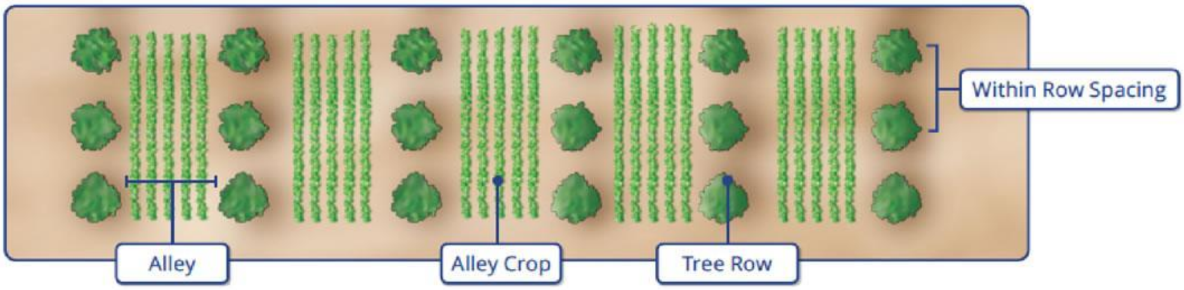


Figure 6.5 Alley Cropping System Concept
(Source: https://www.fs.usda.gov/nac/practices/alley-cropping.php)

2. Fencing Planting this involves creating borders or fences using trees and shrubs, commonly applied in steep hilly areas to conserve soil. The concept is illustrated in **Figure 6.6**.

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

3. Random Planting, this method involves planting both woody and annual crops with irregular spacing, particularly in lowland areas. The concept of random planting is presented in **Figure 6.7.**

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

4. Regular alternating row planting with seasonal crops between the rows on flat and extensive land. An example of an agroforestry model that can be applied in Liquiçá District. is Clove (wood + fruit + spices), with clove as the main crop and supporting crops such as Mahogany, Jackfruit, Mango, Rambutan, Coconut, Coffee, and Turmeric. Another agroforestry model that can be applied is Coffee (wood + fruit + spices), with coffee as the main crop and supporting crops such as Albizia, Jackfruit, Banana, Gmelina, Bamboo, and Teak. This agroforestry model can be implemented at elevations of 500–1500 m with an average annual rainfall of 1500–3000 mm/year.

Cogné & Lescuyer (2024) combined agro-ecological and socio-technical data to identify types of AFS (Agroforestry Systems) in Timor-Leste, which include home gardens that combine perennial crops, spices, and small livestock; integration of crops and fallow land for the development of food crops and trees at specific distances; planting of perennial crops (papaya, banana, chili, etc.) combined with timber plants (palm trees); forest gardens typically located near water sources; and silvopastoral systems that integrate trees, shrubs, and grazing livestock on the same land. Liquiçá District has three agroecological zones (AEZ/Agro-Ecological Zones) based on altitude and North-South orientation. These zones have biophysical parameters such as elevation, average rainfall, and soil types that are crucial in selecting the appropriate crops and agroforestry models to be implemented in Liquiçá District (**Table 6.2**). The agroclimatic zone map of Liquiçá District is presented in **Figure 6.8.**

Table 6.2 Agroecological Zone Data and Main Crop Types

Zone	Height (m)	Rainfall (mm/th)	Main Crops
Zone A	<100	500-1500	Rice, corn, cassava, coconut
Zone B	100-500	500-1500	Corn, cassava, rice, sweet potatoes, peanuts.
Zone C	500-1500	1500-3000	Red beans, coffee, corn, cassava, sweet potatoes, peanuts.

Agroforestry practices in Liquiçá District are traditionally carried out through a method called *Kuda Haur*. The following are recommendations for implementing agroforestry based on agroecological zones in Liquiçá District (Godinho *et al*., 2023):

1. Zone A
   Suitable conservation practices include gabion check dams, ridge terraces, biopore holes, riverbank protection, rainwater reservoirs, and drainage systems. Suitable crops include mahogany, sandalwood, teak, and forest trees that also have high economic value.
2. Zone B
   Conservation techniques that can be applied include terraces with channels, bench terraces, rainwater reservoirs, drainage systems, grass planting, and check dams. Suitable crops for this zone include mahogany, sandalwood, cinnamon, coffee, cocoa, and vanilla.
3. Zone C
   Soil conservation techniques that can be applied include terraces with channels, bench terraces, rainwater reservoirs, drainage systems, grass planting, and check dams. Crops that can be developed in this zone include mahogany, sandalwood, ebony, coffee, vanilla, and clove.

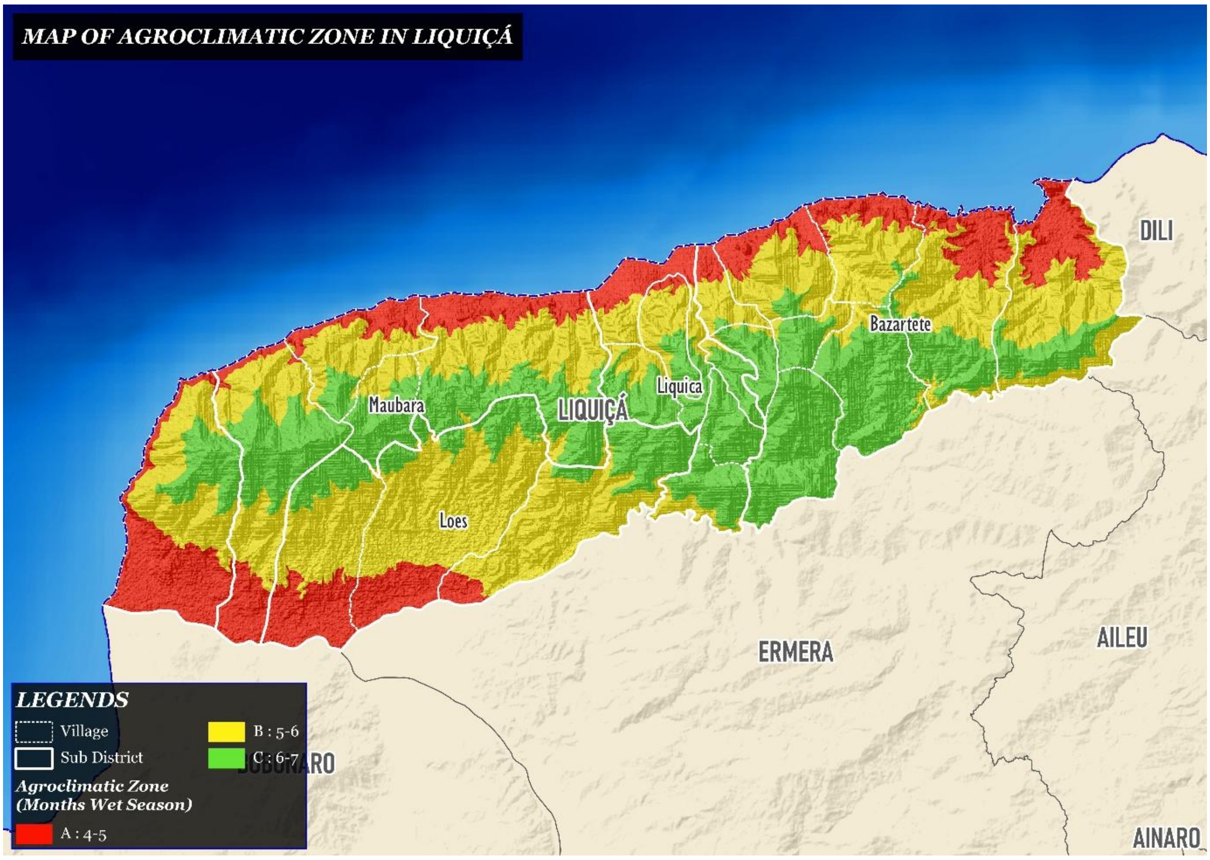


Figure 6.8 Agroclimatic Zone Distribution Map of Liquiçá District

C. CONSERVATION TECHNIQUES IN DISTRICT LIQUIÇÁ

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

1. Check Dam

A check dam is a small, low dam built in riverbeds or other watercourses to reduce the speed of water flow, decrease erosion, and encourage the deposition of eroded material through the spillway. Dams are beneficial for preserving agricultural land and strengthening the structural integrity of embankments in hilly and disaster-prone areas. Some types of check dams include:

a. **Brushwood Dam**, A brushwood dam is made from wood or branches and is typically used for small watercourses. It usually has an effective height of about 1 meter above the ground surface, with a minimum foundation depth for the posts of 0.75-1 meter. The brushwood conservation model is illustrated in **Figure 6.9**. The steps for constructing a brushwood dam include:

1) Digging a trench about 5 cm wide, then inserting wooden posts (150-200 cm) to a depth of about one-third to half the length of the post, with a distance of 30-50 cm between posts.
2) Lowering the middle section of the dam to create a gap that will allow for the maximum flow of water.
3) Weaving branches from trees (e.g., mahogany, rosewood, sesbania) and shrubs between the wooden posts to the desired height.
4) The ends of the intertwined materials should extend into the side of the watercourse at least 30 cm.
5) The back of the dam should be filled with soil.
6) The edges of the brushwood should be about 1.5 to 2.0 times the height of the dam to protect the channel from erosion and be reinforced with galvanized wire.
7) Side walls should be built to direct the flow of water into the dam.
8) The slope of the river channel head should be adjusted to reduce steepness.

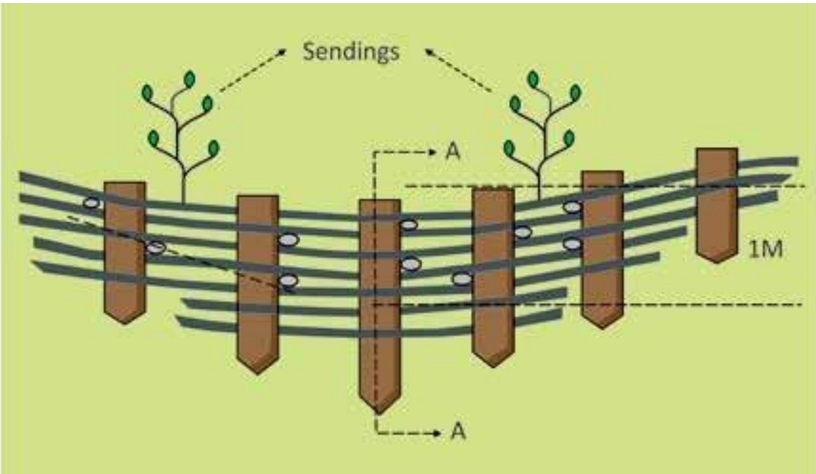


Figure 6.9 Brushwood Check Dam
(Source: Godinho *et al.,* 2023)

b. **Loose Stone**, A loose stone dam is constructed from loose stones to control small to medium-sized watercourses. A boulder dam, similar to a loose stone dam, uses large rocks as the barrier. Typically, these dams have a maximum effective height between 1-2 meters, with a minimum foundation depth of half the effective height, and the thickness of the dam at the spillway ranges from 0.5-1 meter. The loose stone dam model is illustrated in **Figure 6.10**. The steps for constructing a loose stone or boulder dam are as follows:

1) Clear the site and mark the construction line using a rope.
2) Cut the sides of the watercourse with a slope of 1:1. The foundation of the wing walls must be greater than 0.5 meters. The height of the wing walls should match the depth of the spillway.
3) The dam's foundation should extend longer than the spillway.
4) For large dams, two wing walls should be built with an appropriate foundation height to direct the water flow into the spillway or gap, preventing damage to the edges of the watercourse.
5) Boulder stones are used in the gap and downstream sections of the spillway. The center section is kept low to facilitate the water flow.
6) In cases of highwater flow volume, it is necessary to use concrete in the gap and at the top of the dam, or cover the entire structure with wire mesh.
7) An apron made of stone should be built beneath the dam.
8) Large stones are placed at the bottom of the dam, and stones around 50 x 30 cm in size are used throughout the dam.
9) Upstream, the dam must be filled with soil to enhance its stability.

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

c. **Gabion**, A gabion is a dam made from hexagonal or square wire baskets filled with stones. The general specifications for a gabion are that it has a maximum effective height of <5 m, a foundation depth of no more than half the effective height, and a dam thickness at the spillway of <1 m. The concept of gabion conservation is presented in **Figure 6.11.** The steps in building a gabion are as follows:

1) The structure must extend at least 0.5 m into the riverbed and should be protected from floodwater with wing walls.
2) Wing walls with appropriate foundations must be built above the gabion to direct the flow to the spillway or gap and prevent damage to the riverbanks. The space between the dam and the wing walls must be filled with soil.
3) The foundation of the retaining dam should be longer than the spillway.
4) Large stones should be placed along the sides of the gabion box, while smaller stones are used to fill the center. The size of the stones used in the construction should be larger than the size of the wire mesh (mesh size 10 x 10 cm and 15 x 15 cm).
5) If there is debris, a concrete layer should be placed in front of the dam to protect the gabion wire from damage.
6) The dimensions of the spillway should be calculated based on the maximum flow from the river catchment area.
7) An apron should be built beneath the dam.
8) The back of the retaining dam should be filled with soil to increase the strength of the dam.
9) The gabion box should be secured 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 that involves creating a series of terraces to reduce the length and steepness of slopes. Terracing can control water flow directly and reduce the loss of large amounts of soil. It alters the continuity of the topography and reduces slope length by cutting runoff and increasing infiltration time. Terracing can also be combined with buffer strips to control soil erosion (Huang *et al*., 2022). The construction of terraces, combined with agroforestry trees, can help increase land cover and water infiltration gradually, reduce nutrient loss, and improve crop productivity. Terracing is not suitable for shallow soils. The conservation concept using a terracing system is presented in **Figure 6.12**, and the implementation of terracing is shown in **Figure 6.14**.

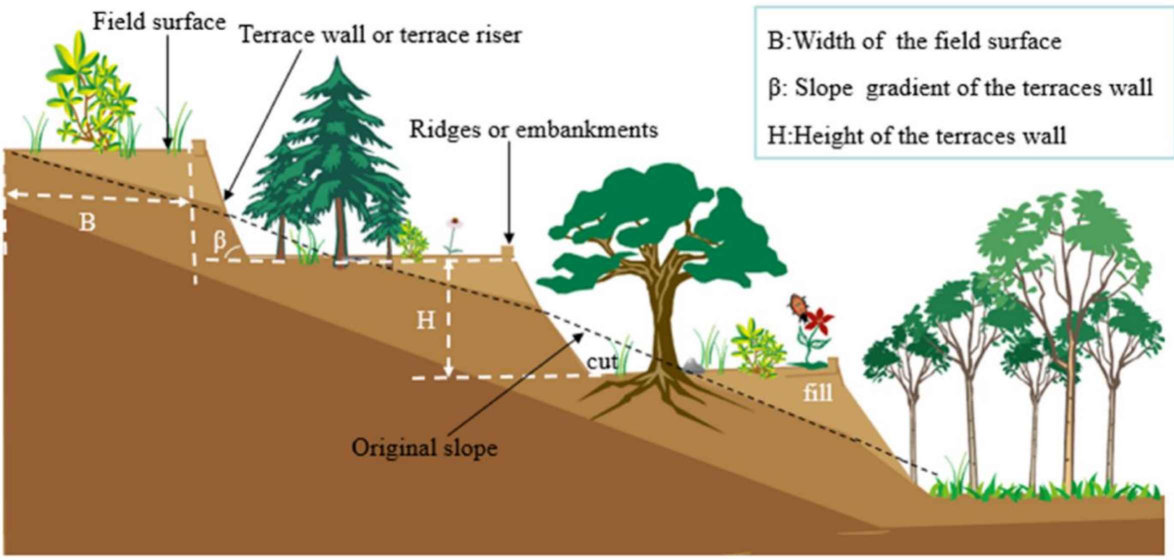
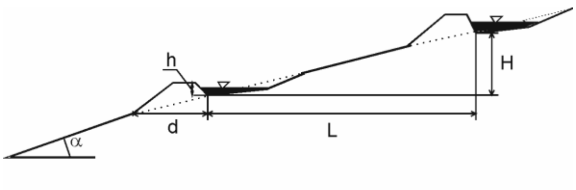


Figure 6.12 The Concept of Terrace Conservation
(Source: Deng *et al.,* 2021)

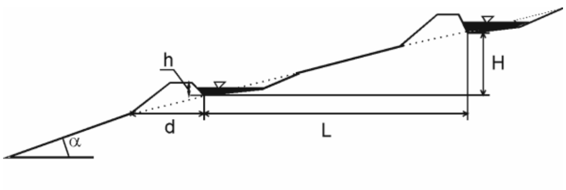
Several types of terraces based on their suitability for slopes include:

a. **Broad Channel Terraces**, These are typically made to capture and channel excess water from fields. These terraces are suitable for wet areas and slopes of no more than 20%.
b. **Ridge Terraces**, These are designed to capture and hold excess water by spreading it across the land area between hilltops. This type of terrace is widely applied on gentle slopes (<3%) because water is dispersed over a larger area without needing to build tall hilltops. Ridge terraces have water channels at the back of the ridge (hill) to drain surface water into the spillway and improve water infiltration into the soil. Ridge terraces divide

the slope into smaller hydrological units, which reduces water flow paths and impacts water circulation on the slope and throughout the watershed. According to Prochal (1984) and Baryła & Pierzgalski (2008), ridge terraces are divided into two types: with and without water outflow. Ridge terraces without water outflow are parallel to the contour. They are built on permeable soils with relatively low rainfall. The water flowing through is retained on the embankment and absorbed into the soil. Ridge terraces with water outflow have either surface or underground drainage. In terraces with underground drainage, water is drained via wells or underground pumps to ditches, rivers, or reservoirs. These terraces are used in areas with high precipitation and on soils with low water absorption. The concept of dividing ridge terraces 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 Concept of Ridge Terraces; Without Outflow (Left); With Outflow (Right) (Source: Baryła & Pierzgalski, 2008)

c. **Bench (Step) Terraces**, These are used on slopes of 20-50% to transform the land into a series of steps separated by vertical walls coated with stones or vegetation for protection. Step terraces can be made flat, sloping inward, or sloping outward, typically created in ecosystems such as rainfed rice fields, dryland farming, and various agroforestry systems.
d. **Individual Terraces**, Terraces built for individual plants, especially for perennial crops. This type of terrace is typically constructed in plantations or fruit orchards.
e. **Orchard Terraces,** Terraces designed for perennial crops, particularly plantation crops and fruit trees. The terraces are built with varying intervals based on planting distance.

Terraces are constructed manually using a cut-and-fill method, where soil from higher levels is cut and moved to lower levels. The specifications for terrace design are as follows:

1) **Terrace Length**: Generally, maximum of 100 m in one direction along the drainage channel for humid tropical climates. The length of the terrace is limited by land size and shape, cutting degree, and soil type.
2) **Terrace Width**: The optimal width is between 2.5 - 5 m (manual construction) and 3.5 - 8 m (machine/tractor construction). The width of the terrace is adjusted based on soil depth, land tillage equipment, type of crops, and other needs.
3) **Terrace Gradient**: The horizontal gradient of the terrace is between 0.5 - 1%, depending on climate and soil type.
4) **Height and Slope of the Sub-Terraces**: Sub-terraces are made from compacted soil and are protected with grass or stone. The height of sub-terraces should not exceed 2 m. The Vertical Interval (VI) between two consecutive terraces can be calculated using the following formula:

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

Description:

S = Slope (%)

Wb = Bench Width (m)

U = Sub-terrace slope (m)

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

3. Biopore Infiltration Holes

A biopore hole is a cylindrical hole drilled into the ground to improve water infiltration, reduce flooding, convert organic waste into compost, reduce greenhouse gas emissions (CO_2 and methane), and utilize the role of soil and plant roots. Biopore holes can increase water infiltration up to 40 times, which helps improve soil moisture and maximize groundwater reserves. In addition, biopores can also enhance soil fertility by converting kitchen waste into compost.

Biopore holes can be made by digging or using a drill to create holes with a depth between 30 - 100 cm. The distance between the holes is approximately 0.5 - 1 m. Biopore holes created around trees can be arranged in three holes 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 placed in the holes. The waste should not be too compact as it may disrupt the water infiltration process. The compost produced is typically ready after 2 - 8 weeks. The concept of applying biopore infiltration holes is shown in **Figure 6.15.**

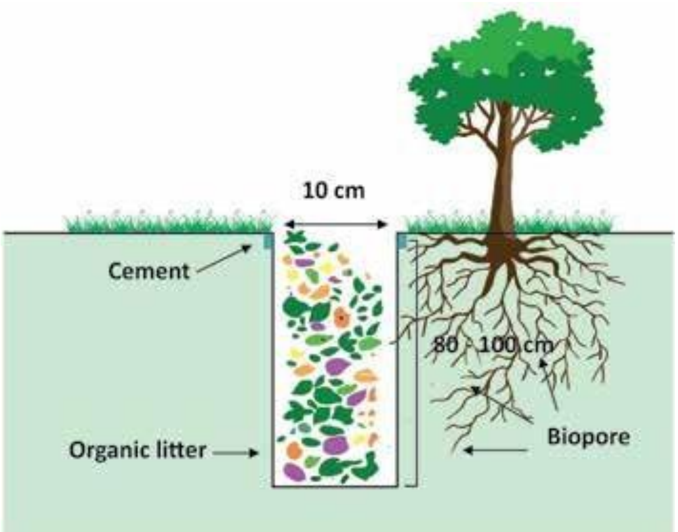


Figure 6.15 Biopore Infiltration Holes
(Source: Godinho *et al.,* 2023)

4. Riverbank Protection

Riverbank is a soil and water conservation technique applied along riverbanks to prevent landslides, reduce soil erosion, improve river water quality, and reduce sedimentation. Riverbank protection can be implemented on exposed riverbanks that are prone to erosion and landslides, steep riverbanks, deforested riverbank areas, and areas with high rainfall. Riverbank management can be carried out by planting grass, shrubs, and trees with deep roots and dense canopies or by installing bamboo frames. The concept of riverbank protection using vegetation is presented in **Figure 6.16.**

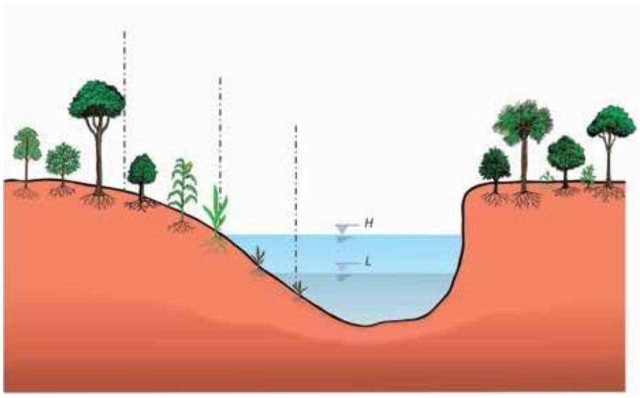


Figure 6.16 Riverbank Protection with Various Layers of Trees, Shrubs, and Grass
(Source: Godinho *et al.,* 2023)

5. Grass Planting

Grass planting is used to control soil erosion. The fibrous root system can form a dense mass of interconnected lateral roots that strengthen, hold, capture, and solidify the soil. Grasses with deep, strong, dense, and fibrous root systems can penetrate and bind soil particles, thus reducing sedimentation. Grass can also serve as a component of functional systems and promote terrace formation, even on steep slopes (Do *et al*., 2023)

Grass planting can be done in three ways:

a. Horizontal/Contour Grass Planting, This method is used on slopes <65 degrees and land prone to erosion. On slopes <30 degrees, the planting distance is 1 x 1 m with a planting hole depth of 10 x 10 cm. For slopes between 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/contour grass planting is shown in **Figure 6.17.**

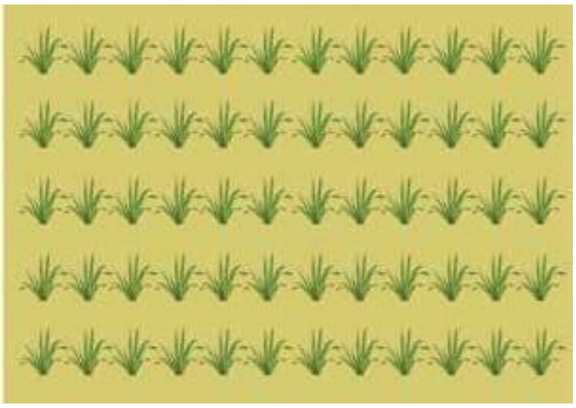


Figure 6.17 Horizontal Grass Planting
(Source: Godinho *et al.,* 2023)

b. Vertical and Downward Grass Planting, This method can be applied on 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.**

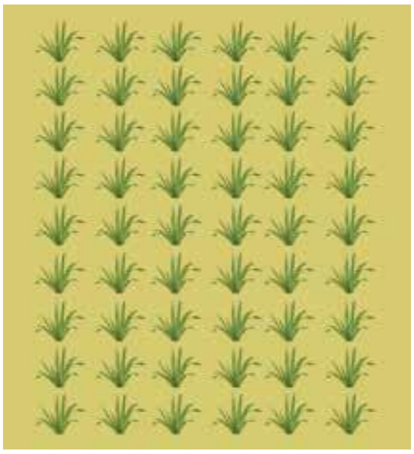


Figure 6. 18 Vertical and Downward Grass Planting
(Source: Godinho *et al*., 2023)

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

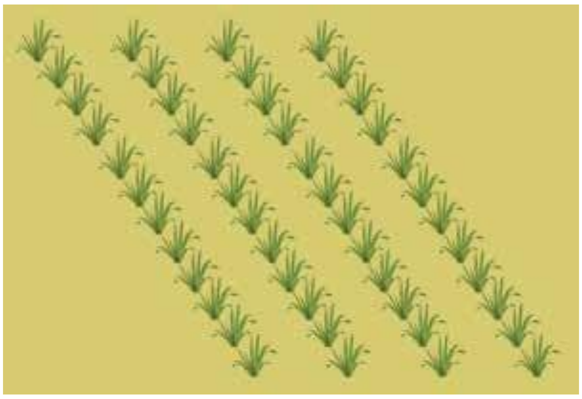


Figure 6.19 Diagonal Grass Planting
(Source: Godinho *et al.,* 2023)

6. Rainwater Reservoir

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

The construction of a rainwater reservoir includes excavation, clay lining, and the construction of overflow channels. During excavation, the embankments or edges of the reservoir should be higher than the ground surface to prevent soil from entering the reservoir. Drainage channels are constructed to prevent overflow of water from the reservoir. The distance between the drainage channel and the surface of the reservoir should be between 25-50 cm. Next, the clay lining serves as reinforcement for the walls or embankments of the reservoir, which are usually made 25 cm thick. The reservoir walls should ideally be built at a 70 – 80 degree slope or in a tiered shape to prevent landslides. For sandy soils, the dam walls need to be lined with plastic, cement, or a mixture of lime and clay (1:1 ratio) to prevent rapid water seepage. Finally, the overflow channel should be directed to the area to be irrigated, with a width between 15-25 cm and a depth of 10-15 cm. Additionally, rainwater reservoirs need to be maintained by cleaning the overflow channels, reservoir edges, and dam walls, as well as removing sediment deposits. The concept of constructing a rainwater reservoir is shown in Figure 6.20.

