Land Suitability Evaluation & Regional Potential Mapping

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

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

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FOREWORD

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

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

As a country endowed with abundant natural resource potential, Timor-Leste faces major challenges in optimally utilising its land in the context of limited resources and the impacts of climate change. This book has been prepared to respond to the urgent need for land resource management that is oriented toward food security, environmental sustainability and poverty alleviation. Through a data-based approach, this study has successfully mapped the potential of different regions 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 six main Sub-Districts, namely Atabae Sub-District, Balibo Sub-District, Bobonaro Sub-District, Cailaco Sub-District and Maliana Sub-District, this book offers strategic guidance for the use of drylands that dominate Timor-Leste. The proposed land suitability zoning approach provides solutions to challenges such as land degradation, erosion hazards and declining soil fertility. Beyond this, the book underscores the importance of integrating environmental conservation and modern technology to support sustainable land productivity.

We are confident that the recommendations presented in this book not only provide direct benefits for food security in Timor-Leste, but also contribute to the achievement of the Sustainable Development Goals (SDGs), particularly 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 close cooperation, we can ensure that agricultural development in Timor-Leste proceeds in line with natural resource conservation, ecosystem sustainability and improved community welfare.

Finally, I extend my gratitude to all parties who have supported the preparation 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 Bobonaro District as an important background for evaluating land suitability and the potential for developing agricultural, plantation, horticultural and forestry commodities. The information covers demography, soil types, geological formations, land use, slope gradient, agroclimatic zones and existing field conditions, using a data-driven approach that is in-depth and comprehensive.

1. Demography: Human Resource Potential as a Foundation

Bobonaro District, with its dominance of drylands and a significant farmer population in Bobonaro Sub-District and Maliana Sub-District, shows considerable potential for the development of the agricultural sector as a backbone of national food security. The district has a high proportion of farmers who can support the implementation of agricultural technological innovation, while areas such as Balibo Sub-District and Lolotoe Sub-District require specific strategies to increase community engagement in land management.

2. Soil Type: Basis for Land Suitability Evaluation

The diversity of soil types in Bobonaro District includes Vertisols (36.93 %), which are suitable for grassland and savanna, Inceptisols (12.82 %), which are often used for intensive agriculture, Entisols (19.13 %), which are young, weakly developed soils and Mollisols (17.68 %), which are fertile. Sound management is required to maintain the fertility of each soil type, particularly Inceptisols, which are prone to becoming less fertile.

3. Land Use: Dynamics of Ecosystems and Human Activities

Land use in Bobonaro District consists of wetlands (irrigated rice fields) and drylands dominated by mixed gardens and forest. The distribution of land use shows that Atabae Sub-District has the largest forest area (15.44 %), while Balibo Sub-District also has high potential in the forestry sector (21.14 %). Bobonaro Sub-District and Maliana Sub-District are more focused on agricultural development, with agricultural land comprising 4.36 % and 5.38 % of their respective areas. Sustainable management is needed so that these resources can be used optimally.

4. **Field Conditions: Constraints and Potential**

Land degradation (erosion, landslides and critical land), limited irrigation infrastructure and suboptimal land management are the main constraints in land management in Bobonaro District. However, the considerable potential for the development of industrial crops and horticulture indicates opportunities that can be optimised through conservation-based approaches and community empowerment.

5. **Utilisation of *Chromolaena odorata*: From Challenge to Opportunity**

The invasive plant *Chromolaena odorata* in Bobonaro District presents significant ecological challenges, but also has substantial potential as a source of organic fertilizer, traditional medicine and bioenergy. Utilisation-based strategies that involve communities and the private sector are key to managing this species in a sustainable manner.

B. RESEARCH METHODS

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

Research Procedure

1. **Soil Sampling**
   a.) Soil samples were collected as composite samples at the following depths:
      - 0–30 for annual crops.
      - 0–60 cm for perennial crops.
2. **Laboratory Analysis**
   The physical and chemical soil parameters analyzed included:
   a.) C-organic *(%)*: *Walkley* and *Black* Method.
   b.) N-total *(%)*: *Kjeldahl* Method.
   c.) Soil texture: Pipette Method.
   d.) Soil pH: Potentiometric Method *(H_2O 1:2.5)*.
   e.) P-available & K-available (ppm):
      - *Bray*-1 Method for pH < 7 (with conversion to mg/100 g).