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

7. Drainage Channel Construction

Drainage channels are used to direct water to areas where it can be absorbed into the soil or stored. The construction of drainage channels is typically equipped with small waterfalls to prevent erosion and soil slips. To construct a drainage channel, begin by digging the soil to a depth of at least 50 cm from the cultivation space and a base width of 50 cm. The bottom of the channel on bench terraces should be sloped outward at a gradient of 0.1 - 0.5%. Grass should be planted across the drainage channel every 1 meter along its length, at a width of 20 cm. Next, the construction of the waterfall involves placing two or three split bamboo poles horizontally at a depth of 0.5 m, with the outer bamboo placed outside. Maintenance efforts include cleaning the channel of sediment, trimming weeds, and repairing any damaged bamboo structures. The concept of a drainage channel is shown in **Figure 6.21.**

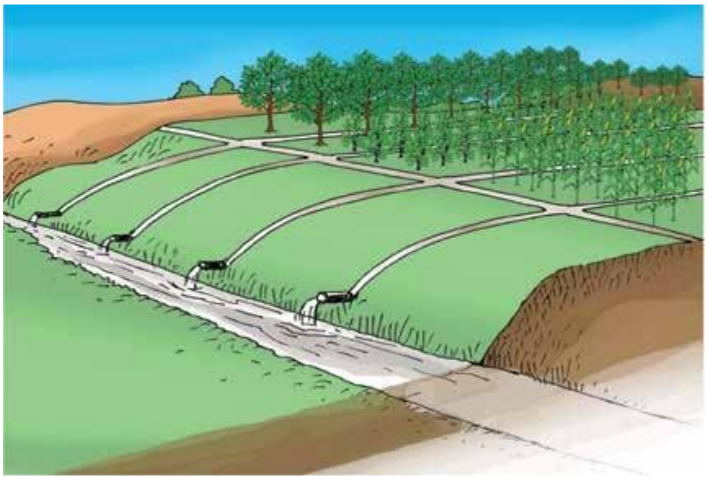


Figure 6.21 Drainage Channel
(Source: Godinho *et al.,* 2023)

8. Wattle Fence / Live Check Dam

Wattle fence is a row of short fences or walls made from vegetative materials and built along the contour. It functions to trap debris moving down the slope, strengthen, and modify the slope. This conservation technique creates micro-conditions for various plant species.

Wattle fence is made by clearing vegetation material (wood or branches) for the posts. Next, 100 cm long posts are inserted at a distance of 100 cm along the fence line. Place two posts, 50 cm long, between the main posts, which should protrude about 20-30 cm from the ground surface. A trench (at least 15 cm deep) is dug along the contour between the posts. The bottom ends of the plant cuttings are placed in the trench, then the cuttings are woven between the posts, and the soil is packed back into the trench. The application concept of the wattle fence is presented in **Figure 6.22.**

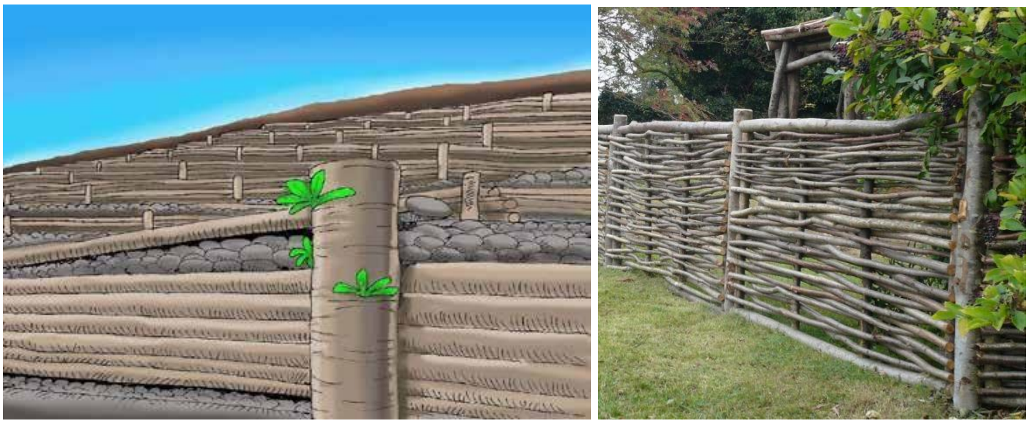


Figure 6.22 Wattle Fence

9. Vegetative Measures

Vegetative measures aim to achieve better soil and water conservation efficiency through the alternating planting of fruit trees, spices, and food crops. Conservation practices need to minimize soil disturbance (minimum tillage), enhance soil coverage, and ensure crop rotation, which are necessary to improve agricultural sustainability (Huang *et al.,* 2022).

a. **Conservation Forests**, in soil and water conservation, conservation forests can reduce surface runoff erosion and maintain or restore soil fertility. Tree species and stand structure are the most important factors determining the effectiveness of conservation. Native tree species and layered vegetation structures (e.g., trees + shrubs + spices) should be prioritized for greening patterns.
b. **Plant Hedges**, the use of plant hedges is also effective in controlling slope soil erosion, holding runoff, and improving soil fertility. Plant hedge species that can be used include *Vetiveria zizanioides*, *Leucaena leucocephala*, Guinea grass, *Gamal* (*Gliricidia sepium*), *Calliandra calothyrsus*, elephant grass (*Pennisetum purpureum*), and others.
c. **Land Covering**, the intensity of land cover is divided into:
    1) Total Cover: Mainly for areas prone to erosion, mountainous regions, around rivers, and reservoirs.
    2) Half Cover: Land cover is only implemented in certain seasons.
    3) Rotational Cover: Applied in lightly eroded areas, divided into several sub-areas for rotational covering.
    4) Cover Combined with Planting: Applied in moderately eroded areas with very low vegetation cover.

Additionally, increasing vegetation cover can be done using mulch, which consists of using leaves, compost, and manure to cover the soil surface. The use of mulch can prevent soil moisture loss due to evaporation, prevent soil erosion, and control weeds. Materials that can be used for mulch include rice and corn straw, legume residues, vetiver grass, and plastic film (Huang *et al*., 2022).

d. **Crop Rotation**, crops planted in rotation yield higher results than those produced continuously. The yield benefits of crop rotation also depend on seasonal weather conditions and long-term practices. Long-term crop diversification can increase agroecosystem productivity compared to monoculture systems and lead to reduced input usage. The combination of legume and brassica crops tends to have a beneficial impact on soil due to the combination of taproots and fibrous roots, promoting a complex and diverse soil organism community (Quintarelli *et al.,* 2022).

e. **Water Reservoir,** According to Rustam (2010), an water reservoir is an artificial structure used to collect and store water with a small volume capacity, smaller than that of a reservoir/dam. Water reservoirs are usually constructed by damming a small river or can be built away from rivers. The water reservoir stores water during the rainy season, and then the water is used by a village during the dry season, prioritized for the population, livestock, and gardens or fields. The amount of water needed determines the water reservoir's height and storage capacity. An example concept for applying conservation by building a water reservoir is shown in Figure 6.23.

Figure 6.23 Application of Water Reservoir

VII. AGRICULTURAL LAND SUITABILITY EVALUATION

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

7.1 LAND SUITABILITY FOR AGRICULTURE

Land suitability assessment based on the current condition uses field survey data. This assessment reflects the land's capacity under existing conditions without additional interventions. Current land suitability, or the suitability of land in its natural state, does not consider any improvement efforts or management practices that can address constraints or limiting factors in each land unit/map unit. To determine the class of actual land suitability, an assessment is first made of each land quality based on the most limiting factors/poorest land characteristics, and then the land suitability class is determined based on the poorest or most limiting land quality.

Potential land suitability refers to land suitability after improvements have been made. For example, land that is currently marginally suitable (S3) due to nutrient deficiencies could become moderately suitable (S2) or even highly suitable (S1) after improvements such as fertilization. The potential land suitability assessment is carried out by implementing possible improvements to the land's quality that act as limiting factors, so the land suitability is expected to improve. With technology, land that naturally has a low suitability class (current suitability) can be improved to a higher suitability class (potential suitability). However, not all land qualities or characteristics can be improved with current technology, or a high level of management may be required to improve them. In land use planning, the main focus is on potential land suitability because this assessment provides an indication of the maximum potential of the land for various uses after improvements are made. Therefore, potential land suitability helps in planning land use effectively and sustainably, as well as determining the necessary improvement steps to achieve optimal results.

7.2 LAND SUITABILITY CLASSIFICATION STRUCTURE

The land suitability classification system according to the **Framework of Land Evaluation (FAO, 1976)** is widely used in Indonesia and other developing countries. The framework of the land suitability classification system uses four categories: order, class, sub-class, and unit (Hardjowigeno, 2015). Systematically, land suitability is presented in **Table 7.1**.

Table 7.1 Land Suitability Classification System (FAO, 1976).

Order	:	Indicates whether land is suitable or not for a specific use.
Class	:	Indicates the degree of suitability of the land.
Sub-class	:	Indicates the type of constraint or the type of improvement required in each class.
Unit	:	Indicates the differences in the magnitude of the limiting factors that affect the management of sub-classes.

Order and class are usually used in land mapping at the reconnaissance scale, sub-class in semi-detailed land mapping, and unit for detailed land mapping. The order is also used in land mapping at a coarse scale (exploration):

Suitability Order

The suitability order describes the general suitability of land, meaning whether the land is suitable or not for a specific land use that has been considered. At the suitability order level, land is classified as either suitable (S) or not suitable (N).

Suitable Order (S)

Land included in this order is land that can be used over a long period of time for a given intended use. The benefits derived from managing this land will be satisfactory when calculated with the inputs provided, with little or no risk of land resource degradation.

Not Suitable Order (N)

Land included in this order is land that faces various difficulties/constraints, either physically (such as very steep slopes, rocky, etc.), or economically (where inputs/efforts are not balanced with the output, thus preventing its use for the intended purpose).

Suitability Class

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

Highly Suitable Class (S1)

Land that has no significant or obvious constraints to sustainable land use or only minor constraints that do not significantly reduce land productivity.

Moderately Suitable Class (S2)

Land that has somewhat serious constraints, requiring a higher level of management to maintain its productivity. The constraints will reduce productivity or profitability and increase the required inputs.

Marginally Suitable Class (S3)

Land that has serious constraints for maintaining the necessary level of management. These heavy constraints may lower productivity and profitability, requiring additional inputs to achieve the expected output.

Not Suitable Class (N1)

Land that has very severe constraints that are difficult to overcome, thus preventing its sustainable use in the long term.

N2: Permanently Not Suitable Land with permanent constraints that prevent any possibility of sustainable land use in the long term.

7.3 LAND SUITABILITY ASSESSMENT RESULTS

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

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

Subsequently, the data obtained is analyzed based on the growing requirements of each plant species in its current state, as well as its potential suitability after various land improvement efforts, such as fertilization, addition of organic matter, or the implementation of soil conservation techniques. This process generates comprehensive information for determining the priority for commodity development, identifying limiting factors, and designing relevant technical solution.

The placement of several plant species in the same column in **Table 7.2** indicates that these plants have similar growing requirements and limiting factors. This means they require similar environmental conditions for optimal growth and face relatively the same constraints in cultivation. Conversely, plants placed in different columns have different growing requirements and constraints, necessitating a tailored management approach for each. This approach forms the basis for the land suitability evaluation in Liquiçá District. The results of this analysis provide strategic guidance for maximizing land productivity while maintaining the sustainability of natural resources in each area.

A. Land Suitability Evaluation for Bazartete Sub-District

Bazartete Sub-District has the potential for the development of various commodities, including food crops such as soybeans and peanuts, vegetables such as shallots and chili, fruit crops like mango and orange, and floral commodities such as roses, asters, and sunflowers. Spices and medicinal plants such as aromatic ginger and turmeric, as well as industrial commodities like robusta coffee and tobacco, can also be developed. Grazing areas can be enhanced by planting legumes and forage crops such as elephant grass and Setaria, along with the addition of organic matter to improve soil fertility. In addition to the aforementioned plants, other crops that can be developed in Bazartete Sub-District are listed in **Table 7.5**.

The main constraints in agricultural development in Bazartete Sub-District include factors such as **slope, erosion, dry months, rainfall, drainage, pH, total nitrogen (N-total), available phosphorus (P-Available), available potassium (Available potassium), and soil texture**. However, these constraints are mainly technical and can be minimized through soil and water conservation techniques, such as terracing, planting vegetation to reinforce terraces, adjusting planting patterns according to the seasons, reforestation, creating adaptive drainage or irrigation systems, treating soil with sulfur or lime (dolomite), applying NPK fertilizers, and adding organic matter. Additionally, **there are permanent limiting factors in the region, such as temperature, rock outcrops, surface rock, and effective soil depth**. Although these factors cannot be completely eliminated, land management practices can still be applied, such as creating planting holes in between rock outcrops and selectively clearing surface rock, which can support the efficiency and productivity of crop cultivation.

This area has a good land suitability potential to support sustainable agriculture. However, commodities such as potatoes, carrots, garlic, cashews, and aromatic ginger are not recommended for cultivation due to permanent temperature constraints that cannot be improved. **Other crops that can be developed in Bazartete Sub-District, in addition to the ones mentioned, are presented in Table 7.5.**

B. Land Suitability Evaluation for Liquiçá Sub-District

Liquiçá Sub-District has the potential for the development of various agricultural commodities, including irrigated ricefield, which falls into the highly suitable (S1) category. In addition, several other commodities can be developed, including dryland food crops such as soybeans and wheat, vegetables such as tomatoes and chili, fruit crops such as mango and soursop, flowers such as roses, asters, and sunflowers, spices and medicinal plants like galangal and lemongrass, and industrial crops such as robusta coffee and sugarcane. Grazing area commodities, legumes, and livestock forage such as elephant grass and setaria can also be developed with the addition of organic matter to improve soil fertility. Other crops that can be developed in Liquiçá Sub-District, in addition to the ones mentioned, are listed in **Table 7.5**.

The development of agricultural crops in Liquiçá Sub-District faces several **main limiting factors, including slope gradient, erosion level, number of dry months, distribution and intensity of rainfall, drainage conditions, pH, total nitrogen (N-total), available phosphorus (P-Available), available potassium (Available potassium), and soil texture**. Although these constraints are technical and may affect the optimization of land productivity, most of them can still be addressed through the application of appropriate soil and water conservation strategies. Mitigation efforts that can be undertaken include terracing to reduce erosion rates, planting vegetation to reinforce terraces and protect soil surfaces, adjusting planting patterns according to the season, reforestation activities, and developing adaptive drainage or irrigation systems. Soil condition improvements can also be made by applying dolomite to neutralize soil acidity, using sulfur to lower soil pH, applying NPK compound fertilizers, and adding organic matter to improve soil fertility sustainably. **In addition to technical factors, there are also permanent constraints that limit land management, such as temperature, rock outcrops, surface rock, and effective soil depth.** These factors have unchangeable characteristics but can still be managed using adaptive approaches, such as creating planting holes in between rock outcrops and selectively clearing surface rock. This approach aims to enhance land use efficiency and support sustainable cultivation.

Overall, Liquiçá Sub-District has good land suitability potential to support the development of sustainable agriculture. However, some commodities such as potatoes, carrots, garlic, cashews, and aromatic ginger are not recommended for cultivation in this area, given the temperature limitations as a permanent constraint that cannot be improved. **Other crops that can be developed in Liquiçá Sub-District, in addition to those mentioned, are listed in Table 7.5**

C. Land Suitability Evaluation for Loes Sub-District

Loes Sub-District has the potential for the development of various agricultural commodities, including irrigated Upland rice, which falls into the highly suitable (S1) category. Additionally, several other commodities can be developed, such as soybeans, sorghum, vegetables like eggplant and mustard, fruit crops such as guava and soursop, flowers like roses, asters, and sunflowers, spices and medicinal plants like vanilla and candlenut, and industrial crops such as robusta coffee and cotton. Grazing area commodities and livestock forage such as elephant grass and legumes can also be developed. Other crops that can be developed in Loes Sub-District, in addition to those mentioned, are listed in **Table 7.5**.

The main limiting factors for agricultural development in Loes Sub-District include several technical aspects such as slope, erosion, dry season duration, rainfall, drainage systems, soil pH, total nitrogen (N-total), available phosphorus (P-Available), available potassium (Available potassium), and soil texture.

However, these constraints are still manageable through the application of various soil and water conservation measures, such as terracing to reduce erosion, planting buffer vegetation on terraces, adjusting planting patterns according to the season, reforestation, and developing adaptive drainage and irrigation systems. Additionally, soil quality improvement can be achieved through treatments such as sulfur application or liming with dolomite, balanced fertilization with NPK, and the addition of organic matter to enhance soil fertility. **Furthermore, there are some permanent limiting factors in the region that cannot be eliminated, such as temperature conditions, rock outcrops, surface rock, and effective soil depth**. However, land management can still be applied with appropriate strategies, such as creating planting holes between rock outcrops and selectively clearing surface rock. This approach will support increased efficiency and productivity in crop cultivation despite facing natural limitations.

With the potential available, Loes Sub-District has the capacity for sustainable agricultural development. However, some commodities such as potatoes, carrots, garlic, cashews, and aromatic ginger are not recommended for cultivation in this area due to permanent temperature constraints that cannot be improved. **Other crops that can be developed in Loes Sub-District, in addition to those mentioned, are listed in Table 7.5**.

D. Land Suitability Evaluation for Maubara Sub-District

Maubara Sub-District has the potential for the development of various agricultural commodities, including food crops such as soybeans and sorghum. Horticultural commodities such as chili, bell peppers, and fruit crops like rambutan and durian. Floral commodities such as roses, asters, and sunflowers, as well as spices and medicinal plants like galangal and cardamom. Industrial crops such as robusta coffee and cotton, and grazing area commodities and livestock forage such as elephant grass and legumes can also be developed. Other crops that can be developed in Maubara Sub-District, in addition to the ones mentioned, are listed in **Table 7.5**.

The development of agricultural crops in Maubara Sub-District faces several limiting factors, both technical and permanent. **Technical limiting factors include slope gradient, erosion level, dry season duration, rainfall, drainage conditions, pH, total nitrogen (N-total), available phosphorus (P-Available),**

available potassium (Available potassium), and soil texture. Despite these challenges, technical constraints can still be addressed through the application of soil and water conservation technologies. Some approaches that can be implemented include terracing, planting vegetation to reinforce slopes, adjusting planting patterns based on the seasons, reforestation, and developing adaptive drainage and irrigation systems. Additionally, soil chemical properties can be improved through sulfur or dolomite application to adjust pH, balanced fertilization with NPK-containing fertilizers, and the addition of organic matter to enhance soil fertility. **On the other hand, Maubara Sub-District also faces permanent natural constraints, such as temperature that is unsuitable for certain crops, rock outcrops, surface rock, and limited effective soil depth**. Although these factors cannot be eliminated, adaptive land management is still possible. For example, planting holes can be created in gaps between rock outcrops, or surface rock can be selectively cleared. This approach aims to maximize land use and enhance the efficiency and productivity of crop cultivation.

Overall, Maubara Sub-District has the potential to be developed as a sustainable agricultural area. However, some commodities such as potatoes, carrots, garlic, cashews, and aromatic ginger are not recommended for cultivation in this area due to temperature limitations that are permanent and cannot be modified through technical interventions. **Other crops that can be developed in Maubara Sub-District, in addition to those mentioned, are listed in Table 7.5**

Table 7.2 Land Suitability Evaluation Analysis Matrix in Liquiçá District.

Commodity	Sub-district	Limiting factors	Potential Land Suitability / Improvement Measures
FOOD COMMODITIES			
Irrigated rice	• Liquiçá • Loes	S3 : Flood	S1 : Flood
Dryland Food Commodities			
Upland rice	• Bazartete • Liquiçá • Loes • Maubara	N : Slope S3 : Drainage, Erosion, Rock Outcrops S2 : Surface Rock	S3 : Rock Outcrops S2 : Slope, Surface Rock
Cassava	• Bazartete • Liquiçá • Loes • Maubara	N : Slope, Flood S3 : Drainage, Erosion, Rock Outcrops S2 : Effective depth, Surface Rock	S3 : Rock Outcrops S2 : Effective depth, Slope, Surface Rock, Flood
Corn Sorghum	• Bazartete • Liquiçá • Loes • Maubara	N : Erosion, Slope, Flood S3 : Rainfall, Drainage, Rock Outcrops S2 : Surface Rock	S3 : Rock Outcrops S2 : Slope, Erosion, Surface Rock, Flood
Soybean Mung bean Peanut Cowpea	• Bazartete • Liquiçá • Loes • Maubara	N : Slope, Flood S3 : Rainfall, Drainage, Erosion, Rock Outcrops S2 : Temperature, Surface Rock	S3 : Rock Outcrops S2 : Temperature, Slope, Surface Rock, Flood
Wheat	• Bazartete • Liquiçá • Loes • Maubara	N : Flood S3 : Rainfall, Drainage, Erosion, Rock Outcrops S2 : Temperature, Slope, Surface Rock	S3 : Rock Outcrops S2 : Temperature, Surface Rock, Flood
Taro	• Bazartete • Liquiçá • Loes	N : Slope, Flood	S3 : Temperature, Rock Outcrops

	• Maubara	S3 : Temperature, Drainage, Erosion, Rock Outcrops S2 : Rainfall, Surface Rock	S2 : Slope, Surface Rock, Flood
Sweet Potato	• Bazartete • Liquiçá • Loes • Maubara	N : Dry month, Slope, Flood S3 : Drainage, Dry month, Erosion, Rock Outcrops S2 : Effective depth, Surface Rock	S3 : Dry month, Rock Outcrops S2 : Effective depth, Slope, Surface Rock, Flood
HORTICULTURAL VEGETABLE COMMODITIES			
Potato **Carrot**	• Bazartete • Liquiçá • Loes • Maubara	N : Temperature, Slope, Flood S3 : Drainage, Rock Outcrops, Erosion S2 : Rainfall, Surface Rock, Texture, N, P, K, CEC, Base saturation	N : Temperature S2 : Slope, Rock Outcrops, Surface Rock, Texture
Eggplant **Bitter melon** **Tomato** **Long bean**	• Bazartete • Liquiçá • Loes • Maubara	N : Slope, Flood S3 : Rainfall, Drainage, Rock Outcrops, Erosion S2 : Temperature, Surface Rock, N, P, K, CEC, Base saturation	S2 : Slope, Rock Outcrops, Temperature, Surface Rock
Bell pepper **Broccoli**	• Bazartete • Liquiçá • Loes • Maubara	N : Slope, Flood S3 : Drainage, Rock Outcrops, Erosion S2 : Temperature, Surface Rock, N, P, K, CEC, Base Saturation	S2 : Slope, Rock Outcrops, Temperature, Surface Rock
Shallot **Cabage**	• Bazartete • Liquiçá • Loes • Maubara	N : Slope, Flood S3 : Drainage, Rock Outcrops, Erosion S2 : Temperature, Surface Rock, Texture, N, P, K, CEC, Base Saturation	S2 : Slope, Rock Outcrops, Temperature, Surface Rock, Texture
Green bean	• Bazartete • Liquiçá	N : Slope, Flood	S2 : Slope, Rock Outcrops, Temperature, Surface Rock

	• Loes • Maubara	**S3 :** Drainage, Rock Outcrops, Erosion **S2 :** Temperature, Surface Rock, DHL, N, P, K, CEC, Base Saturation	
Garlic	• Bazartete • Liquiçá • Loes • Maubara	**N :** Temperature, Slope, Flood **S3 :** Drainage, Rock Outcrops, Erosion **S2 :** Surface Rock, N, P, K, CEC, Base Saturation	**N :** Temperature **S2 :** Slope, Rock Outcrops, Surface Rock
Chili	• Bazartete • Liquiçá • Loes • Maubara	**N :** Slope, Flood **S3 :** Rainfall, Drainage, Rock Outcrops, Erosion **S2 :** Surface Rock, N, P, K, CEC, Base Saturation	**S2 :** Slope, Rock Outcrops, Surface Rock
Caisim	• Bazartete • Liquiçá • Loes • Maubara	**N :** Slope, Flood **S3 :** Drainage, Dry month, Rock Outcrops, Erosion **S2 :** Temperature, Rainfall, Surface Rock, Texture, N, P, K, CEC, Base Saturation	**S2 :** Slope, Dry month, Rock Outcrops, Temperature, Surface Rock, Texture
Snow pea	• Bazartete • Liquiçá • Loes • Maubara	**N :** Slope, Flood **S3 :** Temperature, Drainage, Rock Outcrops, Erosion **S2 :** Surface Rock, N, P, K, CEC, Base Saturation	**S2 :** Slope, Temperature, Rock Outcrops, Surface Rock
Cucumber	• Bazartete • Liquiçá • Loes • Maubara	**N :** Slope **S3 :** Rainfall, Drainage, Rock Outcrops, Flood, Erosion **S2 :** Surface Rock, N, P, K, CEC, Base Saturation	**S2 :** Slope, Rock Outcrops, Surface Rock
HORTICULTURAL FRUIT COMMODITIES			
Guava Jackfruit Soursop Breadfruit	• Bazartete • Liquiçá • Loes • Maubara	**S3 :** Slope, Rock Outcrops, N-total, P-Available	**S2** : Rock Outcrops, Surface Rock, Effective depth

Longan Custard apple Grapes		**S2 :** Rainfall, Erosion, Effective depth, Surface Rock, Available potassium	
Watermelon Melon	• Bazartete • Liquiçá • Loes • Maubara	**N :** Slope **S3 :** Rainfall, Erosion, Rock Outcrops, N-total, P-Available **S2 :** Drainage, Surface Rock, Texture, Available potassium	S2 : Slope, Rock Outcrops, Surface Rock
Banana	• Bazartete • Liquiçá • Loes • Maubara	**N :** Dry month **S3 :** Slope, Rock Outcrops, N-total, P-Available **S2 :** Temperature, Drainage, Erosion, Surface Rock, Available potassium, Texture	S3 : Dry month S2 : Temperature, Rock Outcrops, Surface Rock, Texture
Papaya	• Bazartete • Liquiçá • Loes • Maubara	**S3 :** Slope, Rock Outcrops, N-total, P-Available **S2 :** Temperature, Rainfall, Erosion, Surface Rock, Available potassium	S2 : Temperature, Rock Outcrops, Surface Rock
Orange	• Bazartete • Liquiçá • Loes • Maubara	**S3 :** Slope, Rock Outcrops, N-total, P-Available **S2 :** Erosion, Effective depth, Surface Rock, Texture, Available potassium	S2 : Rock Outcrops, Surface Rock, Effective depth, Texture
Rambutan	• Bazartete • Liquiçá • Loes • Maubara	**S3 :** Rainfall, Slope, Rock Outcrops, N-total, P-Available **S2 :** Temperature, Erosion, Effective depth, Surface Rock, Available potassium	S2 : Temperature, Rock Outcrops, Surface Rock, Effective depth
Avocado	• Bazartete • Liquiçá • Loes • Maubara	**N :** Dry month **S3 :** Slope, Rock Outcrops, N-total, P-Available **S2 :** Erosion, Effective depth, Surface Rock, Available potassium	S3 : Dry month S2 : Rock Outcrops, Surface Rock, Effective depth
Mango	• Bazartete • Liquiçá	**S3 :** Slope, Rock Outcrops, N-total, P-Available	S2 : Rock Outcrops, Surface Rock, Effective depth

	• Loes • Maubara	**S2 :** Rainfall, Erosion, Effective depth, Surface Rock, Available potassium	
Snakefruit	• Bazartete • Liquiçá • Loes • Maubara	**S3 :** Slope, Rock Outcrops, N-total, P-Available **S2 :** Erosion, Surface Rock, Available potassium	**S2** : Rock Outcrops, Surface Rock
Durian	• Bazartete • Liquiçá • Loes • Maubara	**S3 :** Rainfall, Slope, Rock Outcrops, N-total, P-Available **S2 :** Temperature, Erosion, Effective depth, Surface Rock, Available potassium	**S2** : Temperature, Rock Outcrops, Surface Rock, Effective depth
Pineapple	• Bazartete • Liquiçá • Loes • Maubara	**S3 :** Slope, Rock Outcrops, N-total, P-Available **S2 :** Rainfall, Erosion, Surface Rock, Available potassium	**S2** : Rock Outcrops, Surface Rock
Strawberry	• Bazartete • Liquiçá • Loes • Maubara	**N :** Slope **S3 :** Erosion, Rock Outcrops, N-total, P-Available **S2 :** Temperature, Surface Rock, Available potassium	**S2** : Slope, Temperature, Rock Outcrops, Surface Rock
Grape	• Bazartete • Liquiçá • Loes • Maubara	**S3 :** Temperature, Slope, Rock Outcrops, N-total, P-Available **S2 :** Rainfall, Erosion, Effective depth, Surface Rock, Available potassium	**S3** : Temperature **S2** : Slope, Rock Outcrops, Surface Rock, Effective depth
Passion fruit	• Bazartete • Liquiçá • Loes • Maubara	**S3 :** Temperature, Slope, Rock Outcrops, N-total, P-Available **S2 :** Rainfall, Erosion, Effective depth, Surface Rock, Available potassium	**S3** : Temperature **S2** : Slope, Rock Outcrops, Surface Rock, Effective depth
HORTICULTURAL FLOWER COMMODITIES			
Rose	• Bazartete • Liquiçá • Loes • Maubara	**N :** Slope **S3 :** Surface Rock, Rock Outcrops, Drainage, Erosion,	**S2** : Temperature, Surface Rock, Rock Outcrops

		S2 : Temperature, Total Nitrogen, Available potassium	
Aster	• Bazartete • Liquiçá • Loes • Maubara	**N :** Slope **S3 :** Surface Rock, Rock Outcrops, Drainage, Erosion **S2** : N-total	**S2** : Slope, Surface Rock, Rock Outcrops
Sunflower	• Bazartete • Liquiçá • Loes • Maubara	**N :** Slope **S3** : Surface Rock, Rock Outcrops, Drainage, Erosion, Rainfall **S2** : Total Nitrogen, Available potassium	**S2** : Slope, Surface Rock, Rock Outcrops
SPICE AND MEDICINAL COMMODITIES			
Ginger	• Bazartete • Liquiçá • Loes • Maubara	**N** : Rainfall, Dry month, Slope **S3** : Temperature, Erosion, Surface Rock **S2** : Drainage, Effective depth	**S3 :** Temperature, Dry month **S2 :** Rainfall, Slope, Surface Rock, Effective depth
Vetiver root Lemongrass	• Bazartete • Liquiçá • Loes • Maubara	**S3** : Drainage, Rainfall, Erosion, Slope, Rock Outcrops **S2** : Temperature, Surface Rock	**S2 :** Temperature, Surface Rock, Rock Outcrops
Vanilla	• Bazartete • Liquiçá • Loes • Maubara	**N** : Dry month **S3** : Drainage, Erosion, Slope, Rock Outcrops **S2** : Temperature, Effective depth, Surface Rock, N-Total, P_2O_5, K_2O	**S3 :** Dry month **S2 :** Temperature, Effective depth, Surface Rock
Candlenut	• Bazartete • Liquiçá • Loes • Maubara	**N** : Dry month, Erosion **S3** : Drainage, Slope, Rock Outcrops **S2** : Effective depth, Surface Rock	**S3 :** Dry month **S2 :** Erosion, Effective depth, Surface Rock, Rock Outcrops
Cinnamon	• Bazartete • Liquiçá • Loes	**N** : Dry month	**S3 :** Dry month **S2 :** Surface Rock, Effective depth, Rock Outcrops

	• Maubara	**S3** : Drainage, Erosion, Slope, Surface Rock, Rock Outcrops **S2** : Rainfall, Effective depth	
Nutmeg	• Bazartete • Liquiçá • Loes • Maubara	**N** : Rainfall, Dry month **S3** : Drainage **S2** : Temperature, Effective depth, Slope, Surface Rock, Rock Outcrops	**S3 :** Dry month **S2 :** Temperature, Rainfall, Effective depth, Surface Rock, Rock Outcrops
Pepper	• Bazartete • Liquiçá • Loes • Maubara	**N** : Dry month **S3** : Drainage, Erosion, Slope, Rock Outcrops **S2** : Rainfall, Surface Rock	**S3 :** Dry month **S2 :** Surface Rock, Rock Outcrops
Jatropha	• Bazartete • Liquiçá • Loes • Maubara	**S3** : Drainage, Erosion, Slope, Rock Outcrops **S2** : Rainfall, Surface Rock	**S2 :** Surface Rock, Rock Outcrops
Aromatic ginger	• Bazartete • Liquiçá • Loes • Maubara	**N** : Temperature, Drainage, Rainfall **S3** : Erosion, Surface Rock, Rock Outcrops **S2** : Effective depth, Slope, N-Total, Available Potassium	**N :** Temperature **S2 :** Drainage, Rainfall, Surface Rock, Rock Outcrops, Effective depth
Turmeric	• Bazartete • Liquiçá • Loes • Maubara	**N** : Slope **S3** : Erosion, Surface Rock **S2** : Temperature, Rainfall, Effective depth	**S2 :** Temperature, Effective depth Slope, Surface Rock
Galangal	• Bazartete • Liquiçá • Loes • Maubara	**N** : Slope **S3** : Erosion, Effective depth, Surface Rock, Rock Outcrops **S2** : Temperature, Drainage	**S2 :** Temperature, Slope, Effective depth, Surface Rock, Rock Outcrops
Cardamom	• Bazartete • Liquiçá • Loes • Maubara	**N** : Slope **S3** : Erosion, Effective depth, Surface Rock, Rock Outcrops **S2** : Drainage, Rainfall	**S2 :** Slope, Effective depth, Surface Rock, Rock Outcrops
Sesame	• Bazartete • Liquiçá	**N** : Dry month, Slope	**S3** : Dry month

	• Loes • Maubara	**S3** : Erosion, Effective depth, Rock Outcrops **S2** : Drainage	**S2 :** Slope, Effective depth, Rock Outcrops
INDUSTRIAL COMMODITIES			
Rubber	• Bazartete • Liquiçá • Maubara • Loes	**N :** Dry month **S3 :** Rainfall, Slope, Rock Outcrops, Total Nitrogen, P-Available, Available potassium **S2 :** Temperature, Drainage, Erosion, Effective depth, Surface Rock	**S3** : Dry month **S2** : Temperature, Rock Outcrops, Effective depth, Surface Rock
Coconut	• Bazartete • Liquiçá • Maubara • Loes	**N :** Dry month **S3 :** Slope, Rock Outcrops, Total Nitrogen, P-Available, Available potassium **S2 :** Temperature, Rainfall, Erosion, Effective depth, Surface Rock	**S3** : Dry month **S2** : Temperature, Rock Outcrops, Effective depth, Surface Rock
Oil Palm	• Bazartete • Liquiçá • Maubara • Loes	**N :** Dry month **S3 :** Slope, Rock Outcrops, Total Nitrogen, P-Available, Available potassium **S2 :** Temperature, Erosion, Effective depth, Surface Rock	**S3** : Dry month **S2** : Temperature, Rock Outcrops, Effective depth, Surface Rock
Arabica Coffee	• Bazartete • Liquiçá • Maubara • Loes	**N :** Dry month **S3 :** Temperature, Slope, Rock Outcrops , Total Nitrogen, P-Available, Available potassium **S2 :** Erosion, Effective depth, Surface Rock	**S3** : Dry month, Temperature **S2** : Rock Outcrops, Effective depth, Surface Rock
Robusta Coffea	• Bazartete • Liquiçá • Maubara • Loes	**N :** Dry month **S3 :** Slope, Rock Outcrops, Total Nitrogen, P-Available, Available potassium	**S3** : Dry month **S2** : Rock Outcrops, Effective depth, Surface Rock

		S2 : Drainage, Rainfall, Erosion, Effective depth, Surface Rock	
Cacao Clove	• Bazartete • Liquiçá • Maubara • Loes	**N :** Dry month **S3 :** Slope, Rock Outcrops, Total Nitrogen, P-Available, Available potassium **S2 :** Temperature, Erosion, Effective depth, Surface Rock	**S3** : Dry month **S2** : Temperature, Rock Outcrops, Effective depth, Surface Rock
Tea	• Bazartete • Liquiçá • Maubara • Loes	**N :** Dry month **S3 :** Temperature, Rainfall, Slope, Rock Outcrops, Total Nitrogen, P-Available, Available potassium **S2 :** Erosion, Effective depth, Surface Rock	**S3** : Dry month, Temperature **S2** : Rock Outcrops, Effective depth, Surface Rock
Tobacco	• Bazartete • Liquiçá • Maubara • Loes	**S3 :** Rainfall, Erosion, Slope, Rock Outcrops, Total Nitrogen, P-Available, Available potassium **S2:** Surface Rock	**S2** : Rock Outcrops, Surface Rock
Sugarcane	• Bazartete • Liquiçá • Maubara • Loes	**N :** Slope **S3 :** Erosion, Rock Outcrops, Total Nitrogen, P-Available, Available potassium **S2 :** Surface Rock	**S2** : Rock Outcrops, Surface Rock
Cashew	• Bazartete • Liquiçá • Maubara • Loes	**N** : Temperature, Dry month **S3 :** Slope, Rock Outcrops, Total Nitrogen, P-Available, Available potassium **S2 :** Drainage, Rainfall, Erosion, Effective depth, Surface Rock	**N** : Temperature **S2** : Rock Outcrops, Effective depth, Surface Rock
Melinjo	• Bazartete • Liquiçá • Maubara • Loes	**N :** Dry month **S3 :** Slope, Rock Outcrops, Total Nitrogen, P-Available, Available potassium	**S3** : Dry month **S2** : Temperature, Rock Outcrops, Surface Rock, Effective depth

		S2 : Temperature, Erosion, Effective depth, Surface Rock	
Cotton	• Bazartete • Liquiçá • Maubara • Loes	**S3** : Rainfall, Erosion, Slope, Rock Outcrops, Total Nitrogen, P-Available, Available potassium **S2**: Temperature, Surface Rock	**S2** : Temperature, Surface Rock, Rock Outcrops
Kapok	• Bazartete • Liquiçá • Maubara • Loes	**S3** : Rainfall, Slope, Rock Outcrops, Total Nitrogen, P-Available, Available potassium **S2** : Temperature, Erosion, Effective depth, Surface Rock	**S2** : Temperature, Surface Rock, Rock Outcrops, Effective depth
Quinine	• Bazartete • Liquiçá • Maubara • Loes	**S3** : Temperature, Slope, Rock Outcrops, Total Nitrogen, P-Available, Available potassium **S2** : Erosion, Effective depth, Surface Rock	**S3** : Temperature **S2** : Rock Outcrops, Surface Rock, Effective depth
LIVESTOCK GRAZING AREA AND FORAGE FEED COMMODITIES			
Elephantgrass Setaria	• Bazartete • Liquiçá • Loes • Maubara	**S3** : Rock Outcrops, Slope **S2** : Surface Rock, Drainage, Erosion, Base Saturation, pH, Total Nitrogen, P-Available, Available potassium	**S3** : Rock Outcrops **S2** : Surface Rock
Legumes	• Bazartete • Liquiçá • Loes • Maubara	**N**: Slope **S3** : Rock Outcrops, Erosion **S2** : Surface Rock, Drainage, Total Nitrogen, P-Available, Available potassium	**S3** : Rock Outcrops **S2** : Slope, Surface Rock
Grazing	• Bazartete • Liquiçá • Loes • Maubara	**N**: Dry month **S3** : Rock Outcrops, Slope **S2** : Erosion, Surface Rock, pH, Total Nitrogen, P-Available, Available potassium	**S3** : Dry month, Rock Outcrops **S2** : Surface Rock

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

7.4 LAND IMPROVEMENT MEASURES

Improvement efforts for each limiting factor are crucial to increasing the productivity and sustainability of the agricultural sector. Various constraints such as shallow effective soil depth, poor drainage, erosion hazards, and surface rock require appropriate solutions to maximize the land's potential. On the other hand, some soil chemical parameters, such as organic carbon (Soil Organic Carbon (SOC)) and nutrient content (N, P, K), which are relatively low in their current state, require land improvement efforts to enhance them into potential land for agricultural commodity development. Recommendations for improvement measures for each limiting factor, as a basis for implementing the enhancement of potential land suitability for developing agricultural commodities, livestock feed, and grazing areas, are presented in **Table 7.3**. The level of improvement from actual to potential land quality based on management levels is presented in **Table 7.4**, which is then used as a guideline for the transformation of current land suitability into potential suitability.

Table 7.3 Recommendations for Land Improvement Based on Limiting Factors.

No	Land quality/ Characteristics	Type of Land Improvement Efforts	Management Level
1.	**Temperature (tc)** Average Annual Temperature	Improvements Cannot Be Made Replacement with Suitable Varieties	Cannot Be Improved
2.	**Water Availability (wa)** - Rainfall/year - Rainfall During Growth Period	 Irrigation / construction of small reservoirs / drip irrigation Cropping pattern scheduling / planting calendar	 Medium, High
3.	**Root Capacity (rc)** - Drainage - Texture - Effective depth	 Drainage System Improvements, such as the Construction of Drainage Channels, Ridging/Bed Making Cannot Be Improved, can be mitigated by adding organic materials. Generally cannot be Improved, except in soft and thin hardpan	 Medium, High High Medium, High

	- Coarse Materials	layers by breaking them up during land preparation. Depends on the quantity and Distribution in the profile (if the amount is <35%, it is called. Obstructing layer / root growth restricting, which can be managed by adding organic materials and minimum tillage. If the amount is >90%, it is called Restricting Layer / root growth limiting, which is difficult to improve).	High
4.	**Nutrient Retention (nr)**		
	- CEC	Addition of Organic Materials	Medium, High
	- Base Saturation (BS)	Lime Application, Addition of Organic Materials	Medium, High
	- pH	Lime application is done when soil pH is low, while high pH can be corrected with sulfur or ZA fertilizer	Medium, High
	- Soil Organic Carbon (SOC)	Addition of organic materials / organic fertilizers, and returning litter to the soil	Medium, High
5.	**Nutrient Availability (na)**		
	- Total Nitrogen	Fertilization with N (urea and ZA)	Low, Medium, High
	- Available Phosphorus	Fertilization with P (SP36 and TSP)	Low, Medium, High
	- Available Potassium	Fertilization with K (KCl)	Low, Medium, High
		Compound Fertilizers (NPK)	
6.	**Erosion Hazard (eh)**		
	- Slope (%) - Erosion Hazard	Erosion Reduction: terracing, contour planting, planting cover crops, application of mulch/plant residues, implementation of agroforestry.	Medium, High

7.	**Flood Hazard (fh)** - Height - Duration	Construction of flood barriers, creation of drainage channels to accelerate water runoff, construction of infiltration wells	High
8.	**Land Preparation (lp)** - Surface Rock (%) - Rock Outcrops (%)	If the amount is small (remove rocks), if large/very large, implement TOT (No-Till), create planting holes, add organic material.	Medium, High
9.	**Technical Cultural Improvements**	Establishment of plantations, pruning, maintenance/care.	Medium, High

Description:

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

Table 7. 4 Level of Land Quality Improvement from Actual to Potential Based on Management Level.

No	Land Quality and Characteristics	Management Level		Type of Improvements
		Medium	High	
1	**Radiation Regime**	-	-	-
2	**Temperature Regime**	-	-	-
3	**Air Humidity Regime**	-	-	-
4	**Water Availability**			Crop Combination
	- Dry month	+	++	Irrigation
	- Rainfall	+	++	
5	**Root Capacity**			
	- Drainage	+	++	Drainage Channels*)
	- Texture	-	+	Addition of Organic Matter
	- Effective depth	-	+	Planting Hole Creation 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 (SOC)	+	++	
7	**Nutrient Availability**			
	- Total Nitrogen	+	++	Urea Fertilizer
	- Available Phosphorus	+	++	SP36 and TSP Fertilizer
	- Available Potassium	+	++	KCL Fertilizer
8	**Flood Hazard**			
	- Period	+	++	-
	- Frequency	+	++	-
9	**Salinity**			Irrigation and Addition of Organic Matter
	- Salinity	+	++	
10	**Toxycity**			Lime
	- Al Saturation	+	++	Regulating Groundwater Level
	- Depth of Pyrite	-	+	
11	**Ease of Cultivation**	-	+	Mechanization
12	**Terrain (land) Mechanization Potential**	-	+	Terracing
13	**Erosion Hazard**	+	++	Soil Conservation Efforts

Description:

- Not feasible for improvement

+ Improvement is possible and will result in a one-level increase (S3 to S2)

++ Improvement will result in a two-level increase (S3 to S1)

***)** Poor drainage can be improved to better drainage by creating drainage channels, but very fast drainage is difficult to change to moderate/good.

7.5 LAND USE GUIDELINES

The land use guidelines in this study are developed based on the results of the potential land suitability evaluation, after considering various possible improvement interventions. This analysis follows an approach that matches the characteristics of current land with the growth requirements of plants, as formulated in **Table 7.3** and **Table 7.4**. This process results in land use recommendations that not only reflect the existing biophysical conditions but also account for the potential improvements in suitability through management and land improvement actions. The land use directions for various agricultural commodities, forestry, and grazing or livestock forage crops are presented in **Table 7.5**.

The determination of recommended plant commodities is done carefully, based on technical criteria outlined in the land suitability evaluation document. This assessment involves several main limiting factors, including water availability, root medium characteristics, retention capacity and nutrient availability, erosion and flood risks, and the ease of land cultivation. Each of these factors is analyzed in terms of its potential for improvement, whether through mechanical, chemical, or biological approaches.

It is important to emphasize that even though the evaluation results show that certain commodities fall into the highly suitable (S1) land suitability class, this does not mean that the plants will automatically grow and develop optimally based solely on the physical conditions of the land. 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 and planting patterns that suit the local climate, and the application of adequate soil and water conservation techniques.

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

These guidelines are expected to serve as a strategic reference in planning the sustainable use of land resources, while considering productivity, efficiency, and environmental sustainability. Furthermore, this document is intended to support decision-making in determining the zoning for the development of leading commodities, both at the site level and within regional planning scales.

Table 7. 5 Land Use Recommendations (Development Guidelines) for Agricultural, Industrial, Horticultural, Spices, Medicinal, and Forestry Commodities in Liquiçá District.

	DISTRICT	SUB-DISTRICT	FOOD COMMODITY	DRYLAND AGRICULTURE (PLANTATION & HORTICULTURE)	FORESTRY	LIVESTOCK & GRAZING AREA
1	Liquiçá	Bazartete	DRYLAND FOOD CROPS S3 : Taro, Upland rice, Cassava , Corn, Sorghum S2 : Soybean, Mung bean, Peanut, Cowpea, Wheat	INDUSTRIAL S3 : Rubber, Coconut, Oil Palm ,Arabica Coffee, Robusta Coffee, Cacao, Clove, Tea, Melinjo, Quinine. S2 : Tobacco, Sugarcane, Cotton, Kapok FRUIT CROPS S2 : Papaya, Orange, Rambutan, Mango, Guava, Durian, Watermelon, Melon, Jackfruit, Soursop, Custard apple, Bread fruit, Snakefruit, Pineapple, Longan, Strawberry, Grapes. S3: Banana, Avocado, Passion Fruit VEGETABLES S2 : Shallot, Green beans, Broccoli, Chili, Bell pepper, Caisin, Snowpea, Cucumber, Eggplant, Bitter, Vegetable tomato, Cabbage, Longs Beans. FLOWERS S2 : Rose, Aster, Sunflower SPICES AND MEDICINAL PLANTS S2 : Sweet root, lemongrass, Jatropha , Turmeric, galangal, cardamom.	S3 : Albizia, leucaena, acacia, eucalyptus, Sandalwood S2 : Teak, Mahogany, Agathis, Gelam	S3 : Elephant Grass, Setaria, Legumes, Grazing.

				S3 : Ginger, vanilla, Candlenut, Nutmeg, Pepper, Cinnamon, Aromatic ginger.		
2	Liquiçá	Liquiçá	WETLAND FOOD CROPS **S1** : Irrigated Rice DRYLAND FOOD CROPS **S3** : Taro, Upland rice, Cassava , Corn, Sorghum **S2** : Soybean, Mung bean, Peanut, Cowpea, Wheat	INDUSTRIAL **S3** : Rubber, coconut, oil palm, Arabica coffea, robusta coffea, kakao, cengkeh, teh, melinjo, Quinine. **S2** : Tobacco, Sugarcane, Cotton, Kapok FRUIT CROPS **S2** : : Papaya, Orange, Rambutan, Mango, Guava, Durian, Watermelon, Melon, Jackfruit, Soursop, Custard apple, Bread fruit, Snakefruit, Pineapple, Longan, Strawberry, Grapes. **S3**: Banana, Avocado, Passion Fruit VEGETABLES **S2** : Shallot, Green beans, Broccoli, Chili, Bell pepper, Caisin, Snowpea, Cucumber, Eggplant, Bitter, Vegetable tomato, Cabbage, Longs Beans. FLOWERS **S2 :** Rose, Aster, Sunflower SPICES AND MEDICINAL PLANTS **S2** : Sweet root, lemongrass, Jatropha , Turmeric, galangal, cardamom. **S3** : Ginger, vanilla, Candlenut, Nutmeg, Pepper, Cinnamon, Aromatic ginger		**S3 :** Elephant Grass, Setaria, Legumes, Grazing.

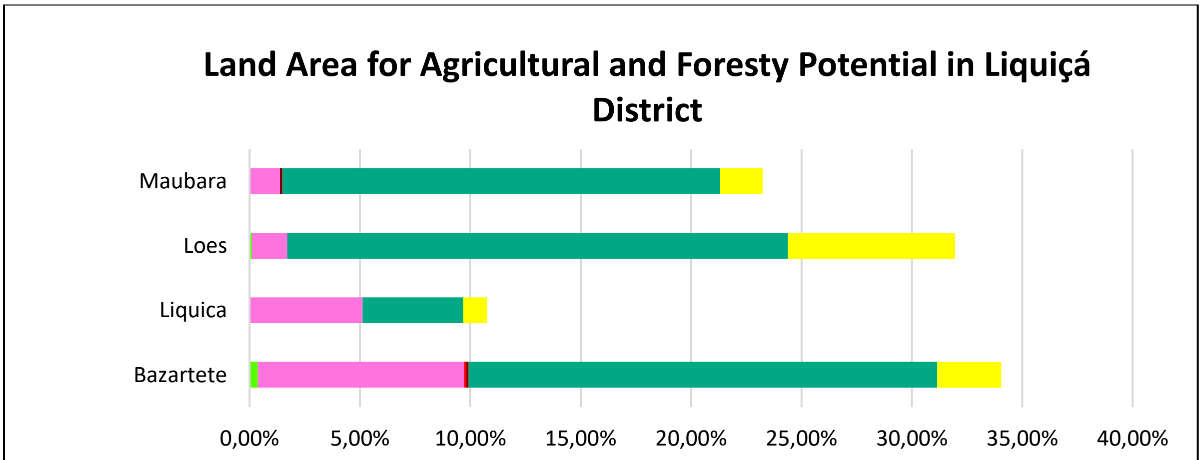
3	Liquiçá	Loes	WETLAND FOOD CROPS S1: Irrigated Rice DRYLAND FOOD CROPS S3 : Taro, Upland rice, Cassava , Corn, Sorghum S2 : Soybean, Mung bean, Peanut, Cowpea, Wheat	INDUSTRIAL S3 : Rubber, coconut, oil palm, Arabica coffea, robusta coffea, kakao, cengkeh, teh, melinjo, Quenine S2 : Tobacco, Sugarcane, Cotton, Kapok FRUIT CROPS S2 : : Papaya, Orange, Rambutan, Mango, Guava, Durian, Watermelon, Melon, Jackfruit, Soursop, Custard apple, Bread fruit, Snakefruit, Pineapple, Longan, Strawberry, Grapes. S3: Banana, Avocado, Passion Fruit VEGETABLES S2 : Shallot, Green beans, Broccoli, Chili, Bell pepper, Caisin, Snowpea, Cucumber, Eggplant, Bitter, Vegetable tomato, Cabbage, Longs Beans. FLOWERS S2 : Rose, Aster, Sunflower SPICES AND MEDICINAL PLANTS: S2 : Sweet root, lemongrass, Jatropha , Turmeric, galangal, cardamom. S3 : Ginger, vanilla, Candlenut, Nutmeg, Pepper, Cinnamon, Aromatic ginger.	S3 : Albizia, leucaena, acacia, eucalyptus, Sandalwood S2 : Teak, Mahogany, Agathis, Gelam	S3 : Elephant Grass, Setaria, Legumes, Grazing.