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

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

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

h.) Total P (mg /100 g) using the 25 % HCl method

i.) Total K (mg/100 g) using the 25 % HCl method

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

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

3. Stages of Land Suitability Classification

a.) Actual Land Suitability

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

b.) Land Improvement Recommendation

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

c.) Potential Land Suitability

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

d.) Zonation of Commodity Development Potential

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

C. CHARACTERISTICS OF AGRICULTURAL AND FOREST LAND

1. Temperature

Air temperature is a key parameter in land suitability evaluation, analysed through the integration of field measurements and the SRTM Digital Elevation Model (DEM) using the Braak approach. Temperature distribution varies among Districts, reflecting complex topography and microclimates. Bobonaro District is dominated by temperatures above 26 °C (35 %), followed by 21-24 °C (29 %) and 24-26 °C (26 %). These temperature ranges support the growth of tropical crops such as Rice and Corn, but areas with higher temperatures face challenges such as increased evaporation. Strategies such as the use of heat-tolerant varieties and efficient irrigation are needed to enhance productivity.

2. Rainfall

Rainfall analysis using CHIRPS data shows that the largest proportion of the area receives moderate to high rainfall (1500–2000 mm/tahun), which supports stable agricultural activity. Areas with high rainfall (>2000 mm/tahun) face erosion challenges, whereas low-rainfall zones (<1000 mm/tahun) require adaptive technologies such as micro-irrigation. Atabae Sub-District, Balibo Sub-District and Maliana Sub-District are dominated by rainfall of 1500–2000 mm, while Bobonaro Sub-District and Lolotoe Sub-District receive more than 2000 mm. This variation affects water availability for agriculture, with some areas requiring improved water management.

3. Dry Month

The distribution of dry-month periods reflects variation in water stability. Most of the district experiences short dry periods (0-1 month), except for Lolotoe Sub-District, which has longer dry periods (4-5 months). These conditions influence water requirements, with drier areas needing efficient water management strategies.

4. Drainage

Drainage in most of the district is classified as good, except in Maliana Sub-District, which is dominated by poorly drained conditions (54 %). Good drainage supports oxygen availability in the soil, whereas areas with poor drainage require improvement to remain productive.

5. Soil Texture

The study area in Bobonaro District is dominated by moderately fine soil texture (41.8 %) and fine texture (38.2 %), which support high water retention and soil fertility, making them ideal for agricultural activities. Sub-Districts such as Bobonaro and Maliana show substantial potential for food-crop agriculture. Meanwhile, areas with coarse or stony textures require conservation-oriented management, such as efficient irrigation techniques and the addition of organic matter, to maintain land productivity.

6. Coarse Fragment

Bobonaro District is dominated by soils with low coarse fragment content (< 5 %) over 66 % of the area, which supports water retention, higher fertility and suitability for food crops such as Rice and Corn. Coarse fragment contents of 5-10 % and 15-20 % each account for 10 %, while soils with moderate coarse fragment content (10-15 %) account for only 4 %. Areas with high coarse fragment contents (> 20 %), namely 20-25 % (2 %), 35-50 % (5 %) and > 50 % (3 %), are limited and generally not ideal for intensive agriculture. These rocky areas require conservation strategies such as efficient irrigation and the use of organic amendments to maintain productivity. Overall, Bobonaro District has high agricultural potential, but differentiated management is needed for rocky land.

7. Surface Rock

Most of Bobonaro District has low Surface Rock content (0-5 %) over 53 % of the area, which is highly favourable for agricultural activities. Areas with medium to high Surface Rock (20-50 %) account for 17 %, while very high Surface Rock (>50 %) accounts for only 9 % and is more suitable for forestry or conservation. Areas with low to medium Surface Rock (5-20 %) can still be cultivated for agriculture using appropriate conservation techniques. With suitable management, the potential of these areas can be optimised for agricultural activities and sustainable land management.

8. Rock Outcrops

Most of Bobonaro District has low Rock Outcrops (0-5 %) over 59 % of the area, which offers good agricultural potential because the soils are easy to till and have high water-retention capacity. Rock Outcrops from medium to high (20-50 %) account for 19 % of the area, while very high Rock Outcrops (> 50 %) cover only 3 %, which are more suitable for conservation or livestock. Areas with low to medium Rock Outcrops (5-20 %) can also be managed for agriculture through conservation techniques and irrigation systems. Overall, agricultural potential in this district can be optimised through land management that is adjusted to rock characteristics.

D. SOIL FERTILITY STATUS

The analysis shows that most soils in Bobonaro District have low fertility status (70.91 %), followed by medium (21.82 %) and high (7.27 %). These categories were determined based on chemical soil parameters such as cation exchange capacity (CEC), base saturation (KB), soil organic carbon (SOC), Phosphorus (P) and Potassium (K). Low soil fertility is caused by several key factors, including low C-organic and Potassium contents and soil properties that favour nutrient leaching in high-rainfall areas. Most of the district has low-fertility soils, particularly in the central and southern parts. In the north, some areas show medium fertility, whereas highly fertile land is limited and scattered in separate locations.