4	Liquiçá	Maubara	DRYLAND FOOD CROPS S3 : Taro, Upland rice, Cassava , Corn, Sorghum S2 : Soybean, Mung Bean, Peanut, Cowpea, Wheat	INDUSTRIAL S3 : Rubber, coconut, oil palm, Arabica coffea, robusta coffea, kakao, cengkeh, teh, melinjo, Quenine S2 : Tobacco, Sugarcane, Cotton, Kapok FRUIT CROPS S2 : Papaya, Orange, Rambutan, Mango, Guava, Durian, Watermelon, Melon, Jackfruit, Soursop, Custard apple, Bread fruit, Snakefruit, Pineapple, Longan, Strawberry, Grapes. S3: Banana, Avocado, Passion Fruit VEGETABLES S2 : Shallot, Green beans, Broccoli, Chili, Bell pepper, Caisin, Snowpea, Cucumber, Eggplant, Bitter, Vegetable tomato, Cabbage, Longs Beans. FLOWERS S2 : Rose, Aster, Sunflower SPICES AND MEDICINAL PLANTS: S2 : Sweet root, lemongrass, Jatropha , Turmeric, galangal, cardamom. S3 : Ginger, vanilla, Candlenut, Nutmeg, Pepper, Cinnamon, Aromatic ginger		S3 : Elephant Grass, Setaria, Legumes, Grazing.

7.6 ZONING FOR AGRICULTURAL DEVELOPMENT POTENTIAL

The research results indicate that Liquiçá District has significant resource potential to support the development of the agriculture and forestry sectors. To maximize this potential, a land suitability evaluation was conducted using a comprehensive scientific approach, which included field observations, laboratory testing of soil samples, and matching plant growth requirements with the region's agroclimatic maps. The results of this evaluation generated a scientifically-based zoning system to identify the potential for developing various strategic commodities. This zoning reflects the diversity of land utilization potential to support agriculture, forestry, and livestock sectors sustainably, contributing to food security, environmental protection, and improved community welfare. With structured and sustainable management efforts, the region's vast potential can be optimized through synergy between the government, policymakers, and local communities, ensuring that the benefits are felt by all parties.

Liquiçá District has land development potential divided into several main categories: rainfed rice fields covering 73.96 km² (13.47%), grazing areas covering 0.53 km² (0.10%), dryland farming or mixed orchards covering 95.92 km² (17.47%), agroforestry areas covering 2.62 km² (0.48%), mangrove forests covering 1.11 km² (0.20%), and protected and conservation forests covering 374.94 km² (68.28%), as shown in **Figure 7.1**. The spatial distribution of these zones is presented in **Figure 7.2**. This zoning reflects the diversity of land utilization potential to support agriculture and forestry sectors sustainably, contributing to food security, environmental protection, and enhanced community welfare.



	Bazartete	Liquica	Loes	Maubara
Agroforestry	0,37%	0,00%	0,11%	0,00%
Dryland Farming	9,36%	5,12%	1,61%	1,38%
Grazing Area	0,10%	0,00%	0,00%	0,00%
Mangrove Forest	0,09%	0,00%	0,00%	0,11%
Protected Forest	21,23%	4,55%	22,67%	19,84%
Rainfed Rice Fields	2,90%	1,09%	7,57%	1,91%

Figure 7.1 Land Area for Agricultural and Forestry Commodity Development in Liquiçá District.

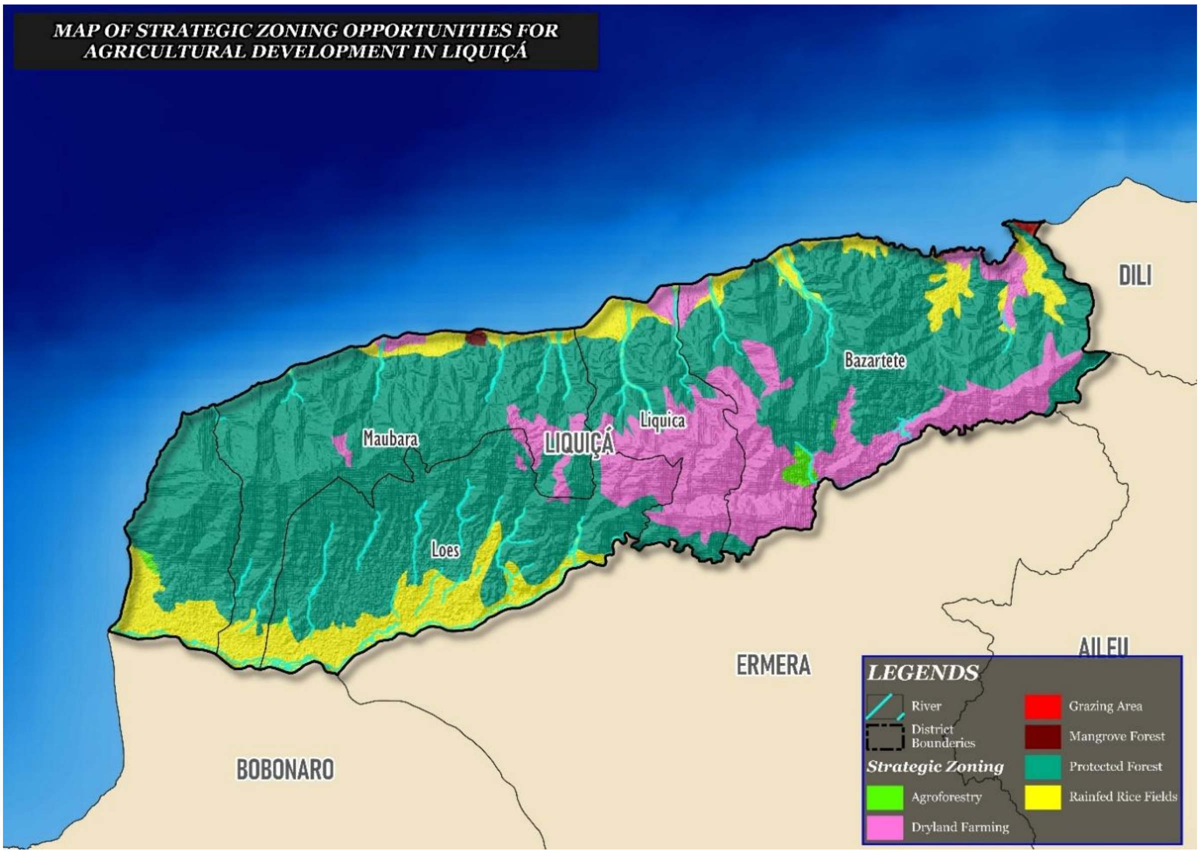


Figure 7.2 Spatial Distribution of Agricultural and Forestry Commodities in Liquiçá District.

A. Rainfed Rice Fields

The rainfed rice field zone in Munisípiu Liquiçá covers 73.96 km² or 13.47% of the total area, located at an elevation of 50–100 m above sea level with a slope gradient of 0–8%. The geological conditions are dominated by loose sedimentary lithology, ranging from clay to boulders, with soil types primarily consisting of Entisols and a monomodal agroclimatic regime. These characteristics result in limited productivity for the rainfed rice fields due to their dependence on rainfall, but the area still holds potential for development through the application of water conservation technologies and appropriate land management practices.

The key commodities that can be cultivated in this zone include cassava, corn, legumes, sorghum, and horticultural crops, which serve as sources of plant-based protein and contribute to local food diversification. With a management strategy based on balanced fertilization, the use of adaptive varieties, and crop rotation systems, this zone can be directed to enhance food security for the local population while reducing reliance on rice as the main staple food.

B. Dryland Agriculture (Mixed Orchards and Upland Farming)

The dryland agriculture zone in Munisípiu Liquiçá plays a crucial role, covering an area of 95.92 km² or about 17.47% of the total area. This zone is located at elevations ranging from 0-1000 m above sea level with a slope gradient of 0–40%, resulting in a variety of biophysical conditions. Geologically, the area is dominated by lithologies such as phyllite, schist, amphibolite, slate, and some volcanic rocks, with the primary soil type being Inceptisols. Agroclimatically, this zone falls within a monomodal regime, which affects planting patterns based on seasonal water availability. The commodities that can be developed in this zone include food crops, horticultural crops, spices and medicinal plants, and industrial crops.

However, the dryland agriculture zone in Munisípiu Liquiçá faces significant challenges that impact agricultural productivity. Several plantation and fruit crops, such as apples, fail to produce, mangosteen trees do not bear fruit, coffee production has declined, and many avocado and *rambutan* trees have died. These conditions indicate limitations in land suitability and environmental factors that affect cultivation success. Therefore, the focus for agricultural development in Liquiçá is directed more toward horticulture, food crops, and rice fields, which are considered more adaptable to the local dryland conditions.

C. Grazing Area

The grazing area in Liquiçá District is relatively small, covering 0.38 km^2 or about 0.10% of the total area. This zone is located at an elevation of 500–1000 m above sea level with a slope gradient of 8–20%, making it more suitable for grazing activities than for intensive agriculture. Geologically, this zone is dominated by lithologies such as phyllite, schist, amphibolite, slate, and some volcanic rocks, with the primary soil type being Inceptisols, which generally have moderate fertility. Agroclimatically, this area falls within a monomodal regime, which influences the availability of forage for livestock according to the rainy and dry seasons.

The main commodities in this grazing zone are elephant grass and gamal, which play an important role as high-quality forage. Elephant grass has high productivity, grows well on sloping land, and helps stabilize the soil against Erosion. Meanwhile, Gliricidia, a leguminous tree, not only provides forage with a good protein content for livestock but also enriches the soil through nitrogen fixation, thereby naturally improving soil fertility. With management based on rotational grazing, planting forage along contours, and integration with livestock, this area has the potential to increase livestock productivity while strengthening food security through the availability of animal protein and organic fertilizer for surrounding agriculture.

VIII. FORESTRY POTENTIAL

8.1 LAND SUITABILITY ASSESSMENT RESULTS

Land suitability analysis is a fundamental step in designing strategies for the sustainable management of land resources. This evaluation process is based on an integrated approach that includes the use of geospatial data, field observations, as well as physical and chemical soil analysis in the laboratory. This approach allows for the identification of the potential and limitations of the biophysical characteristics of the land for the development of various agricultural, horticultural, and forestry commodities.

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

Subsequently, the obtained data is analyzed based on the actual growth requirements of each crop type, as well as the potential suitability after various land improvement efforts, such as fertilization, organic matter addition, or the application of soil conservation techniques. This process produces comprehensive information for determining the priority of commodity development, identifying limiting factors, and designing relevant technical solutions.

The placement of several types of crops in the same column in Table 8.1 indicates that these crops have similar growth requirements and limiting factors. This means that they require similar environmental conditions to grow optimally and face relatively similar constraints in the cultivation process. Conversely, crops placed in different columns have distinct growth requirements and limiting factors, thus necessitating a management approach tailored to their individual needs. This approach forms the basis for the land suitability evaluation in Liquiçá 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 Bazartete Sub-District

Bazartete Sub-District has potential for forestry commodity development, classified as moderately suitable (S2) to marginally suitable (S3). Commodities classified as S2 include teak, mahogany, agathis, and Melaleuca, while those classified as S3 include Albizia, *lamtoro*, acacia, eucalyptus, and sandalwood. The main limiting factors for the development of forestry crops in Bazartete Sub-District include slope gradient, erosion, dry months, pH, total nitrogen, available phosphorus, available potassium and soil texture.

This area has good land suitability potential to support sustainable agriculture. However, commodities such as Altingia and pine are not recommended for cultivation due to permanent Temperaturee-related limiting factors that cannot be improved. **In addition to the crops already mentioned, Table 8.1 presents other plants that can be developed in Bazartete Sub-District**.

B. Land Suitability Evaluation of Loes Sub-District

Loes Sub-District has potential for the development of forestry commodities, classified as moderately suitable (S2) to marginally suitable (S3). Commodities classified as S2 include teak, mahogany, agathis, and gelam, while those classified as S3 include albizia, *lamtoro*, acacia, eucalyptus, and sandalwood. **The main limiting factors for the development of forestry crops in Loes Sub-District include several technical aspects, such as slope gradient, Erosionon, dry season, soil pH, total nitrogen, available phosphorus available potassium and soil texture.**

Given the existing potential, Loes Sub-District holds promise for the development of sustainable agriculture. However, some commodities, such as Altingia and pine, are less recommended for cultivation in this area due to the presence of permanent Temperaturee-related limitations that cannot be improved. **In addition to the crops already mentioned, Table 8.1 presents other plants that can be developed in Loes Sub-District.**

Table 8. 1 Land Suitability Evaluation Matrix for Forestry Crops in Liquiçá District

Commodity	Sub-district	Limiting Factors	Potential Land Suitability
Teak	• Bazartete • Loes	**N :** Dry month **S3:** Erosion, Slope, Rock outcrop, N, P, K **S2**: Temperature, drainase, Rainfall, Effective soil depths, Surface rocks	**S3** : Dry month **S2** : Temperature, Rock outcrop, Effective soil depths, Surface rocks
Mahogany	• Bazartete • Loes	**N :** Rainfall, Dry month **S3:** Erosion, Slope, Rock outcrop, N, P, K **S2** : Temperature, drainase, Effective soil depths, Surface rocks, Texture	**S3** : Dry month **S2** : Temperature, Rock outcrop, Effective soil depths, Surface rocks, Texture, Rainfall
Agathis	• Bazartete • Loes	**N :** Dry month **S3** : Rainfall, Erosion, Slope, Rock outcrop, N, P, K **S2** : Temperature, Effective soil depth, Surface rocks, Texture	**S3** : Dry month **S2** : Temperature, Rock outcrop, Surface rocks, Texture, Effective soil depth
Altingia	• Bazartete • Loes	**N :** Temperature, Dry month **S3** : Erosion, Slope, Rock outcrop, N, P, K **S2** : Rainfall, Effective soil depth, Surface rocks, Texture	**N** : Temperature **S3** : Dry month **S2** : Rock outcrop, Effective soil depth, Surface rocks, Texture
Albizia	• Bazartete • Loes	**N :** Rainfall, Dry month **S3**: Erosion, Slope, Rock outcrop, N, P, K **S2** : Effective soil depth, Surface rocks	**S3** : Dry month **S2** : Rock outcrop, Effective soil depth, Surface rocks, Rainfall
Leucaena	• Bazartete • Loes	**N :** Dry month	**S3** : Dry month

		S3 : Erosion, Slope, Rock outcrop, N, P, K S2 : Rainfall, Surface rocks, pH	S2 : Rock outcrop, Surface rocks
Acacia	• Bazartete • Loes	N : Dry month S3 : Erosion, Slope, Rock outcrop, N, P, K S2 : Surface rocks, pH, Texture	S3 : Dry month S2 : Rock outcrop, Surface rocks, texture
Melaleuca	• Bazartete • Loes	S3 : Drainase, Rock outcrop, N, P, K S2 : Surface rocks, pH	S2 : Rock outcrop, Surface rocks
Pine	• Bazartete • Loes	N:Temperature, Rainfall, Dry month S3 : Erosion, Slope, Rock outcrop, N, P, K S2 : Drainase, Surface rocks, Texture	N : Temperature S3 : Dry month S2 : Rock outcrop, Surface rocks, Texture, Rainfall
Sandalwood	• Bazartete • Loes	N : Rock outcrop S3 : Erosion, Slope, Surface rocks, N, P, K S2 : Rainfall, Coarse fragment, pH, C-organic	S3: Rock outcrop S2 : Surface rocks, Coarse fragment

8.2 LAND IMPROVEMENT MEASURES

Efforts to address each limiting factor are crucial for increasing productivity and ensuring the sustainability of the agricultural sector. However, these constraints are primarily technical and can be minimized through soil and water conservation techniques, such as adjusting planting patterns according to the seasons, treating the soil with sulfur or lime (dolomite), applying NPK fertilizers, and adding organic matter. **Furthermore, there are permanent limiting factors present in the region, such as temperature, rock outcrops, surface rocks, and effective soil depth.** While these factors cannot be fully eliminated, land management remains possible, such as by creating planting holes between rock outcrops and selectively removing surface rocks, which can support cultivation efficiency and productivity.

8.3 FOREST COMMODITY DEVELOPMENT ZONING

The forest zones in Liquiçá District are divided into three main categories: agroforestry zones, protected and conservation forest zones, and mangrove forest zones, each fulfilling complementary ecological and socio-economic functions. Of the total area of Liquiçá District, the agroforestry zone dominates, covering approximately 378.67 km² or 68.96%, reflecting the important role of integrated agriculture in supporting the livelihoods of the local community. The agroforestry system in this region typically combines plantation crops such as coffee, coconut, cocoa, and food crops with forest trees, thus improving land productivity while maintaining ecosystem balance. Meanwhile, the protected and conservation forests serve to protect water resources, prevent Erosion on, and preserve habitats for endemic flora and fauna, while the mangrove forests along the coast play a crucial role in preventing coastal erosion, absorbing carbon, and providing breeding grounds for marine life. Together, these three forest categories form a sustainable landscape system that not only supports environmental resilience but also strengthens the economic resilience of the community in Liquiçá District.

A. Agroforestry

The agroforestry area covers 2.62 km², or about 0.48% of the total land area, located at elevations between 500 and 1000 meters above sea level (m.a.s.l) with slope gradients ranging from 15 to 40%. Geologically, this region consists of Phyllite, Schist, Amphibolite, Slate, and some volcanic rocks, forming relatively complex land physical characteristics. The dominant soil type is Inceptisols, with a monomodal agroclimatic regime characterized by a single peak rainy season per year, which influences planting patterns and land productivity.

One of the main commodities developed within the agroforestry system in this region is coffee. Coffee cultivation is typically carried out using a multistrata system, where coffee plants grow under the shade of hardwood trees. This pattern provides significant ecological benefits, such as reducing Erosion on rates through the root systems of the shade trees, increasing soil moisture, and enriching organic matter content through leaf litter. Additionally, the multistrata system creates a more complex habitat, thus supporting biodiversity conservation. Economically, coffee holds a high market value, both domestically and internationally. This potential is further enhanced if managed according to environmentally friendly principles, as coffee produced through sustainable practices has the potential to command premium prices in the global market.

Farmer groups in Liquiçá District (**Figure 8.1**) have developed a coffee agroforestry system as a strategy to improve agricultural productivity and the economic well-being of the community sustainably. This system integrates coffee plants with various types of protective trees, fruit plants, and soil conservation plants to maintain soil fertility, reduce Erosionon, and create income diversification for farmers. With the support of local government and partner organizations, farmers have received training on sustainable coffee cultivation techniques and integrated agricultural ecosystem management. The implementation of coffee agroforestry has proven not only to enhance the quality and yield of harvests but also to strengthen the economic resilience of farmers' households while supporting green economic development in Liquiçá District.

Figure 8.1 Farmers Group in Liquiçá District.
(Source*:* Research Documentation, 2025)

From an agroclimatic suitability perspective, both Coffee arabica and Coffee canephora (robusta) can be developed with S3 (marginally suitable) land suitability in Bazartete, Liquiçá, Maubara, and Loes Districts. Coffee arabica generally requires highland conditions with cooler temperatures to grow optimally, with temperature being the limiting factor. Coffee canephora (robusta) has a higher tolerance for hot temperatures, is more adaptive to local agroclimatic conditions, and is relatively more resistant to pest and disease attacks. While Coffee arabica grows optimally in highland conditions with lower temperatures, Coffee canephora tends to thrive in mid to lowland areas with higher temperatures compared to Coffee arabica. This species has better resilience to climate variations, particularly heat and high humidity. Additionally, Coffee canephora is more adaptable to various local agroclimatic conditions and has stronger resistance to pests and diseases, such as leaf rust and root nematodes. With proper management, the development of robusta coffee in agroforestry systems has the potential to achieve more stable productivity, while enhancing the competitiveness of Liquiçá coffee in both domestic and international markets.

Thus, the availability of extensive agroforestry land, supportive agroclimatic conditions for robusta, and local traditions in coffee cultivation are vital assets for positioning this commodity as a key driver of the local economy. A targeted development strategy will ensure that robusta coffee from Liquiçá not only serves as a regional flagship product but also symbolizes the integration of economic productivity, environmental conservation, and social empowerment.

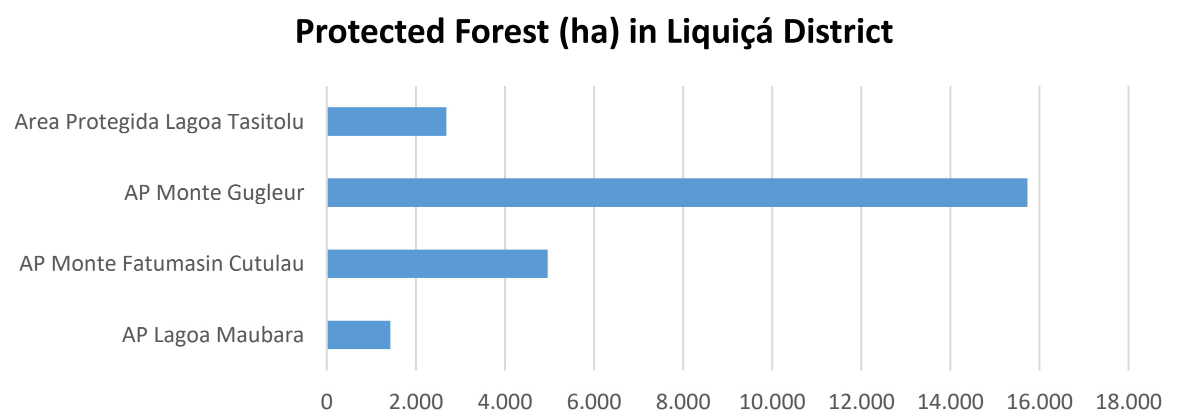
B. Protected and Conservation Forests

The protected and conservation forest areas cover the largest area, approximately 374.94 km^2, or 68.28% of the total land area, thus playing a crucial role in supporting ecological and environmental functions. These forests are vital in maintaining the region's hydrological balance by regulating the water cycle through the natural absorption, storage, and release of groundwater. Additionally, this area serves as an important habitat for various species of endemic flora and fauna, contributing significantly to biodiversity conservation.

Ecologically, the existence of protected and conservation forests functions as an effective carbon sink in climate change mitigation and helps reduce the risks of land degradation, such as erosion, landslides, and droughts. From a socio-economic perspective, this area also provides indirect benefits to the surrounding communities through environmental services, such as protection of water catchment areas, air pollutant absorption, and microclimate stabilization.

Therefore, the sustainable management of protected and conservation forests is a key factor in maintaining the balance between environmental conservation and regional development sustainability.

Administratively, the protected forest areas in Liquiçá District consist of several designated conservation areas (Area Protegida, AP), including AP Lagoa Tasitolu, AP Monte Gugleur, AP Monte Fatumasin Cutulau, and AP Lagoa Maubara. These four areas play a crucial role in preserving ecosystems, protecting biodiversity, and maintaining the region's hydrological functions. In addition to serving as conservation areas, these protected forests also hold potential for sustainable development activities such as agroforestry, ecotourism, and the utilization of non-timber forest products, thereby providing economic benefits to the local community without diminishing their ecological value and protective functions. The protected forest areas of Liquiçá District are shown in **Figure 8.2.**



	AP Lagoa Maubara	AP Monte Fatumasin Cutulau	AP Monte Gugleur	Area Protegida Lagoa Tasitolu
Liquica	1424,761904	4959,096184	15732,78993	2681,252834

Figure 8.2 Protected Forest Areas in Liquiçá District.

C. Mangrove Forest

The mangrove forest area covers 1.11 km², or approximately 0.20% of the total area, and is generally distributed along the coastal zone. This forest has a critical ecological function, particularly in protecting the coastline from erosion and seawater intrusion through the role of the strong mangrove roots in absorbing wave energy and stabilizing beach sediments. Additionally, the mangrove ecosystem serves as an essential habitat for various coastal species, making it one of the most biodiverse areas in the coastal region.

Ecologically and economically, mangrove forests also support the sustainability of fisheries ecosystems by providing spawning, nursery, and feeding grounds for various fish species and other marine life with high economic value. Furthermore, the mangrove ecosystem contributes significantly to blue carbon sequestration, helping mitigate global climate change and enhancing coastal resilience against natural disasters such as storms and tidal surges. Therefore, the preservation and rehabilitation of mangrove forests are crucial strategies for maintaining the balance of coastal ecosystems, supporting the sustainability of fisheries resources, and improving the well-being of coastal communities.

8.4 SANDALWOOD DEVELOPMENT POTENTIAL

Sandalwood (*Santalum album* L.) is a highly valuable tree species that plays an important role ecologically, economically, and culturally. Sandalwood is known for its high-quality essential oil, which is widely used in the perfume, cosmetics, and pharmaceutical industries, as well as having symbolic significance in various traditions and cultures in Asia, including in Timor-Leste. In addition, its wood and oil are also used to create crafts, carvings, and high-value art products, making sandalwood a commodity with high market value and sustainable market prospects.

Based on the land suitability evaluation, the potential for sandalwood development in Liquiçá is classified as S3 (marginally suitable), which can be developed in Bazartete and Loes Sub-Districts. This classification indicates that the 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 do not pose an obstacle to making sandalwood a regional flagship commodity.

Additionally, the government of Timor-Leste has begun a sandalwood tree inventory program as a strategic step to secure investments and ensure the sustainability of this resource's management. The program aims to document the number, distribution, and condition of sandalwood trees in various regions, including Liquiçá, providing a data-driven foundation for more targeted development planning. Therefore, the development of sandalwood in Liquiçá District has significant potential. If managed sustainably, sandalwood will not only serve as a source of income for the community but also as a symbol of cultural identity and successful local resource conservation.

IX. LIVESTOCK POTENTIAL

9.1 INTRODUCTION

Timor-Leste is a country predominantly characterized by mountains and highlands. Administratively, Timor-Leste is divided into 14 Districts: Ainaro, Aileu, Autoridade Administrativa Atauro Bobonaro, Baucau, Covalima, Dili, Ermera, Lautém, Liquiçá, Manufahi, Manatuto, Região Administrativa Especial Oe-Cusse Ambeno (RAEOA), and Viqueque. The country experiences two distinct seasons, the dry season from June to November, and the rainy season from December to May. The predominantly hilly topography, combined with its proximity to the Australian continent, causes Timor-Leste to be influenced by the dry east monsoon winds. As a result, many areas tend to experience drought. Additionally, the low rainfall impacts the growth of vegetation in many regions.

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

Forage for livestock can come from both natural sources and cultivation, including from grazing lands (Priyanto, 2016). The optimal use of livestock land is heavily influenced by anthropogenic factors and the biophysical conditions of the land. Therefore, the application of various technological innovations and institutional approaches is necessary to ensure that land resources are used effectively and optimally (Suryana and Rahman, 2006).

Overall, the livestock sector in Timor-Leste faces various challenges. One of the main reasons is the traditional and extensive livestock management system, which has not yet optimized production. Low awareness, knowledge, and technological expertise among farmers also hinder the sector, especially regarding the provision of adequate and high-quality forage. Livestock is generally kept as household savings, to be sold in emergencies, and in some communities, livestock is still used as draft power for land cultivation under traditional management systems.

The success of livestock enterprises depends on three main factors: breeding stock, feed, and management (Aman *et al.*, 2019). These three factors form an interconnected system, if one is neglected or insufficiently addressed, the effective management of the other factors, no matter how good, will not lead to optimal outputs. Livestock productivity, particularly for ruminants, heavily depends on effective feed management in terms of quantity, quality, and sustainable 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 livestock forage is influenced by factors such as forage variety, genotype, harvest maturity, season, and the applied management practices (Adesogan *et al*., 2015).

One of the initial steps in the development of the livestock sector in Timor-Leste is optimizing land use for sustainable forage production. To optimize land use, it is necessary to align the land characteristics with the types of forage that will be cultivated. Therefore, land suitability evaluation becomes an essential approach in assessing the potential and carrying capacity of land resources (Harahap *et al*., 2019). This evaluation not only assesses the land's potential but also determines its suitability for various uses based on the level of management applied (Nugroho *et al*., 2014). Land suitability evaluation requires environmental and soil quality data for a specific area. This assessment is carried out by identifying various land characteristics, such as topography, climate, soil condition and quality, and other physical environmental properties (Iswan *et al.*, 2019). Through this evaluation process, information is obtained regarding the biophysical resources of the land, including climate and soil, allowing for the determination of land suitability classes and the identification of limiting factors that need to be improved (Jawang *et al*., 2018).

9.2 RESEARCH METHODS

The research was conducted using survey and descriptive analysis methods in the study area selected purposively, namely the KTS Center (*Karau Timor Susubeen)* and the recommended livestock land. The types of data collected included both quantitative and qualitative data sourced from primary and secondary data. Primary data consisted of interview results covering livestock production and socio-economic aspects, as well as biophysical land observations and soil characteristics for forage land suitability. The biophysical and soil properties were further analyzed according to laboratory standards. The secondary data used were from the 2019 Timor-Leste agricultural census.

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

A. Research Procedure

1. Observation of Livestock Production and Socio-Economic Aspects

Observations were made using interviews with the following parameters:

- Livestock types
- Livestock population
- Land area
- Maintenance/pen system
- Feed and nutrition management system
- Water source
- Breeding system
- Livestock health management system
- Livestock products
- Marketing
- Infrastructure
- Farmer characteristics
- Customs/traditions

2. Forage Land Suitability

The procedure for researching forage land suitability has been described in Chapter III (Research Methods).

9.3 GENERAL OVERVIEW

A. Existing Conditions Globally

The livestock sector plays a crucial role in supporting the livelihoods of many households in Liquiçá District. The distribution of households engaged in livestock farming shows a significant difference across each Sub-District. Maubara Sub-District has the largest number of households involved in livestock farming, with 421 households (43.45%). In contrast, Liquiçá Sub-District has the fewest households engaged in livestock farming, with 260 households (26.83%).

Nevertheless, their contribution remains important in fulfilling local needs while preserving the livestock traditions that have become an integral part of local life. With these differences, each Sub-District contributes to the sustainability of the livestock sector in Liquiçá district. The number of agricultural households involved in livestock farming is presented in **Figure 9.1**.

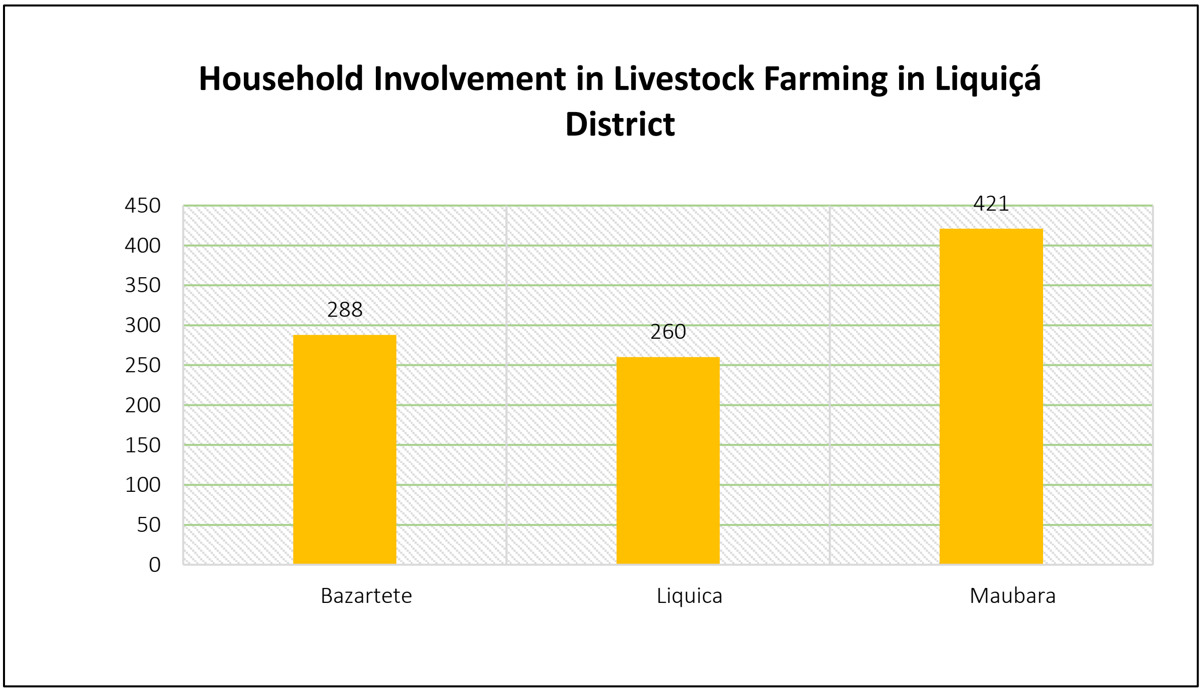


Figure 9.1 Number of Households Engaged in Livestock Farming
(Source: Timor-Leste Agriculture Census, 2019)

Figure 9.2 and **Figure 9.3** show that the majority of livestock farming in Liquiçá District consists of cattle farming. Maubara Sub-District has the highest number of cattle-keeping households, with 1,754 households (42.34%) and a total cattle population of 6,879 head. In contrast, Liquiçá Sub-District has the smallest number of cattle-keeping households, with 1,099 households (26.53%) and a total of 2,446 head.

For large livestock, such as horses, Maubara Sub-District also has the highest number of horse-keeping households, with 60 households (46.15%) and a population of 98 horses. On the other hand, the fewest households keeping horses are found in Liquiçá Sub-District, with 29 households (22.31%) and a population of 38 horses.

For buffalo, Bazartete Sub-District dominates with 727 households (14.90%) and a population of 1,359 buffalo. In contrast, the fewest buffalo-keeping households are found in Liquiçá Sub-District, with 50 households (5.48%) and a population of 111 buffalo. Notably, no dairy cattle households were reported in any of the Sub-Districts.

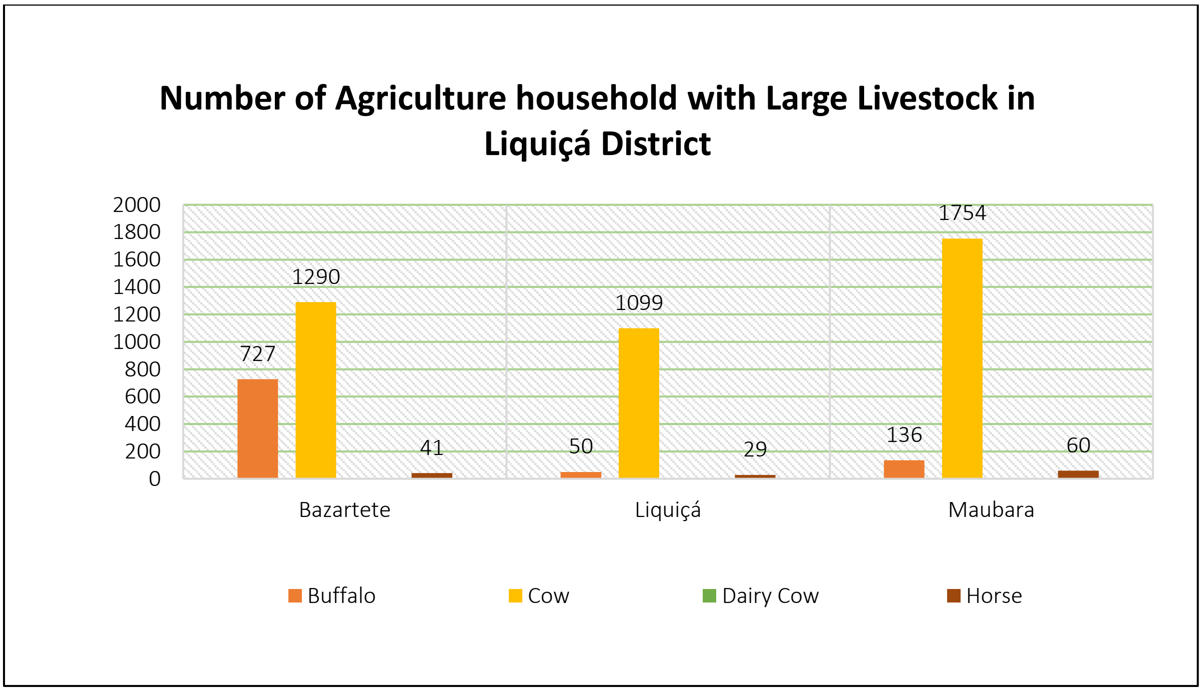


Figure 9.2 Number of Households with Large Livestock
(Source: Timor-Leste Agriculture Census, 2019)

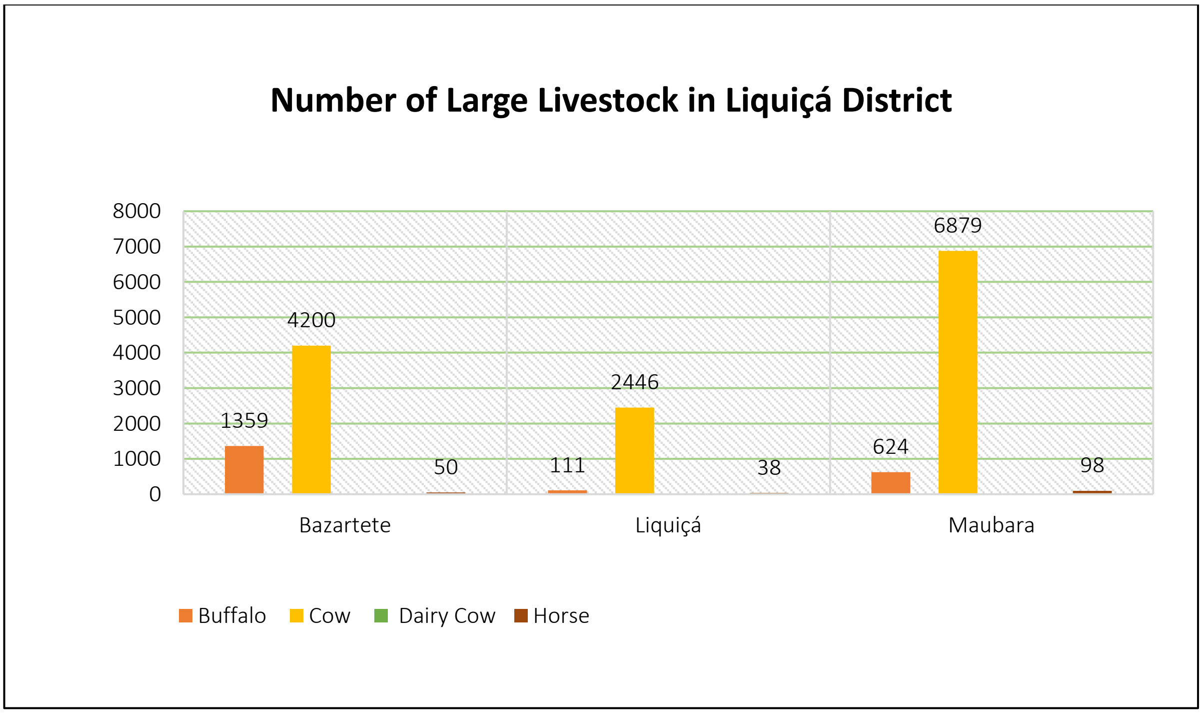


Figure 9.3 Number of Large Livestock
(Source: Timor-Leste Agriculture Census, 2019)

Liquiçá District has small livestock, particularly pigs, as the most widely kept livestock. Bazartete Sub-District has the highest number of pig-keeping households, with 3,045 households (37.07%) and a pig population of 10,872. The lowest number of pig-keeping households is found in Liquiçá Sub-District, with 2,262 households (27.53%) and 6,473 pigs.

The number of households keeping goats shows more variation, with Maubara Sub-District having the highest number of goat-keeping households, reaching 2,227 households (43.75%) and 9,450 goats, while the fewest goat-keeping households are in Liquiçá Sub-District, with 1,156 households (22.71%) and 3,954 goats.

Rabbits are also raised, but in smaller numbers. Bazartete Sub-District has 3 households (60%) keeping rabbits, with the smallest number in Maubara Sub-District, where only 2 households (40%) keep rabbits. No rabbit farming was reported in Liquiçá Sub-District.

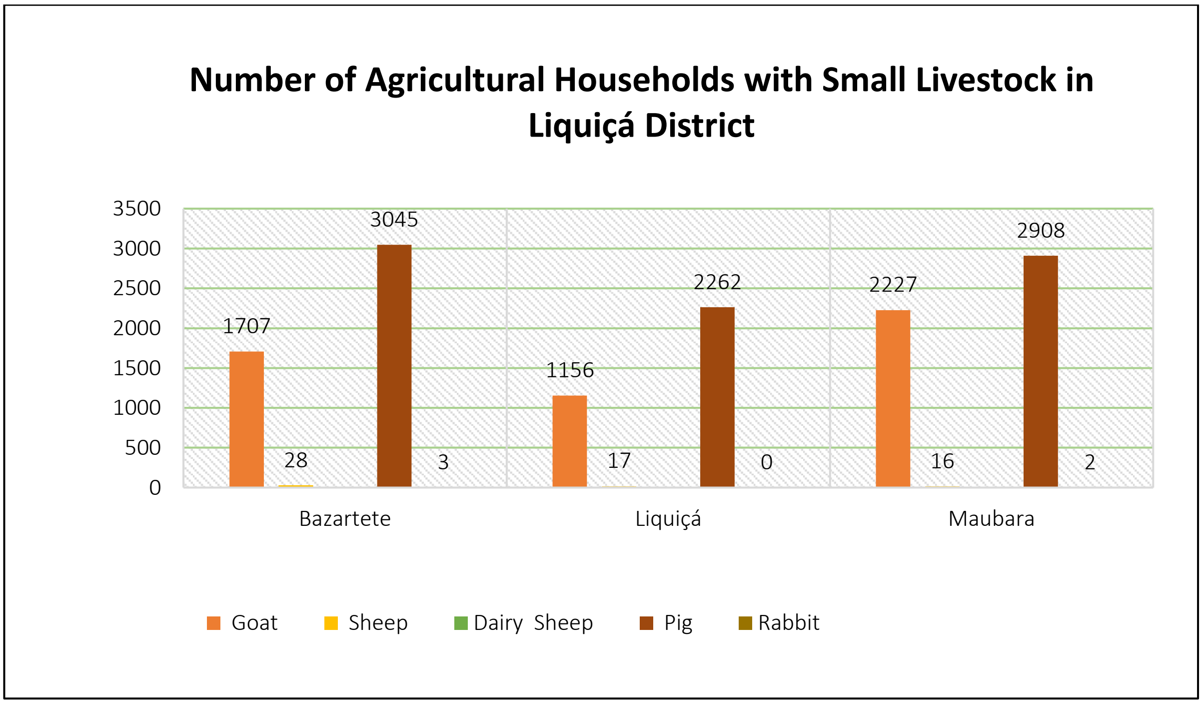


Figure 9.4 Number of Households with Small Livestock
(Source: Timor-Leste Agriculture Census, 2019)

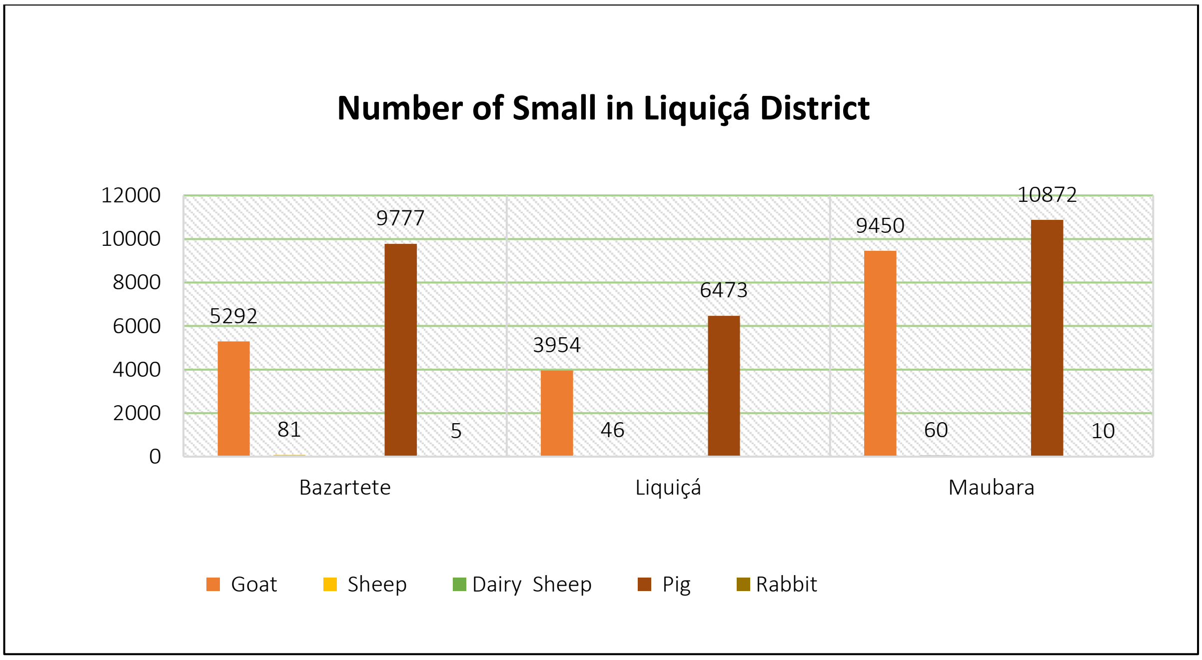


Figure 9.5 Number of Small Livestock
(Source: Timor-Leste Agriculture Census, 2019)

The number of households keeping poultry in Liquiçá District shows significant differences between Sub-Districts, with chickens being the most commonly raised type of poultry (**Figure 9.6**). Bazartete Sub-District has the highest number of poultry-keeping households, with 3,282 households, or approximately 39.72%, keeping 34,655 chickens. Meanwhile, Liquiçá Sub-District has the fewest poultry-keeping households, with 2,248 households (27.21%) keeping 4,408 chickens (**Figures 9.6 and 9.7**).

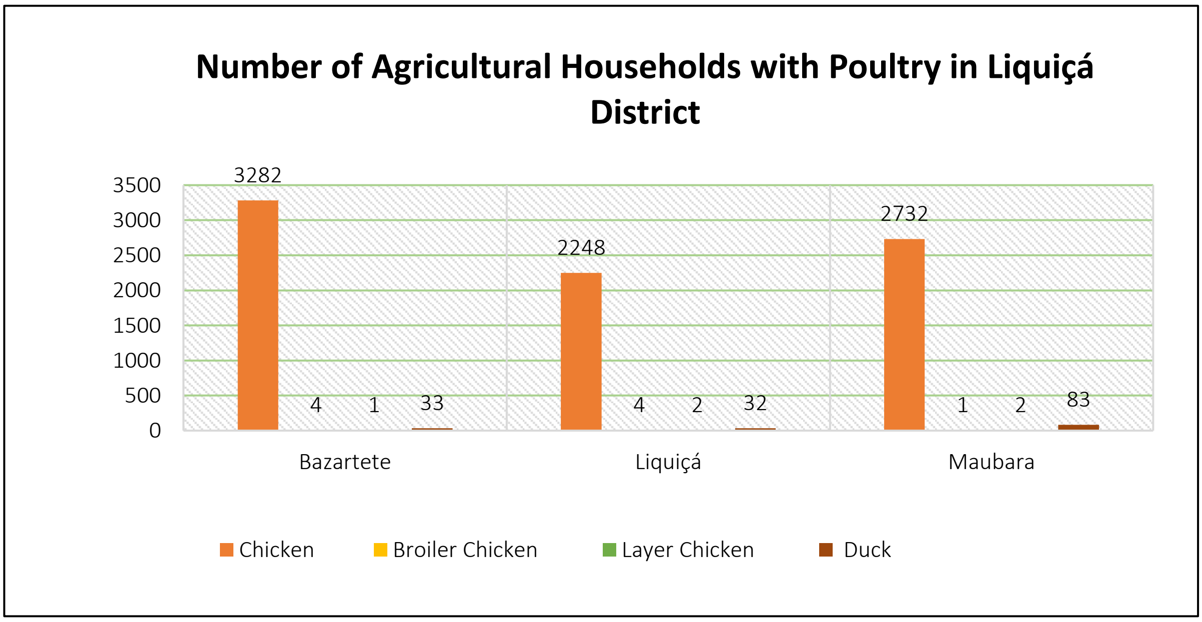


Figure 9.6 Number of Households with Poultry
*(***Source***: Timor-Leste Agriculture Census, 2019)*

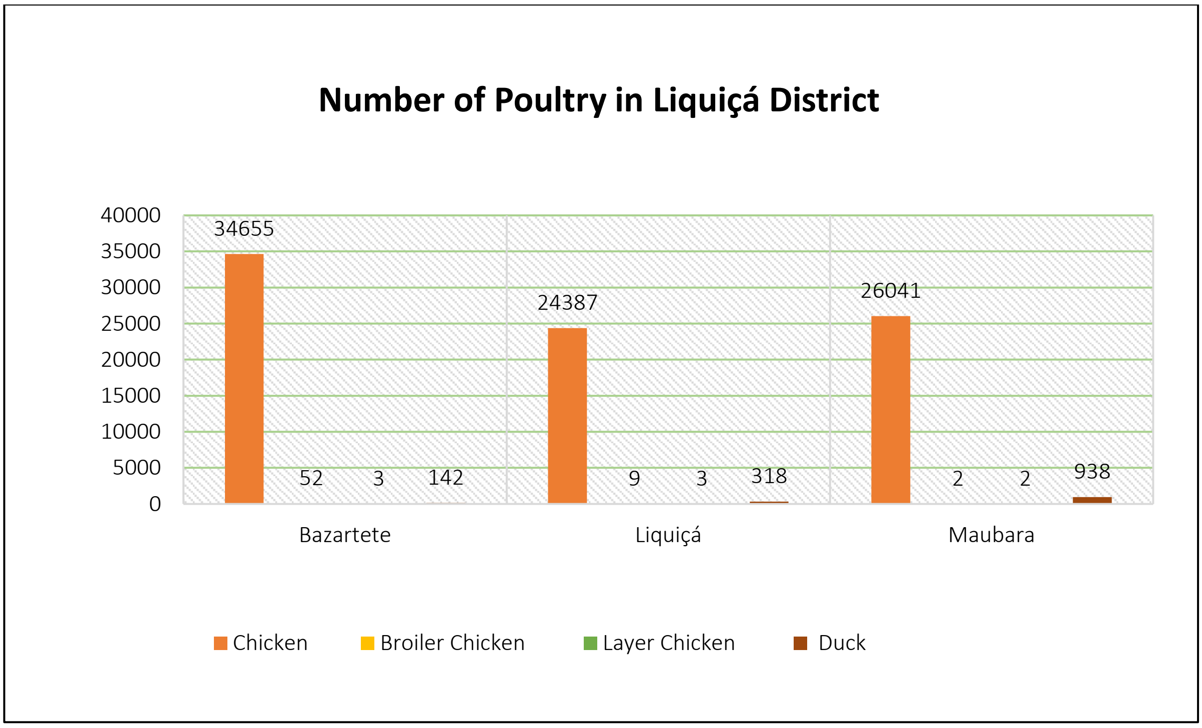


Figure 9.7 Number of Poultry
(Source: Timor-Leste Agriculture Census, 2019)

The potential of grazing land is one of the important assets that can serve as a primary source of livestock feed, particularly for animals such as cattle, goats, and sheep, which require high-quality grass to support growth and production in sustainable livestock farming. Liquiçá District has two types of grazing lands, temporary and permanent grazing lands.