E. EROSION AND AGROFORESTRY-BASED CONSERVATION

1. Soil Erosion

Soil erosion plays an important role in land suitability evaluation and in the sustainability of land use. In Bobonaro District, factors such as steep slopes, low vegetation cover, granular soil structure and minimal conservation practices accelerate erosion rates. The results show that 69.05 % of the district experiences severe and very severe erosion, leading to loss of fertile topsoil and declining soil productivity.

The main factors causing erosion in this area include:

- Topography: Dominant steep slopes
- Soil type: Vertisols and Entisols, which are highly susceptible to erosion, particularly at slope gradients >15 %.
- Rainfall: High rainfall intensity that leads to severe to very severe erosion.
- Limited vegetation cover: Contributes to the loss of topsoil due to surface runoff.
- Anthropogenic: Land management that does not follow conservation principles accelerates erosion.

Spatial data show that Bobonaro District has the highest proportion of very severe erosion at 30.95 %, severe erosion at 38.55 %, moderate erosion at 21.24 % and slight erosion at 9.27 %. These conditions underscore the need for conservation measures based on ecological approaches to manage land and minimise soil degradation.

2. Agroforestry-Based Conservation

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

- Increasing vegetation cover: Reducing surface runoff and maintaining 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:

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

3. Implementation of Agroforestry in Bobonaro District

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

- **Alley cropping:** Planting crops between tree rows on steep slopes to control erosion.
- **Live fences:** Using erosion-tolerant plants such as Vetiver Root to stabilise slopes.
- **Live stakes:** Using perennial species such as Leucaena as live stakes to control erosion, combined with Pepper and other climbing crops.
- **Layered planting:** Combining trees, shrubs and groundcover crops to stabilise soil and reduce runoff.
- **Silvopastoral systems:** Combining forest vegetation with livestock to manage erosion in grazing areas.

4. Conservation Recommendations

- **Expansion of agroforestry** practices in erosion-prone zones, such as Bobonaro Sub-District and Cailaco Sub-District.
- **Spatial data-based management** to identify priority locations for conservation interventions.
- **Capacity building for farmers** through training and adoption of modern agroforestry techniques.

- **Strengthening soil conservation policies** by integrating agroecology-based approaches into spatial planning.

F. EVALUATION OF AGRICULTURAL LAND SUITABILITY

1. Atabae Sub-District

- Food crops that can be developed include irrigated rice, upland rice, corn, sorghum and wheat.
- In addition to food crops, there is horticultural potential for commodities such as chili, eggplant, bitter melon and pineapple.
- Forestry commodities with development potential include teak, mahogany and agathis.

2. Bobonaro Sub-District

- Food crops that can be developed include corn, sweet potato and sorghum.
- Horticultural crops such as chili, tomato and bitter melon are moderately suitable for cultivation in Bobonaro Sub-District.
- Spice crops such as turmeric and galangal have potential for slope stabilisation through contour planting systems.

3. Cailaco Sub-District

- Food crops that can be developed in Cailaco Sub-District include corn.
- Horticultural crops that can be developed include snakefruit and durian.
- Industrial crops such as coconut, robusta coffee and tobacco have moderately suitable land for development in Cailaco Sub-District.

4. Lolotoe Sub-District

- Food crops that can be developed include corn, mung beans and cowpea.
- Horticultural crops such as chili, tomato, bitter melon and pineapple show moderately suitable land conditions.
- Spice crops such as turmeric and galangal can also be developed in Lolotoe Sub-District.

5. Maliana Sub-District

- Food crops that can be developed in Maliana Sub-District include corn, peanut, cassava and taro.
- Industrial crops such as sugarcane, tobacco and cotton can be developed in this area.

- Horticultural crops such as durian and avocado can also be developed.
- Spice crops such as turmeric have moderately suitable land conditions in Maliana Sub-District.

6. **Balibo Sub-District**

- Food crops that can be developed in Balibo Sub-District include irrigated rice, upland rice, corn and cowpea.
- Spice and medicinal crops such as vanilla, aromatic ginger, galangal and jatropha also have good development potential in this area.

G. LIVESTOCK POTENTIAL IN BOBONARO DISTRICT

This study aimed to evaluate land suitability and the potential for livestock development in Bobonaro District, Timor-Leste, to support food security, community nutrition and the local economy. The focus of the analysis included the availability of forage crops, ecological suitability for livestock and the socio-economic conditions of livestock keepers. The methods used included field surveys, interviews, bio-physical soil analysis and GIS-based mapping.

Hasil menunjukkan sektor peternakan Muisipiu Bobonaro didominasi sapi, babi, kambing, dan ayam, dengan potensi padang penggembalaan cukup luas terutama di Postu Balibo dan Lolotoe. Evaluasi kesesuaian lahan menempatkan HPT seperti rumput gajah, setaria, dan leguminosa pada kategori cukup sesuai (S2), meski terkendala faktor N-total, K-tersedia, curah hujan, kedalaman efektif, pH, erosi, dan lereng.