The size of the grazing land area in Liquiçá District varies across Sub-Districts. Liquiçá Sub-District has the largest permanent grazing land area, covering 132.30 ha (95.52%), followed by Maubara Sub-District with 4.52 ha (3.27%), and Bazartete Sub-District with the smallest permanent grazing area of 1.68 ha (1.22%). For temporary grazing land, Bazartete Sub-District shows the highest area, with 123.91 ha (62.18%), followed by Liquiçá and Maubara with 68.93 ha (34.59%) and 6.45 ha (3.24%), respectively. The grazing land areas are presented in **Figure 9.8.**

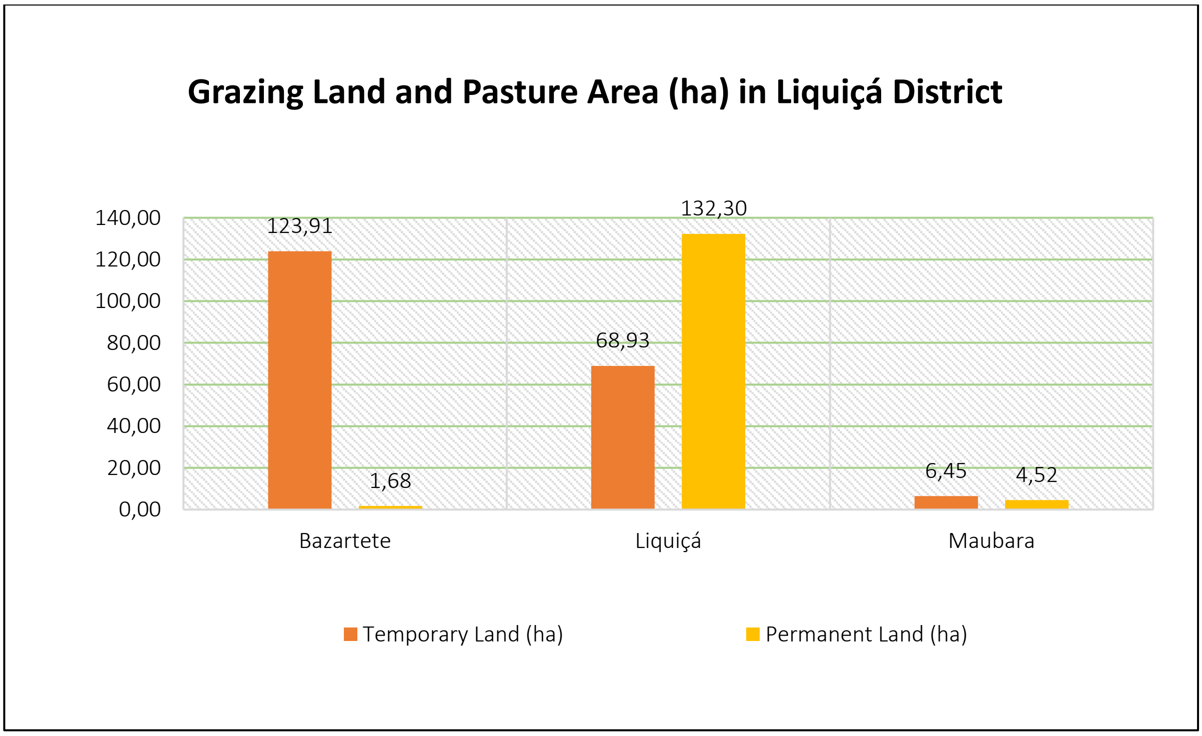


Figure 9.8 Grazing Land Area
(Source: Timor-Leste Agriculture Census, 2019)

B. Existing Survey Location Conditions

Observations were conducted at two locations, Batubora and Lisadila. In Batubora, 3 ha area has been prepared for pig breeding. Although the land was still vacant during the observation, initial infrastructure such as fencing had already been built as part of the preparation. Meanwhile, in Lisadila, there is an intensive livestock unit owned by a veteran member, where bali cattle and goats are raised. The total area is 36 ha, with around 13 ha already utilized for the construction of livestock pens, training facilities, and the cultivation of forage crops (HPT). The types of forage crops that have been cultivated at this site include *Lamtoro taramba*, *Gamal*, and several varieties of grass, all of which are showing good growth and adaptability to local conditions.

Figure 9.9 Existing Conditions at the Survey Location in Liquiçá
(Source: Researcher's Documentation, 2025)

9.4 DISCUSSION

A. Forage Land Suitability Evaluation (HPT)

Land suitability analysis for livestock forage in Liquiçá District is a method used to evaluate the suitability of land for growing various types of forage plants and grasses on grazing lands in a specific area. The purpose of this analysis is 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 to which a piece of land is suitable for a specific use. Land suitability can be assessed based on current conditions (actual land suitability) or after improvements have been made (potential land suitability). In Timor-Leste, land suitability evaluation is carried out using a matching method, where land characteristics and quality data are compared with suitability criteria based on the growth requirements of the evaluated crops. Several forage crops that were mapped in accordance with land resource potential include elephant grass (*Pennisetum purpureum*), leguminous plants, and field grasses.

The results of the land suitability evaluation in Liquiçá District show potential for the development of livestock forage crops, including elephant grass, setaria, legumes, and grazing land, as presented in **Table 7.3** of this report. According to the table, land for grazing varies in suitability from S2 (moderately suitable) to N (not suitable), with limiting factors such as rainfall, drainage, total nitrogen (N-total), available phosphorus (P), available potassium (K), pH, slope, erosion, and surface rocks. Additionally, there are limiting factors such as the dry season for grazing areas. These factors can still be improved through technical interventions, such as adjusting planting patterns, creating and improving drainage, adding NPK fertilizers, adding organic matter, planting terrace-strengthening plants, creating terraces, setting up irrigation systems like sprinklers, and clearing land. However, there are permanent limiting factors such as surface rock outcrops, which cannot be mitigated.

Several important steps need to be taken to improve the quantity and quality of forage, including:

1. **Planting Leguminous Forage**

   Planting leguminous forage should be prioritized, as leguminous plants generally have higher nutritional content compared to grasses. However, because legumes have limitations in their usage, attention must be given to the proportion of legumes relative to grasses. As a reference, Susetyo (1980) recommended that the ideal composition for grazing land should consist of 60% grasses and 40% legumes. Additionally, according to Skerman (1977), leguminous plants help combat erosion, even more effectively than forests, due to their strong and deep root systems.

2. **Increasing Forage Species Diversity, Both Leguminous and Grass Types**

   Increasing the diversity of forage species, both legumes and grasses, is a crucial aspect of livestock feed development. The higher the diversity of forage species consumed by livestock, especially ruminants, the greater the likelihood of meeting their complete nutritional needs. Several legume species with high nutritional content that have potential for development include *Indigofera*, *Kaliandra*, *Turi*, and *Stylo*. A commonly found local legume species is *Lamtoro taramba*. It is important to note that the feeding of *Lamtoro* to pregnant livestock should be done with caution. Although it contains high nutritional value, *Lamtoro* leaves contain anti-nutritional substances such as mimosine and cyanide acid, which can be toxic if consumed in excess. This can be mitigated by providing *Lamtoro* in moderate amounts, mixed with other feeds, and ensuring it is wilting (air-dried), which reduces the anti-nutritional substance content.

B. Livestock Ecological Potential and Suitability

Liquiçá District has a total area of 54,865.90 ha, with 39,341.18 ha allocated for livestock sector development. This potential must be optimized through human resource empowerment and effective land use. One important factor in determining the potential of an area for livestock development is the environmental suitability or ecological condition of the region. Areas that do not meet the ecological suitability indicators are categorized as less potential for livestock development. Therefore, the development of livestock enterprises in Liquiçá District must consider ecological suitability aspect

After obtaining measurements from each field parameter, such as geophysical parameters like rainfall and temperature, and soil chemical parameters such as organic carbon, total potassium (K-total), available potassium (K-available), cation exchange capacity (CEC), base saturation (KB), the data is analyzed using a Geographic Information System (GIS) application to determine the ecological suitability of five types of livestock: sheep, beef cattle, dairy cattle, pigs, and buffalo. The ecological land suitability for livestock in Liquiçá District can be seen in **Figure 9.10.**

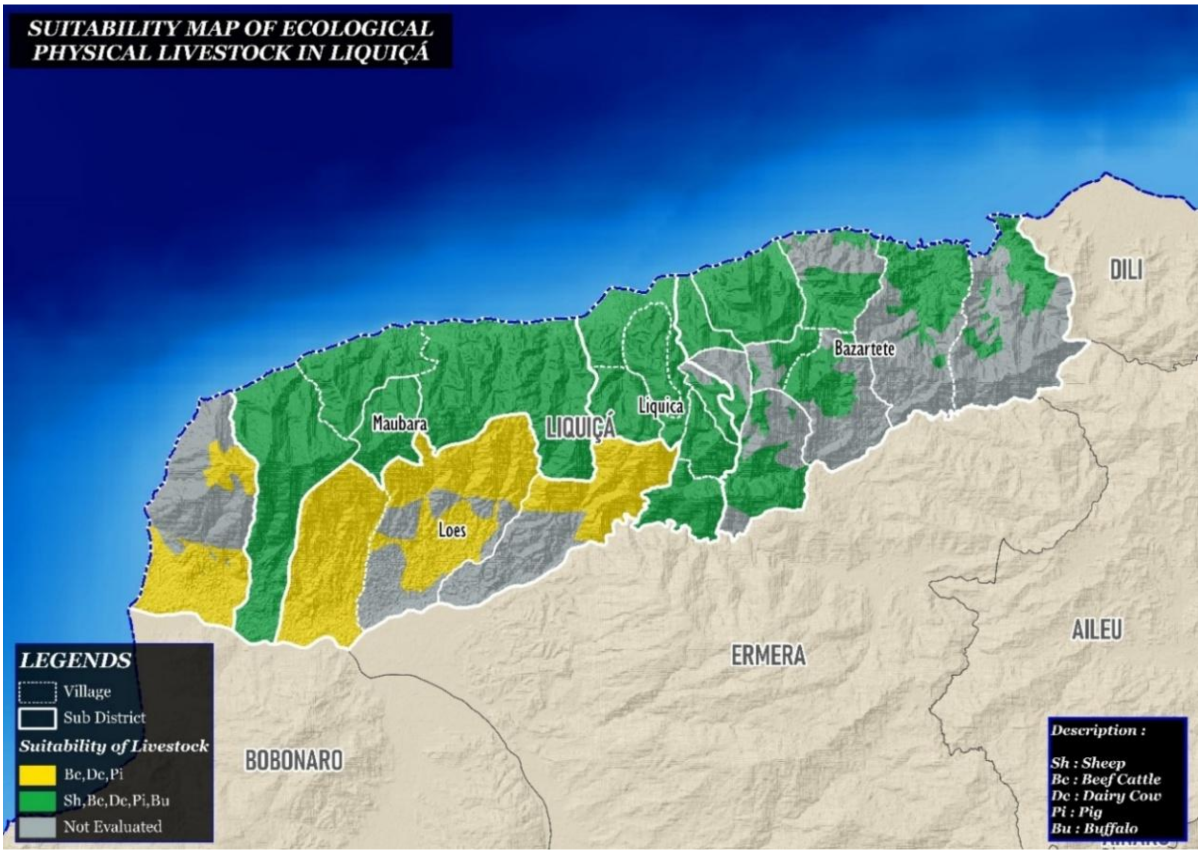


Figure 9.10 Ecological Physical Suitability Map for Livestock in Liquiçá District

The land available for livestock development in Liquiçá District includes areas designated for mixed gardens and grazing land. These lands are categorized as available because they are assumed to be capable of producing livestock forage in the form of grasses, legumes, and crop residues. On the other hand, land designated for purposes such as forests and rice fields is categorized as unavailable for livestock development. From a technical perspective, this can be addressed by ensuring that livestock pens have proper air circulation and ventilation systems. However, for dairy cattle, temperature is a critical factor that must be met for successful cultivation.

Table 9.1 Livestock Development Area in Liquiçá District

Sub-district	Livestock development suitability results					Area(ha)
	Sheep	Beef cattle	Dairy cow	Pig	Buffalo	
Liquiçá	S	S	S	S	S	5.803,17
Bazartete	S	S	S	S	S	9.353,11
Loes	N	S	S	S	N	11.434
Maubara	S	S	S	S	S	12.750,90

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 varied spatial distribution across the study area. Maubara Sub-District is the most dominant area for large livestock development in Liquiçá District, followed by Loes and Bazartete Sub-Districts. In contrast, Liquiçá Sub-District has the smallest area for livestock development.

Liquiçá, Bazartete, and Maubara Sub-Districts are suitable for the development of sheep, beef cattle, dairy cattle, pigs, and buffalo. Meanwhile, Loes Sub-District is suitable for beef cattle, dairy cattle, and pigs, but not suitable for sheep and buffalo due to temperature-related limiting factors.

The ecological suitability of land for poultry farming in the study area shows very high and uniform suitability, with coverage reaching 100%. This reflects the biological characteristics of poultry, which have a broad adaptability to various environmental conditions, making poultry farming possible across nearly all available land types.

To support the development of the livestock sector, it is important to identify and map areas primarily designated for livestock farming and forage crop cultivation. Liquiçá District has an average environmental temperature of approximately 24.21°C and an annual rainfall of 1,726.28 mm/year, providing a conducive ecological potential for supporting the sustainable development of livestock farming. This condition also supports the continuous availability of livestock forage throughout the year. Environmental temperature plays a central role in determining thermal comfort and livestock productivity. Low environmental temperatures can cause cold stress in livestock, triggering an increase in body heat production and basal metabolic rate. If this condition persists without adequate feed support, the metabolic energy of the livestock decreases, reducing their ability to withstand extreme temperatures. This results in impaired growth, reduced productivity, and a significantly increased risk of disease outbreaks.

Conversely, excessively high environmental temperatures cause livestock to reduce feed intake and increase their water consumption. This reduction in nutrient intake directly impacts the performance of livestock production. Therefore, optimal environmental management, particularly controlling temperature and humidity levels, is a key prerequisite for a sustainable livestock farming system. These efforts aim to create conditions that support the physiological balance of livestock, allowing for maximal productivity.

C. Socio-Economic Aspects of Livestock Farming

For the people of Liquiçá District, livestock plays a vital and multifunctional role, far beyond just a source of food. Livestock is an integral part of the subsistence farming system and the evolving civilization. It is still common to find livestock, such as cattle, buffalo, and horses, being used as draft animals for plowing rice fields and farmlands. The use of livestock as draft power allows farmers to cultivate larger areas of land, significantly increasing agricultural productivity. Additionally, in some cultures, livestock holds social, economic, or ritual significance. For example, in certain traditions, livestock is used as dowries or offerings during cultural ceremonies. Moreover, the number of livestock owned by an individual is often used as an indicator of wealth and social status within the community.

One endemic livestock species in Timor-Leste is the Timor buffalo (*karau timor*). The Timor buffalo holds an important role in the social life of Timor-Leste, particularly as an offering during death, birth, and marriage ceremonies. It is also used in traditional transactions such as land sales, with its manure utilized as fertilizer for crops. Additionally, the milk of the Timor buffalo has traditionally been consumed for its protein content, making it a valuable resource. As a result, the Timor buffalo is considered expensive

Buffalo milk has been consumed by local communities for centuries and is one of the most popular types of milk, alongside cow and goat milk. Buffalo milk is thicker and has a distinctive smell compared to cow milk. In the past, people commonly consumed Timor buffalo milk directly without further processing, making it an important aspect of cultural identity

Livestock farming, in general, is still practiced using the traditional free-range grazing system, known as the extensive system. According to Williamson and Payne (1993), in an extensive livestock system, animals are raised freely, grazing on the available forage in the environment. In this system, animals are allowed to roam, usually consisting of one male and several females in a single population. The main characteristic of extensive farming is that no pens are provided and no supplementary feed is given (Jamili, M. A., 2022). The extensive system has advantages such as low labor requirements, short working hours, and livestock's ability to find forage in grazing lands and former agricultural fields. However, the downside of this system is the difficulty in controlling the animals' nutritional intake, and livestock is more susceptible to diseases and death. Unsupervised and free-roaming livestock can also lead to social issues, such as livestock theft and damage to farmers' crops caused by the animals.

The livestock farming model still relies on local knowledge passed down through generations. The absence of large-scale livestock industries has meant that livestock production has not reached its maximum potential, with many areas still requiring improvements. Livestock distribution in the community remains low due to limited capital and poor breeding practices. This is because increasing livestock numbers requires significant costs and time, which makes people view livestock not as a primary source of income, resulting in lower livestock production in the region (Serey *et al*., 2014).

According to interviews, the community received assistance in the form of cattle and buffalo in 2014 from MAPPF (Ministry of Agriculture and Fisheries of Timor-Leste). However, over time, due to poor oversight and a lack of community education, the livestock assistance has not been effectively maintained or expanded.

Another challenge encountered in livestock farming is very complex, spanning from upstream to downstream, as well as the need for infrastructure and facilities that also require development. In terms of animal breeding, the community still applies a natural mating system without using Insemination Breeding (IB) technology, making livestock breeding for sustainability difficult. The community is still unaware of good livestock management practices. They have not been educated on the importance of quality feed for livestock productivity. Furthermore, in terms of marketing, livestock farmers can only sell live animals, making it difficult to increase the selling price of livestock products. Despite the opening of access between Dili, the capital, and other Districts, many roads still lack sufficient infrastructure. This has become a barrier for the community in marketing their livestock products to broader market access.

Given the numerous challenges faced from pre-production to post-production, it is crucial to address these issues to create a foundation for designing a livestock development master plan. Improvement recommendations should start with educating the community on breeding techniques, while also introducing IB technology. Additionally, education on the importance of good livestock management is necessary to motivate the community to focus more on the economic aspects of livestock farming, rather than viewing it solely as a family savings tool.

The government should not only focus on education but also provide financial support, such as credit loans, to help facilitate the community's livestock businesses. Increasing the market value of livestock products can be achieved by educating farmers and opening up new marketing channels beyond just selling live animals.

X. FRESHWATER FISHERIES POTENTIAL

10.1 INTRODUCTION

Timor-Leste, as an archipelagic country, possesses vast natural resource potential, particularly in the marine and fisheries sectors. Liquiçá District, as one of the administrative regions, offers various topographic, soil, water quality, and climatic conditions that have significant potential for developing both freshwater and brackish aquaculture. Aquaculture not only contributes to local food security but also opens sustainable economic opportunities for surrounding communities.

However, the development of aquaculture ventures requires an in-depth study of land suitability. The proper selection of locations is crucial to the success of these ventures, as each fish species has different tolerances to environmental factors such as topography, hydrology, soil conditions, water quality, and climate. Therefore, land suitability analysis becomes an important initial step in aquaculture planning.

This study aims to evaluate the land suitability in the Liquiçá District area based on several biophysical parameters identified in the assessment matrix. This matrix includes four main factor groups: topography and hydrology, soil conditions, water quality, and climate. Each factor is assigned a specific weight that reflects its importance in determining land suitability for aquaculture.

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

10.2 RESEARCH METHODS

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

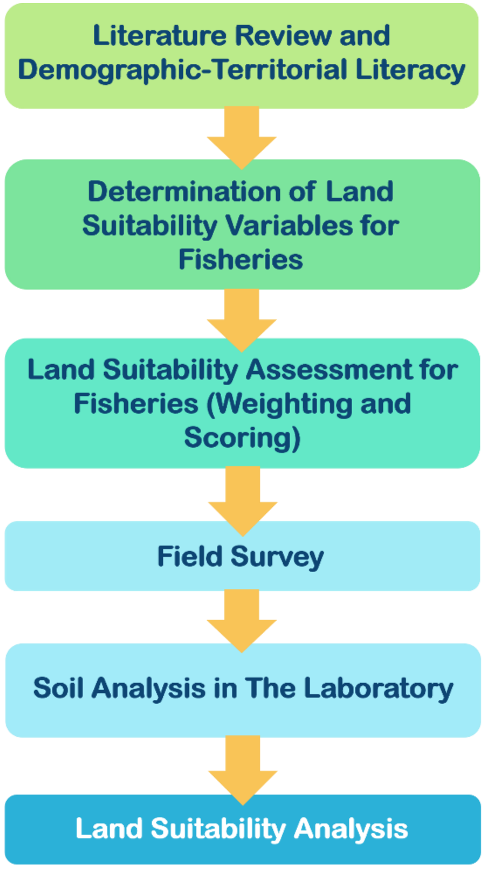


Figure 10.1 Flowchart of The Research Process For Land Suitability in The Aquaculture Sector

A. Literature Review and Regional–Demographic Information

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

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

B. Determination of Aquaculture Land Suitability Variables

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

Table 10. 1 Considerations for Factors Assumed in Determining Variables For Aquaculture Land Suitability

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

C. Design of the Aquaculture Land Suitability Matrix and Parameters

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

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

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

Table 10.2 Relationship Between Parameters, Data Acquisition, and Data Sources

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

Table 10.3 Land Suitability for Pond Aquaculture Parameters

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

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

Table 10.4 Land Suitability Scoring Calculation

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

E. Field Survey

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

Table 10.5 Field Survey Activities by Area in Liquiçá District

No.	Schedule	Sub-District	Village	Purpose (Ownership)
1	18 May 2025	Bazartete	Ulmera	Non-Business (Goverment)
2	18 May 2025	Bazartete	Ulmera	Non-Business (Goverment)

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

Liquiçá District has significant potential in fisheries and aquaculture, particularly because it borders directly on the Savu Sea, making marine capture fisheries one of the area's leading sectors. Based on data from the Directorate of Fisheries, Aquaculture, and Marine Resource Management in 2022, marine capture fisheries production in Liquiçá in 2019 was recorded at 120,560 kg. However, in 2020 it declined slightly to 118,420 kg. In 2021, production increased again to 122,315 kg and continued to rise to 125,906 kg in 2022. Meanwhile, in the aquaculture sector, production in 2019 reached 8,432 kg, decreased to 7,856 kg in 2020, then increased again in 2021 to 8,019 kg and was estimated to reach 8,215 kg in 2023. These conditions indicate that Liquiçá has substantial potential for the development of brackish-water and marine-based aquaculture, supported by cultivation technology and enhanced capacity of the local human resources.

A. Capture Fisheries

According to official reports from the Ministry of Agriculture and Fisheries of Timor-Leste, the development of the fisheries sector in Liquiçá District has shown positive progress in recent years. This has been driven by efforts to improve fisheries infrastructure, provide training for fishers and local aquaculture farmers, and apply modern technologies for capture fisheries and aquaculture. The abundance of marine resources, particularly in the waters of the Savu Sea, together with the commitment of the local government and active community engagement, are important assets for strengthening food security, increasing community income, and creating new employment opportunities in this sector.

1. Number of Fishing Households

Based on the data in **Figure 10.2** and **Figure 10.3**, the number of fishing households recorded in Liquiçá District shows a varied distribution across each Sub-District. Bazartete Sub-District has the highest number of fishing households, with 193 households or about 41.77 % of the total fishing households in the district. Maubara Sub-District ranks second with 144 households or 31.17 %. Meanwhile, Liquiçá Sub-District has 125 fishing households, representing around 27.06 %. This distribution shows that capture fisheries potential is more concentrated in Bazartete, which is likely due to more favorable geographic conditions and fisheries infrastructure, as well as the high dependence of the local community on fisheries as their primary source of livelihood. This provides an important basis for formulating policies for sustainable fisheries development and strengthening fishers' capacity in Liquiçá District.

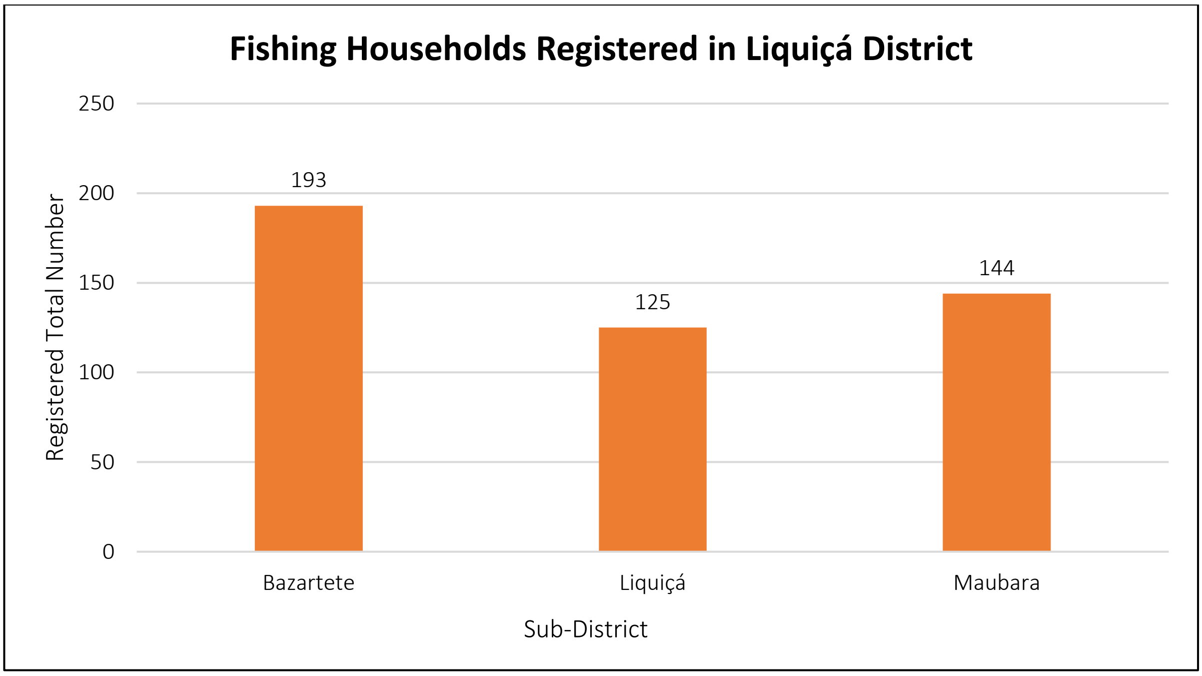


Figure 10.2 Fishing Households in Liquiçá District
(Source: Timor-Leste Agriculture Census, 2019)

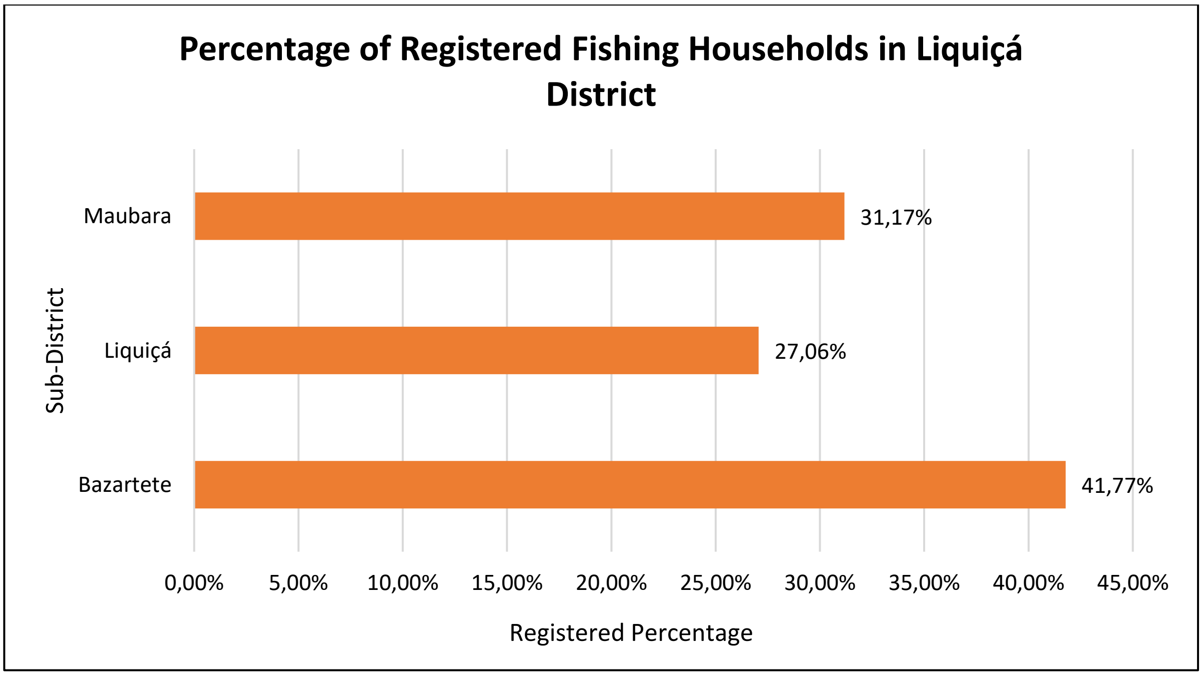


Figure 10.3 Percentage of Fishing Households in Liquiçá District
(Source: Timor-Leste Agriculture Census, 2019)

2. Households Involved in Fishing Activities

Households involved in fishing are grouped into three categories of activity, namely for consumption and social obligations, for consumption and occasional sales, and for direct sale.

Based on the data in **Figure10.4** and **Figure 10.5**, the number of fishing households recorded in Liquiçá District shows a varied distribution across each Sub-District. Bazartete Sub-District has the highest number of fishing households, with 193 households or about 41.77 % of the total fishing households in the district. Maubara Sub-District ranks second with 144 households or 31.17 %. Meanwhile, Liquiçá Sub-District has 125 fishing households, representing around 27.06%.

This distribution shows that capture fisheries potential is more concentrated in Bazartete, which is likely due to more favorable geographic conditions and fisheries infrastructure, as well as the high dependence of the local community on fisheries as their primary source of livelihood. This provides an important basis for formulating policies for sustainable fisheries development and strengthening fishers' capacity in Liquiçá District.

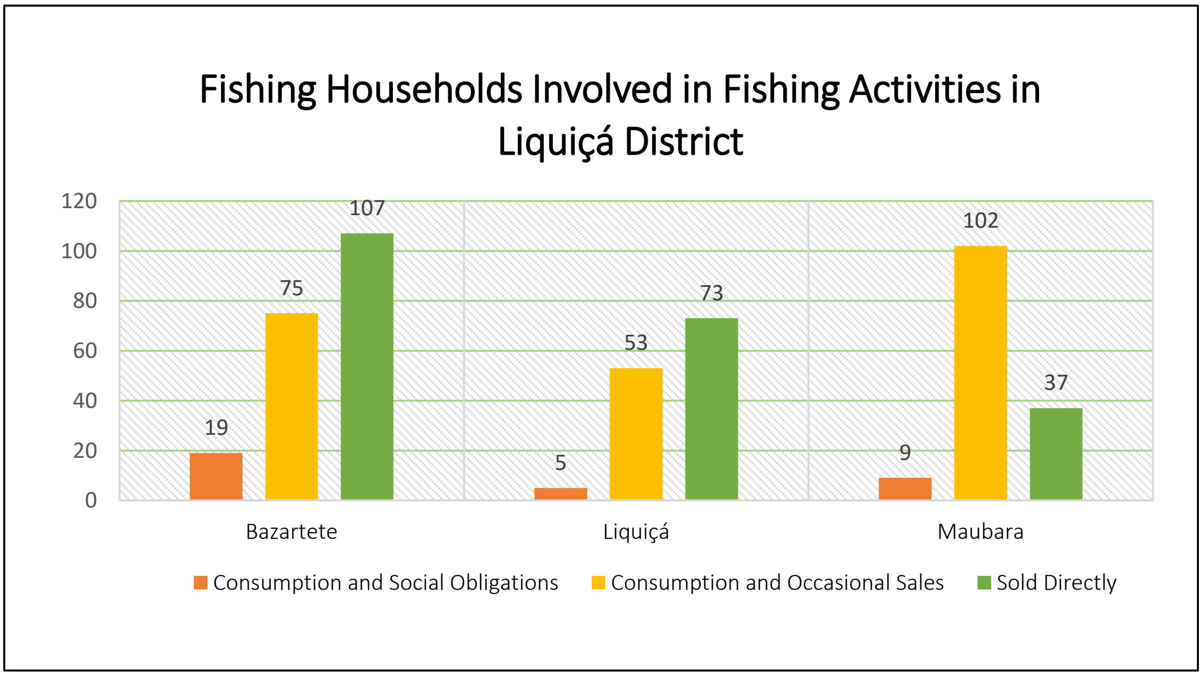


Figure 10.4 Number of Households Involved in Fishing Activities
(Source: Timor-Leste Agriculture Census, 2019)

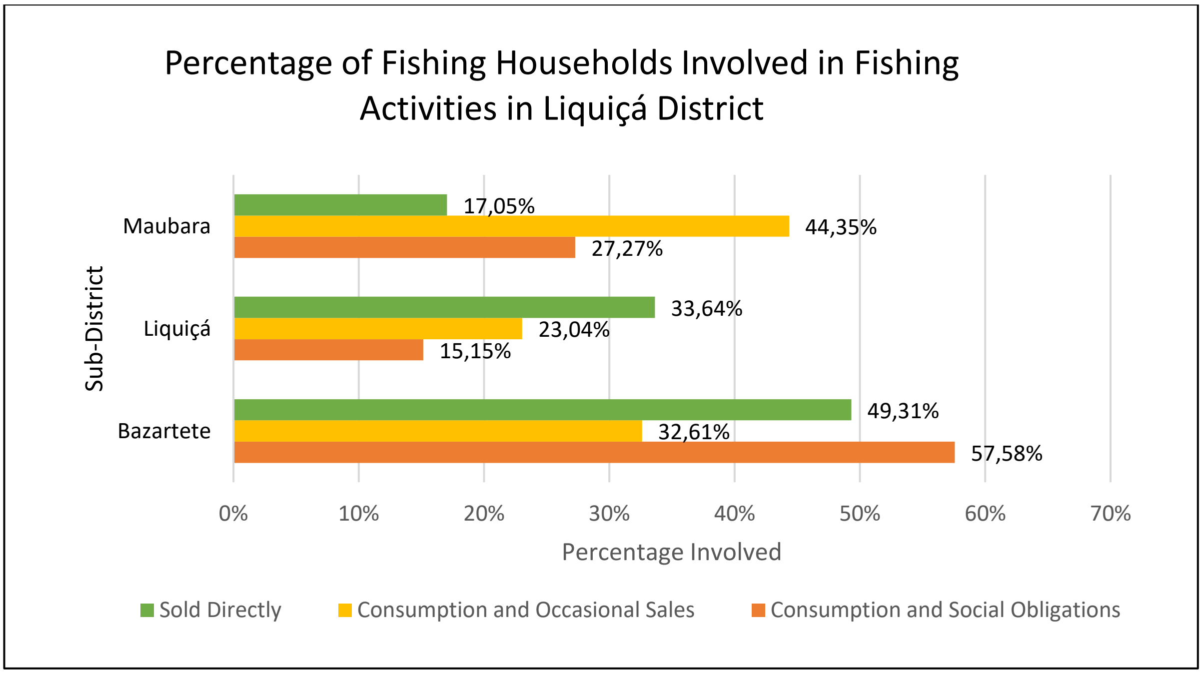


Figure 10.5 Number of Households Involved in Fishing Activities
(Source: Timor-Leste Agriculture Census, 2019)

B. Aquaculture

Aquaculture in Liquiçá District has significant potential for further development, particularly with the support of coastal resources and culture areas distributed across several Sub-Districts. Based on data from the Directorate of Fisheries, Aquaculture, and Marine Resource Management in 2022, the consumption of aquaculture fish in Liquiçá showed a fluctuating trend. In 2019, aquaculture fish consumption in the district reached 0.42 kg per person per year. In 2020, however, it declined slightly to 0.38 kg per person per year, and this figure tended to remain stagnant up to the projected value for 2023. This decline is closely related to changes in production capacity and aquaculture land management in several Sub-Districts, particularly outside Bazartete, which dominates the area under aquaculture. The consistent consumption levels in subsequent years indicate considerable opportunities to increase aquaculture production and efficiency, while playing an important role in meeting the fish protein needs of the population and supporting regional food security.

1. **Proportion of Land for Aquaculture**

Based on **Figure 10.6** and **Figure 10.7**, the area of aquaculture land in Liquiçá District is dominated by Bazartete Sub-District, which reaches 23.79 ha or about 78.91 % of the total aquaculture land area in the district. Meanwhile, Maubara Sub-District has 3.541 ha (11.75 %), and Liquiçá Sub-District covers 2,8179.13 ha (9.34 %). These data show a very high concentration of aquaculture development in Bazartete compared with the other two Sub-Districts. These findings can serve as the basis for considering infrastructure development, capacity-building programs for aquaculture farmers, and a more balanced development of the aquaculture sector so that the potential in other Sub-Districts can also be optimally and sustainably developed.

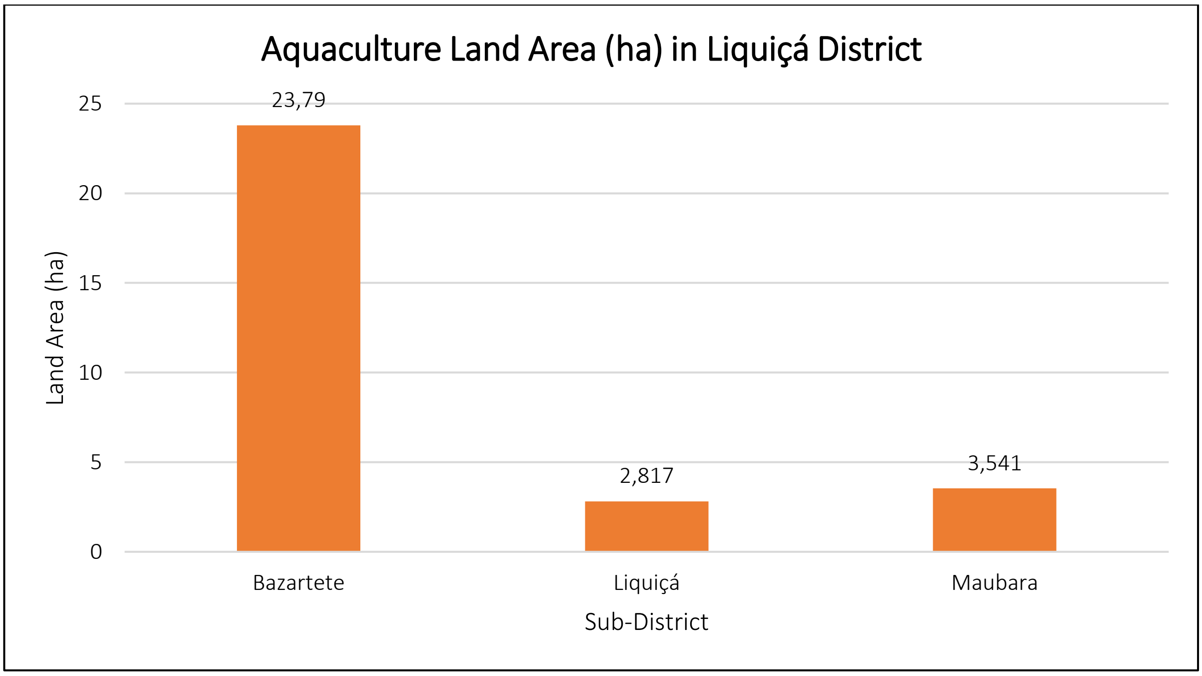


Figure 10. 6 Aquaculture Land Area in Liquiçá District
(Source: Timor-Leste Agriculture Census, 2019)

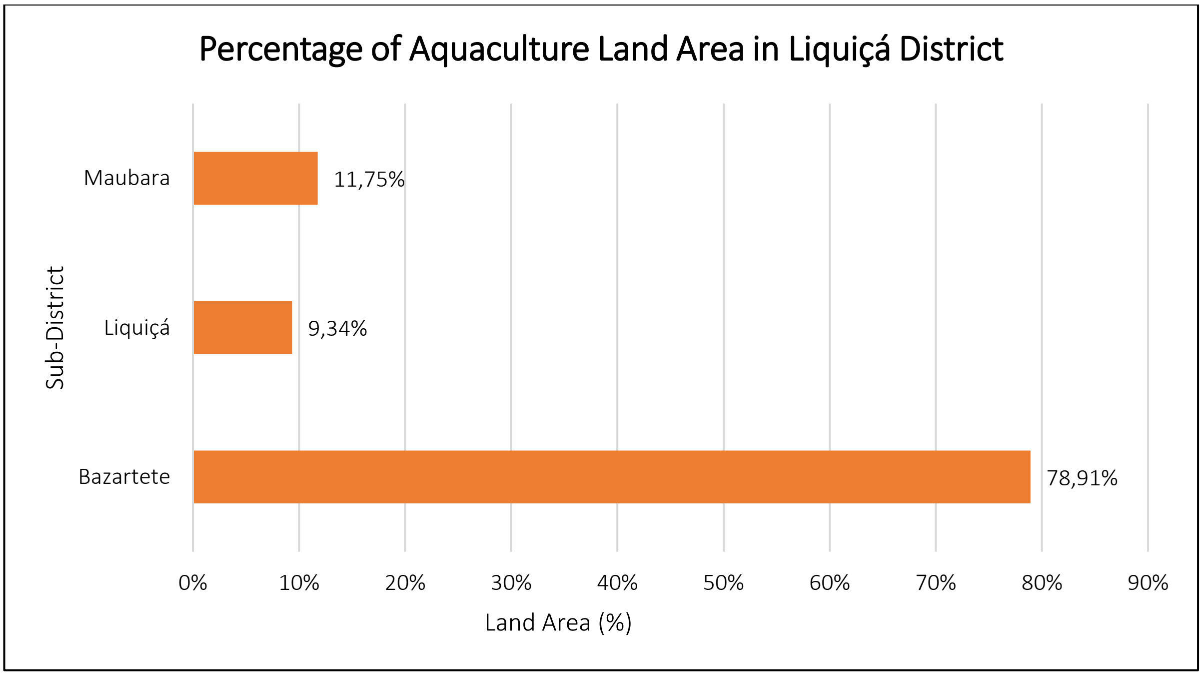


Figure 10.7 Percentage of Aquaculture Land in Liquiçá District
*(*Source: Timor-Leste Agriculture Census, 2019*)*

2. Aquaculture Households

Based on **Figure 10.8** and **Figure 10.9**, the number of aquaculture households recorded in Liquiçá District shows a fairly diverse distribution in each Sub-District. Bazartete Sub-District dominates with 54 households or about 49.09 % of the total aquaculture households. Maubara Sub-District has 29 households (26.36 %), and Liquiçá Sub-District has 27 households (24.55%).

These data show that Bazartete plays an important role in the development of the aquaculture sector in the district. The substantial proportion of aquaculture households in Maubara and Liquiçá also indicates potential that can be further developed, particularly through policy support, capacity-building for aquaculture farmers, and optimization of available land to increase the contribution of aquaculture to local food security and the local economy.

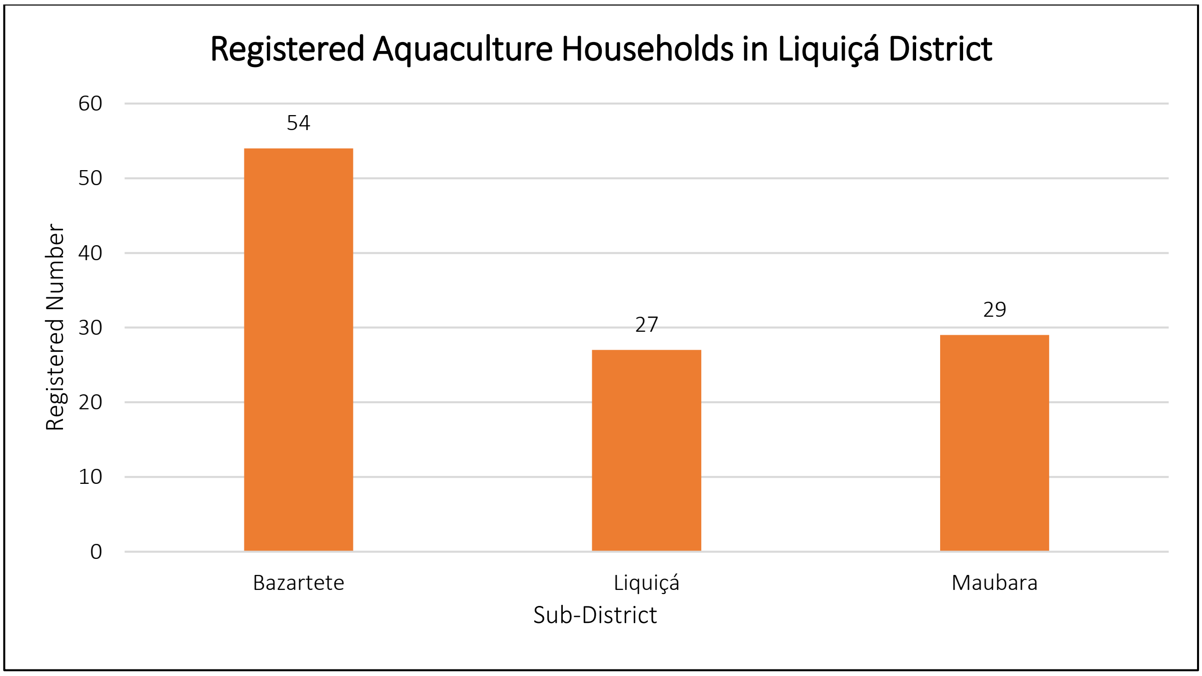


Figure 10.8 Aquaculture Households in Liquiçá District
(Source: Timor-Leste Agriculture Census, 2019)

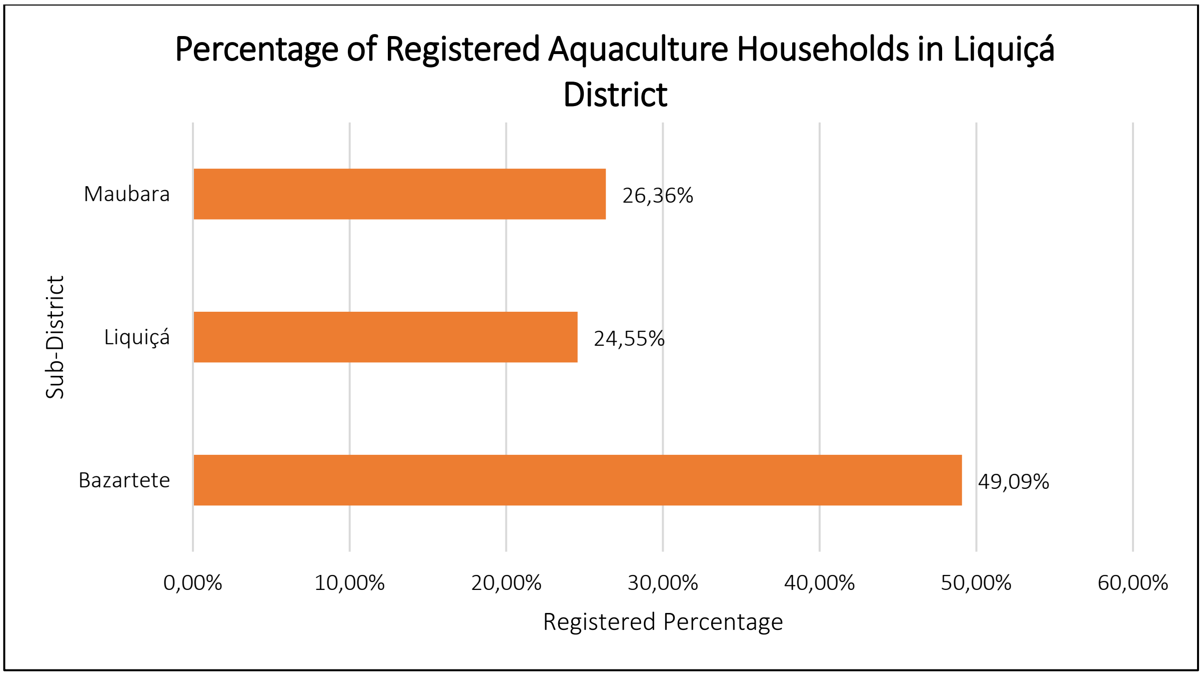


Figure 10. 9 Percentage of Aquaculture Households in Liquiçá District
(Source: Timor-Leste Agriculture Census, 2019)

3. Aquaculture Systems

Based on the data in **Figure 10.10** and **Figure 10.11**, the aquaculture systems recorded in Liquiçá District are described both in terms of the number of units and their percentage contribution to the total systems in each Sub-District.

The aquaculture systems included in these data comprise fish ponds, fish cages, brackish-water ponds, rice-fish systems, and nursery units.

Bazartete is the Sub-District with the highest number and diversity of aquaculture systems. There are 90 fish pond units, 4 brackish-water pond units, and 1 fish cage unit. In percentage terms, fish cages account for 100 %, indicating that for this system, their presence covers all potential locations where such systems are applied. In addition, fish ponds and brackish-water ponds account for 67 % and 60.81 %, respectively, of the total systems recorded. Rice-fish systems and nursery units were not found in this Sub-District. This dominance in both number and diversity indicates that Bazartete is the main aquaculture center in Liquiçá.

Liquiçá Sub-District has 47 fish pond units and 1 brackish-water pond unit. In percentage terms, fish ponds dominate with 31.76 %, while brackish-water ponds account for 17 %. No fish cages, rice-fish systems, or nursery units were recorded in this Sub-District. This shows that aquaculture activities in Liquiçá are still largely concentrated in a single type of system. Maubara Sub-District shows the most limited aquaculture activity, with only 11 fish pond units and 1 brackish-water pond unit recorded. In percentage terms, fish ponds account for 17 % and brackish-water ponds only 7.43 %. No fish cages, rice-fish systems, or nursery units were found. This reflects the limited application of diverse aquaculture systems in this area.

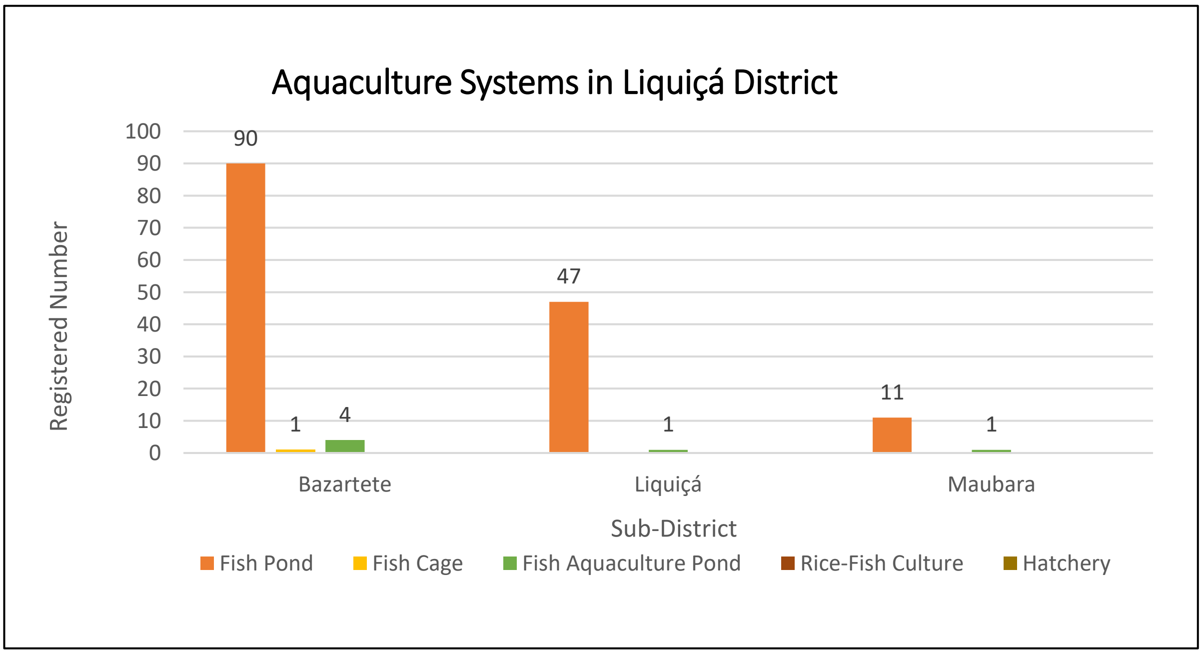


Figure 10.10 Aquaculture Systems in Liquiçá District
(Source: Timor-Leste Agriculture Census, 2019)

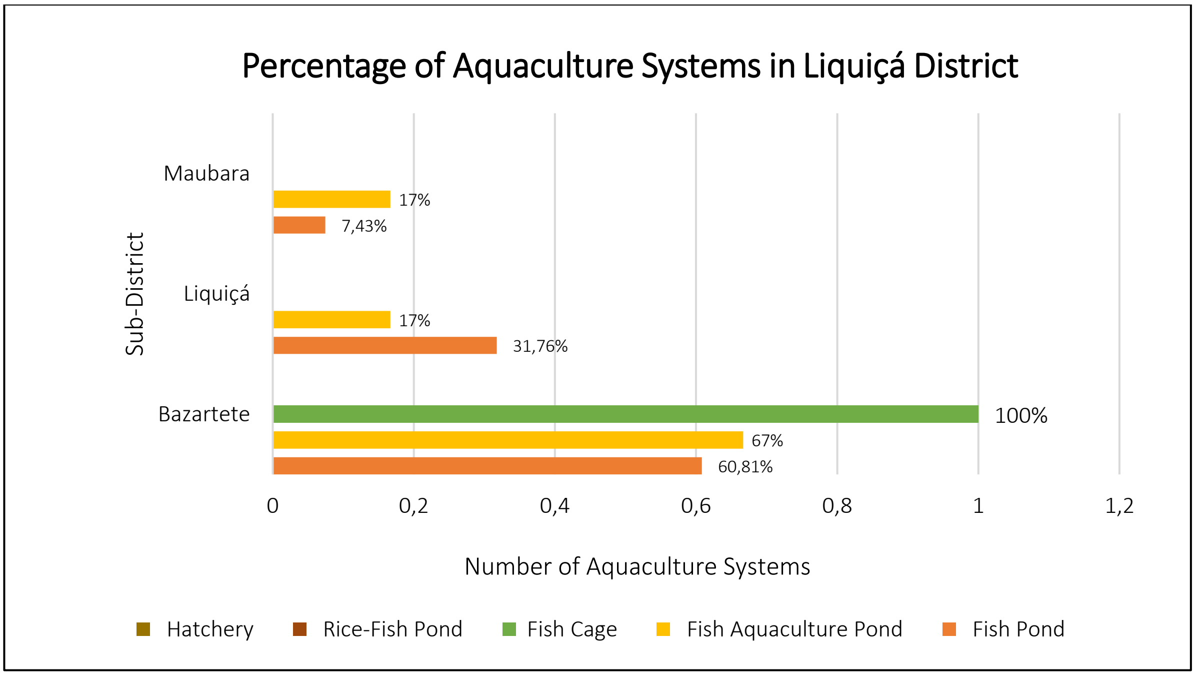


Figure 10.11 Percentage of Aquaculture Systems in Liquiçá District
(Source: Timor-Leste Agriculture Census, 2019)

Based on these numbers and percentages, Bazartete is the most advanced Sub-District in terms of aquaculture systems, both in quantity and diversity, particularly in the use of fish ponds, fish cages, and brackish-water ponds. In contrast, Liquiçá and Maubara still exhibit limitations in both the number of units and the variety of systems. These conditions indicate the need for further support and encouragement for aquaculture development in the two Sub-Districts so that aquatic resources can be utilized optimally.

C. Field Observation Results

Aquaculture activities in Liquiçá District show the involvement of coastal communities in utilizing available land and water resources in a traditional manner. Culture sites are distributed across coastal and inland areas, with management approaches that are still conventional and involve minimal application of intensive aquaculture technologies. The main constraints faced by aquaculture farmers are generally related to limited facilities, suboptimal management systems, and dependence on natural seed sources.

In Ulmera Village, Bazartete Sub-District, culture activities are conducted in privately owned earthen ponds measuring about 20 × 30 m with a depth of 0.8 m. This site is located in a coastal area surrounded by mangrove vegetation and palmyra palms, and uses tidal water as the main source for filling the ponds. The main commodity cultured is milkfish, with seed obtained directly from the wild.

At the beginning of the stocking season, between 5,000 and 10,000 fry are stocked, while harvest yields vary between 5,000 and 15,000 individuals depending on environmental conditions and seed availability.

Figure 10.12 Milkfish Culture Pond in Ulmera Village
(Source: Research Documentation, 2025)

Milkfish grow-out is carried out extensively, with feed requirements of about five sacks per cycle. The absence of aeration systems and limited control of stocking density are key challenges that constrain productivity gains. In addition to milkfish, farmers also attempt small-scale crab grow-out, with yields of around 200 individuals per cycle and an average carapace size of 10 cm. However, the methods used remain simple, using jerry cans as grow-out media placed inside the milkfish ponds, so that there is no optimal spatial separation of culture areas between species. The low productivity of crabs is caused by the limited availability of natural seed and culture methods that are not yet appropriate. Farmers expressed the need for technical training, particularly on stocking density management and more suitable crab grow-out techniques.

Figure 10.13 Crab Grow-Out Media in Ulmera Village
(Source: Research Documentation, 2025)

Meanwhile, in Lissadila Village, Loes Sub-District, culture activities are carried out by community groups with an educational background at the senior high school level. There are 10 conventional earthen pond units measuring 10 × 20 m managed by 10 groups. The main commodity cultured at this site is tilapia, with water sourced from groundwater. Culture activities are not yet equipped with aeration systems or adequate irrigation systems. Husbandry practices are conducted manually, with feed provided at a rate of 1 to 2 sacks per month, and structured aquaculture management principles have not yet been applied.

Figure 10.14 Conventional Earthen Ponds in Lissadila Village
(Source: Research Documentation, 2025)

In general, Liquiçá District has potential for the development of freshwater and brackish-water aquaculture, particularly in areas with access to tidal water and natural buffer vegetation such as mangroves. However, challenges in aquaculture development include the availability of sustainable seed supplies, the technical capacity of aquaculture farmers, and the need for technological interventions to improve culture efficiency and productivity. Support programs, training, and provision of basic infrastructure are required to promote more optimal aquaculture management in this district.

10.4 COMPREHENSIVE LAND SUITABILITY ANALYSIS FOR AQUACULTURE

A. Aquaculture Land Suitability in Liquiça District

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

The evaluation of current land suitability is based on field survey data and reflects the land's capacity in its natural state, without additional interventions. This evaluation does not yet consider improvements or management measures that could address constraints or limiting factors present in each land unit. To determine the current land suitability class, the quality of the land is assessed based on limiting factors. This is followed by scoring and evaluation, which provides an honest view of the existing challenges.

Potential land suitability refers to the suitability of land after improvements have been made. For example, land that is currently only marginally suitable (S3) due to certain constraints could improve to moderately suitable (S2) or even highly suitable (S1) after appropriate improvements, such as modifying topography or adjusting water quality. The evaluation of potential land suitability is conducted by implementing possible improvements to land quality, addressing limiting factors to enhance land suitability.

With technology, lands that naturally have a low suitability class (current land suitability) can be improved to a higher suitability class (potential land suitability). However, not all land characteristics can be improved with current technologies or may require high levels of management. In land-use planning for aquaculture, the primary focus is on potential land suitability, as this evaluation gives an overview of the maximum potential of land for various uses after improvements. Therefore, potential land suitability helps in planning land use effectively and sustainably, while also determining the improvements necessary to achieve optimal results.

B. Results of Aquaculture Land Suitability Evaluation in Liquiça District

Land suitability analysis is a fundamental step in designing sustainable land resource management strategies for aquaculture. This evaluation process is based on an integrated approach that includes the use of geospatial data, field observations, as well as physical and chemical analysis of water and soil in laboratories. This approach allows for the identification of both the potential and limitations of the land for developing various aquaculture commodities.

The data obtained are analyzed based on the growth requirements of each aquatic commodity in its current condition, as well as the potential suitability after various land improvement efforts, such as topographic modification, water quality management, or the application of adaptive cultivation techniques. This process provides comprehensive information to prioritize commodity development, identify limiting factors, and design relevant technical solutions. This scientific approach serves as the basis for land suitability evaluation in Liquiçá District. The results of this analysis provide strategic guidance for maximizing land productivity while maintaining the sustainability of aquatic resources in each area. The field and laboratory data used as the basis for land suitability evaluation are presented in relevant supporting documents. A map of the land distribution for aquaculture in Liquiçá District is shown in **Figure 10.15**.

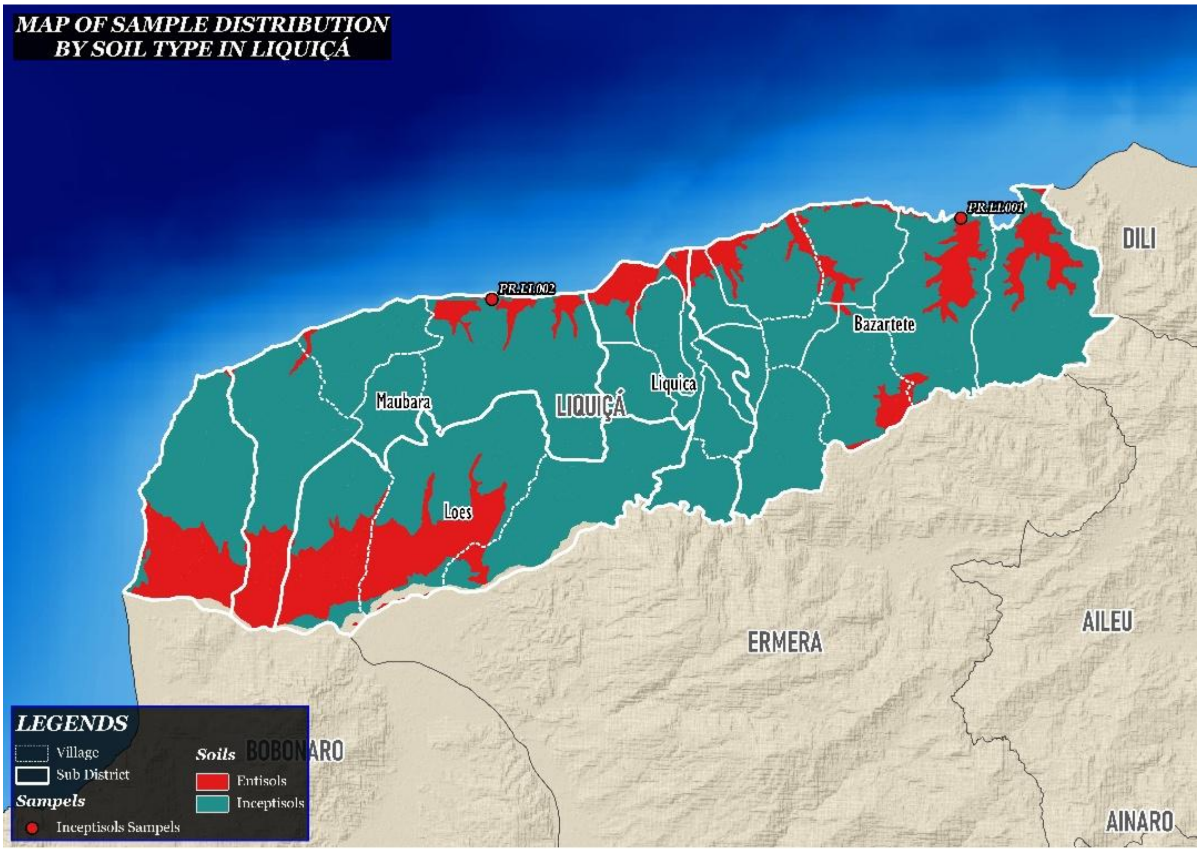


Figure 10.15 Map of Soil Distribution on Aquaculture Land in Liquiçá District

a. Land Suitability Evaluation in Bazartete Sub-District

Bazartete Sub-District in Liquiçá District is one of the areas with potential for aquaculture development, although it faces several significant bio-physical limiting factors. The land suitability evaluation for seven major commodities—both freshwater such as gourami, catfish, tilapia, and carp, and brackish-water commodities like milkfish, mangrove crab, and vannamei shrimp—shows that in its current condition, most of the land falls into the unsuitable (N) category for several important parameters. Other current limiting factors can be seen in **Table 10.9**, while the improvement efforts to upgrade the current condition to potential suitability are outlined in **Table 10.10.**

One of the most dominant and recurring constraints for almost all commodities is slope gradient. The steep topography directly hinders the construction of efficient and safe aquaculture ponds. In the current condition, all commodities are rated as N for the slope factor. However, this factor can still be improved through technical approaches. The recommended solution is the implementation of terraced pond systems, where ponds are constructed following the slope contours. While this method is technically challenging and requires higher initial investment, this intervention allows the suitability value to improve to S3 (marginally suitable), enabling aquaculture activities to continue.

Another critical limiting factor is the dry months, which indicate limitations in water supply during the dry season. Nearly all commodities in the evaluation show an N value for this factor, and unfortunately, dry months are a parameter that cannot be improved because it is rooted in climatic conditions. Therefore, even though improvements are made in other aspects, the dry month factor remains a limiting factor that hampers overall land suitability improvement.

Other factors that affect land suitability but are still manageable include rainfall, dissolved oxygen (DO), and low salinity for brackish-water commodities. In the current condition, rainfall is rated as S3, which means it is suboptimal but not entirely unsuitable. By managing rainwater, such as by constructing reservoirs or storage systems, and improving pond water usage efficiency, land suitability could be upgraded to S2. The issue of low DO can be addressed through aeration technology, such as simple water fountains or aerators to circulate and add oxygen to the pond water. This intervention is crucial, particularly for commodities like tilapia and carp, which require high oxygen levels for optimal growth.

For brackish-water commodities like milkfish, mangrove crabs, and vannamei shrimp, the main constraint is low salinity, meaning the salt content in the water is insufficient for ideal habitat conditions. The recommended solutions include mixing seawater, either conventionally or using pumps. While this method is moderately to highly technically difficult, it is still feasible, especially if the distance to the seawater source is not too far. However, if the distance to the seawater source is too far, aquaculture development can focus on freshwater commodities.

Overall, the evaluation shows that Bazartete Sub-District faces primary challenges related to slope gradient and dry months but still holds potential for development, especially for freshwater commodities like catfish and tilapia, which are more tolerant to environmental conditions and have less complex technical needs. By applying the recommended technical solutions, the land suitability value can be significantly improved, although not all factors can be fully addressed. Careful planning and technology adaptation will be key to making this area one of the most productive and sustainable aquaculture centers in the future.

Table 10.9 Land Suitability Analysis for Aquaculture Commodities in Bazartete 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: pH, Rainfall	3.08	N: Dry months S3: Slope gradient S2: Rainfall	3.44
Catfish (*Clarias batrachus*)	N: Slope gradient, dry months S3: Rainfall	3.22	N: Dry months S3: Slope gradient S2: Rainfall	3.4
Carp (*Cyprinus carpio*)	N: Slope gradient, dry months S3: Rainfall S2: DO, high temperature	3.02	N: Dry months S3: Slope gradient S2: Rainfall	3.4
Tilapia (*Oreochromis niloticus*)	N: Slope gradient, dry months S3: Rainfall S2: DO	3.07	N: Dry months S3: Slope gradient S2: Rainfall	3.4
Milkfish (*Chanos chanos*)	N: Slope gradient, dry months S3: Low salinity S2: Rainfall	3.08	N: Dry months S3: Slope gradient S2: Rainfall	3.4
Mangrove crab (*Scylla serrata*)	N: Low salinity, dry months S3: Slope gradient S2: DO, rainfall	3.25	N: Dry months S2: Rainfall, slope gradient	3.52
Vannamei (*Litopenaeus vannamei*)	N: Slope gradient, dry months S3: Low salinity, rainfall S2: DO	3.09	N: Dry months S3: Slope gradient S2: Rainfall	3.4

C. Aquaculture Land Improvement Efforts

The results of the current land suitability evaluation in Liquiçá District show various limiting factors that make most areas categorized as unsuitable or only marginally suitable for aquaculture activities. To improve these land suitability classes, land improvement efforts or corrective actions are required to address the limiting factors, as far as possible. Land improvement in the context of aquaculture refers to any technical intervention aimed at improving the bio-physical conditions of the land and water quality to better match the optimal requirements of the cultivated commodities. Improvements can include habitat modifications (such as improving pond conditions physically), manipulating water quality, and providing supporting infrastructure.

According to **Table 10.10**, there are different types of improvement efforts with varying management difficulty levels. The management difficulty levels are divided into three categories: low, medium, and high. These levels have assumptions about the evaluation to enhance the actual land quality suitability to potential suitability, as shown in **Table 10.11**.

Table 10.10 Recommended Improvement Measures for Limiting Parameters

No	Parameter	Improvement Measures	Management Difficulty Level
1	High Temperature	- Planting shading trees - Using roof with hapa/paranet nets - Building indoor ponds	- Low - Medium - High
2	Low Salinity	- Conventional seawater mixing - Seawater mixing with pump system	- Medium - High
3	Water pH	- Regular water changes - Use of zeolite	- Medium - High
4	DO	- Use of simple gravity aeration system - Use of aerator pumps/wheel	- Low - High
5	Slope Gradient	- Use of stepped pond system	- High
6	Rainfall	- Cannot be improved	
7	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 10.11 Assumptions for Improving Actual Land Quality to Potential, Based on Management Difficulty Levels

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

Description:

- *Not feasible for improvement*

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

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

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

XI. RECOMMENDATIONS

11.1 RECOMMENDATIONS FOR THE AGRICULTURAL SECTOR

1) Land Potential and Spatial Distribution

The Villages of Lissadila and Leoteala (Loes Sub-District) have potential for irrigated rice fields but are limited by water availability; the Villages of Gugleur (Maubara Sub-District) and Guico (Loes) are suitable for sorghum development; intensive grazing is concentrated in the Villages of Fahilebo and Leorema (Bazartete Sub-District), with dominant forage species being elephant grass (*Pennisetum purpureum*) and gliricidia (*Gliricidia sepium*). This configuration opens up options for the development of irrigation blocks, feed corridors, and dryland farming that complement each other.

2) Diversification of Food Crops

The commodities of corn, cassava, sorghum, legumes, upland rice, sweet potato, taro, *porang*, and cowpea are distributed across all sub-districts, with productivity varying according to soil characteristics and cultivation management. This diversification strengthens food security based on local carbohydrates and forms the foundation for adaptive seasonal rotations.

3) Horticulture and Economically Valuable Fruits

Vegetables (caisim, water spinach, eggplant, chili, tomato, cucumber, broccoli, lettuce, carrot, pak choy, long beans, chayote, green beans, spinach) and fruits (banana, papaya, melon, mango, lime, pineapple, jackfruit, rambutan, guava, avocado, sweet orange, snakefruit, dragon fruit, soursop, mangosteen, durian, Jamaican guava, pumpkin, watermelon, starfruit, strawberries especially in Leorema) indicate a strong horticultural base. Prioritize locations with cool microclimates, improve post-harvest handling, and establish a cold chain to maintain quality.

4) Strategic Industrial Commodities

Coconut, arabica and robusta coffee, and cacao have high economic value and opportunities for strengthening the value chain. Rejuvenation of plantations, balanced fertilization, protective tree shading, and standardization of harvest and post-harvest quality are necessary to improve productivity and quality.

5) Spices and Medicinal Plants by Region

Galangal, turmeric, ginger, betel, clove, vanilla, pepper, cinnamon, and candlenut are cultivated in Leoteala, Hatuquessi, Açumano (Liquiça), Leorema (Bazartete), Vatuvou, and Gugleur (Maubara). The integration of spices with hardwood trees and fruit in agroforestry systems enhances income and improves soil health.

6) Forest Vegetation and Ecosystem Services

Fahilebo, Metagou, Fatumasi, Ulmera, Motaulun, Tibar, Leorema (Bazartete), and Vatuboro (Loes) feature cover from teak, albizia, gliricidia, pine, mahogany, bamboo, agarwood, and sandalwood. This vegetation acts as an erosion control, organic material supplier, shade provider, and stabilizer of the local climate, supporting surrounding land productivity.

7) Key Agronomic Constraints

Apples in Maubara have not borne fruit despite long cultivation; mangosteen in Fahilebo does not bear fruit; coffee production has declined due to insufficient fertilization, a reduction in protective trees not being rejuvenated, and a shift to vanilla; avocado in Leoteala died suddenly; coconuts in Açumano have disrupted fruit growth; rambutan in Loidahar and Dato died before becoming productive; the potential for snakefruit, cacao, and citrus is hindered by shallow solum and groundwater limitations. In addition to technical factors, distribution and marketing are weak (for example, in Darulete), while human resource capacity is low and some potential (e.g., tea in Leoteala) has yet to be utilized.

8) Recommendations for Water and Irrigation at the Regional Scale

Develop rainwater harvesting and small-to-medium infrastructure: village ponds, shallow wells, rehabilitation of canals, weirs, and storage tanks, as well as water-saving irrigation systems (drip/sprinkler) for vegetables and fruits. In Lissadila–Leoteala, the priority is to ensure the continuity of water during the dry season so that irrigated rice fields remain viable both agronomically and economically.

9) Soil Improvement and Fertility

Apply balanced fertilization based on soil test results, add organic matter (compost/manure), use mulch and cover crops, and implement minimum tillage on land susceptible to erosion. This package improves water and nutrient retention, enhances soil structure, and stabilizes yields.

10) Commodity Zoning and Crop Rotation

Irrigated rice fields should be prioritized in Lissadila - Leoteala when water is guaranteed; semi-arid dryland in Gugleur - Guico should focus on sorghum and legumes; upland rice and secondary crops should be planted on hill slopes with soil and water conservation; intensive horticulture should be focused in cool microclimate pockets; fruit orchards should be located on deep, well-drained soils. Implement a rice secondary crops legumes rotation to break pest cycles and maintain soil fertility

11) Livestock and Forage Management

Manage grazing through rotational grazing systems with fenced paddocks, a cut and carry system in sensitive zones, build forage banks (elephant grass, gliricidia), and implement silvopasture on farm edges. This approach reduces pasture degradation, supports plant regeneration, and sustainably increases livestock weight.

12) Coffee Rehabilitation and Cereal Diversification

Restore shading (e.g., albizia and local hardwoods), prune for production, apply scheduled fertilization, and use organic mulching. Gradual diversification can be maintained but should not undermine the care of existing coffee plantations.

13) Addressing Specific Commodity Issues

Evaluate the suitability of apple varieties and cultivation practices in Maubara; for mangosteen, improve pruning, irrigation, and nutrition; avocado issues in Leoteala are indicative of root or drainage problems, requiring orchard sanitation and improved soil aeration; coconut fruit enlargement issues in Açumano need better nutrient and water management; rambutan in Loidahar–Dato requires location adjustments, healthy seedlings, and juvenile stage protection; for snakefruit, cacao, and citrus on shallow solum, use raised beds, thick mulch, and water conservation.

14) Access, Marketing, and Institutional Support

Improve farm access roads and small bridges, provide collection points and simple cold storage facilities, and form or strengthen cooperatives for contract harvesting and input financing. These steps will reduce logistics costs and enhance farmers' bargaining power.

15) Strengthening Human Resources and Technical Assistance

Organize field schools focused on soil fertility, water, pest and disease management (PHT), and post-harvest handling; build demonstration plots for each priority commodity; identify local champions in each village to promote the adoption of good practices and ensure the sustainability of training efforts.

16) Implementation Stages

Quick Wins: Guarantee simple water supply for vegetables and fruits, establish a sorghum demonstration plot in Gugleur–Guico, develop a soil test-based fertilization standard operating procedure (SOP), and implement rotational grazing management.

Medium-Term: Develop communal ponds and wells, implement block-scale terracing, integrate agroforestry systems combining spices, fruits, and protective trees, establish a mini cold chain for horticulture, and create marketing partnership schemes.

11.2 RECOMMENDATIONS FOR THE LIVESTOCK SECTOR

Based on the evaluation of land suitability for forage crops and livestock ecological suitability, two locations show potential to become pilot projects for livestock sector development.

1. **Vatuboro Village, Loes Sub-District,** A comprehensive analysis of forage land suitability and ecological suitability for livestock indicates that the geographic and climatic conditions in this area are highly ideal for pig breeding activities. The availability of fertile land ensures a sustainable supply of high-quality feed, which is crucial for the health and productivity of breeding sows and their offspring. A stable environment minimizes stress and disease risks, thereby enhancing growth rates and reproductive efficiency. As such, Vatuboro can serve as a strategic base for the sustainable production of superior pig breeding stock.
2. **Lissadila Village, Loes Sub-District,** recommended as a pilot project for integrated livestock farming with food crops. Forage crops such as Setaria and legumes like Calliandra, Gliricidia, and Leucaena can be integrated with food crops like banana and papaya, which are already present.

11.3 RECOMMENDATIONS FOR THE FISHERIES SECTOR

Liquiça District shows significant potential for the development of aquaculture, both for freshwater and brackish water commodities, supported by the presence of coastal areas, access to tidal water resources, and natural vegetation such as mangroves and lontar. However, aquaculture activities in this region are still carried out conventionally and are subsistence-oriented, with very limited technological intervention.

Aquaculture activities in Ulmera Village and Lissadila Village show enthusiasm from the community in utilizing land independently; however, productivity remains low due to several constraints. The main limiting factors are the lack of quality seeds, low technical capacity among farmers, inadequate basic infrastructure, and the absence of sustainable, ecosystem-based aquaculture practices with appropriate technologies.

Land suitability evaluation results in Liquiça District, particularly in Loes Sub-District, indicate that the area is highly suitable for the development of various aquaculture species, both freshwater and brackish water. The actual suitability values range from 3.02 to 3.25, with milkfish (*Chanos chanos*), mangrove crab (*Scylla serrata*), and catfish (*Clarias spp.*) being the most viable commodities (actual values of 3.25 and 3.22, respectively). The potential values significantly increase for almost all species to a range of 3.40 to 3.52, indicating that with proper interventions, aquaculture productivity and sustainability can be improved.

Based on the combination of land suitability values and the bio-physical conditions of the region, Liquiça District is recommended as a priority area for the development of brackish water aquaculture systems, especially for mangrove crab and milkfish commodities, as well as simple polyculture systems with support from appropriate technologies. On the other hand, freshwater commodities such as catfish and tilapia remain viable for development, especially in land areas such as Lissadila Village.

Based on field observations, land suitability analysis, and actual and potential weighting, Loes Sub-District is recommended as the location for the integrated aquaculture pilot project. The recommended development should focus on Ulmera Village, with primary commodities being milkfish and mangrove crab. The recommended model for development is a simple Integrated Multi-Trophic Aquaculture (IMTA) system in tidal ponds. The area already has existing ponds, is located in the coastal zone with mangrove vegetation, and has prior aquaculture experience, albeit basic.

To ensure sustainable and inclusive aquaculture development in Liquiça District, the following strategic actions are required from both central and local government bodies:

1. Develop local seed production units or distribute national seeds to potential sites (Ulmera and Lissadila) to ensure a sustainable supply of quality seeds.
2. Implement community-based training programs that are sustainable and adaptive, involving technical institutions (such as the Fisheries Technical School or the Fisheries Department of District) to enhance the technical capacity of local communities.
3. Facilitate access to production resources through subsidy schemes or micro-credit groups, for the provision of feed, simple aerators, and other basic infrastructure.
4. Integrate aquaculture development into regional development plans, emphasizing coastal ecosystem conservation and efficient use of marginal lands.

Conduct regular, data-based monitoring and evaluation, involving national research institutions and universities, to ensure that programs are relevant and adaptive to climate change and local dynamics.

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Liquiçá Municipality

Liquiçá Municipality is a strategic area for comprehensive agricultural development, with land-use proportions that include rainfed rice fields (13.47 %), dryland farming (17.47 %), grazing areas (0.10 %), and forestry zoning consisting of agroforestry systems (0.48 %), protected forests (68.28 %), and mangrove forest (0.20 %). The Municipality is recognized as one of the centers for horticultural and industrial development in Timor-Leste, with leading commodities including Arabica coffee, Robusta coffee, and citrus crops. In addition, Liquiçá has a fruit village in Leorema Village that serves as a development center for orange, snakefruit, and durian, thereby strengthening locally based agricultural commodity diversification.

Land suitability potential in Liquiçá includes food crops such as irrigated rice, rainfed rice, sorghum, and corn; fruit horticulture such as orange, snakefruit, and durian; vegetable horticulture such as shallot, chili, and caisim; and spices and medicinal plants including pepper, turmeric, and betel. Suitable industrial commodities for development include Arabica coffee, Robusta coffee, and cacao, while the forestry sector shows prospects for high-value species such as sandalwood, mahogany, and Melaleuca. In the livestock sector, Liquiçá has potential for the development of pigs, Bali cattle, goats, and buffalo, supported by forage feed commodities such as elephantgrass, Leucaena, and Gliricidia. Two livestock observation sites are located in Vatuboro Village and Lissadila Village (Loes Administrative Post), which serve as models for the management of pigs, Bali cattle, and goats.

In addition to agriculture and livestock, the fisheries sector in Liquiçá shows development potential in Ulmera Village (Bazartete Administrative Post), with leading commodities including milkfish, catfish, Nile tilapia, and crab. To support food security and sustainable development, multisector strategies are directed through an integrated farming system based on the five key farming practices, livestock integration, and aquaculture intensification. Three Villages, namely Ulmera (Bazartete Administrative Post), Vatuvou (Maubara Administrative Post), and Lissadila (Maubara Administrative Post), are recommended as pilot projects for integrated agriculture. This program is expected to strengthen national food security, improve rural community welfare, and support Timor-Leste's readiness in responding to regional dynamics, including the process of accession to ASEAN.