The results show that the livestock sector in Bobonaro District is dominated by cattle, pigs, goats and chickens, with extensive grazing potential, particularly in Balibo Sub-District and Lolotoe Sub-District. Land suitability evaluation places forage crops such as elephantgrass, setaria and legumes in the moderately suitable (S2) category, although they are constrained by factors such as low N-Total, K-available, rainfall, effective soil depth, pH, erosion and slope.

The main challenges are limited availability of quality feed, low adoption of breeding and livestock management technologies and marketing that is still largely limited to live animals. Proposed solutions include improving forage quality through grass–legume combinations, applying breeding technologies such as artificial insemination (AI), providing credit for livestock enterprises and training in feed management, animal health and biosecurity. The Sentra KTS

Korluli in Maliana is recommended as a pilot project site because of its land potential and supporting infrastructure, with a focus on the development of cattle, buffalo and small ruminants.

H. FRESHWATER FISHERIES POTENTIAL IN BOBONARO DISTRICT

This study aimed to evaluate land suitability for aquaculture development in Bobonaro District, Timor-Leste, as an effort to support food security and improve nutrition. The methods used included Geographic Information Systems (GIS) analysis to map land suitability. There are two main locations that currently serve as centres of aquaculture activities, which have already implemented earthen ponds and concrete ponds:

1. Leohito Village (Balibo Sub-District), the main problems in this location are high dependence on imported feed and the risk of fish mortality due to water pollution. Proposed solutions include: developing community-scale independent feed production units; implementing integrated biosecurity systems, including simple aeration and water quality monitoring; and providing community-based training in disease management and biosecurity.
2. Raifun Village (Maliana Sub-District), the main problems in this location are limited water discharge and pollution from domestic activities. Solutions include conducting renewed mapping of clean water sources and constructing simple filtration systems for inlet water.

Based on land scores, infrastructure and community participation, a freshwater pilot project is recommended in Leohito Village, Balibo Sub-District, with commodities including catfish, gourami and high-quality common carp seed to support the sustainability of the aquaculture sector.

I. ZONING OF AGRICULTURAL COMMODITY DEVELOPMENT IN BOBONARO DISTRICT

Bobonaro District has substantial land resource potential to support the development of agriculture, forestry and livestock. Based on land suitability evaluation, zoning was designed systematically through field observation, laboratory analysis and agroclimatic mapping. This zoning aims to maximise land management efficiency, support food security and improve community welfare.

1. **Irrigated Rice Fields (8.89% of the total area)**
   - **Area**: These zones are located at low elevations (<100 to >500 m above sea level) with slope gradients of 0-8%.
   - **Main area**: Maliana Sub-District, covering 8.43 % of the total area of Bobonaro District.
   - **Strategy**: Development of additional irrigation, such as piped distribution and pumping systems, in areas with low rainfall.
2. **Rainfed Rice Fields (11.65 % of the total area)**
   - **Area**: 160.33 km^2. Rainfed rice fields are located at elevations from < 100 to > 500 m above sea level, with rainy seasons lasting 4 to 8 months per year.
   - **Main area**: Cailaco Sub-District, covering 4 % of the total area, followed by Atabae Sub-District and Balibo Sub-District, each covering 3 % of the district area.
   - **Strategy:** Recommended strategies include the construction of farm ponds, the use of drought-tolerant Rice varieties and improved water management to increase yields.
3. **Dryland Agriculture (22.52 % of the total area)**
   - **Area:** 309.88 km^2, this zone is located at elevations from < 100 to > 500 m above sea level with slope gradients of 8 to 25 %.
   - **Main area:** Atabae Sub-District and Cailaco Sub-District have the largest dryland agriculture areas, each covering 5 % of the total area. Lolotoe Sub-District and Maliana Sub-District occupy the second position, each covering 4 % of the total area.
   - **Main commodities:** Upland Rice, Corn and Soybean (food crops); vegetables, fruits and flowers (horticulture); and Coffee, Coconut and spices (industrial crops).
   - **Strategy**: The use of strip cropping and crop rotation to maintain soil stability and sustain land fertility.
4. **Grazing Area (0.46 % of the total area)**
   - **Area:** 6.35 km^2, dominated by grassland and savanna.
   - **Main area:** Bobonaro Sub-District.
   - **Strategy:** Rotational grazing systems and integration of agroforestry.

J. FORESTRY POTENTIAL

Agroforestry (48.43 % of the total area)

- **Area:** 667.78 km² at elevations of 500 to 1,000 m above sea level with slope gradients of 25 to 45 %.
- **Main areas:** Balibo Sub-District (16 %), Atabae Sub-District (10 %), Bobonaro Sub-District (9 %) and Cailaco Sub-District (6 %).
- **Strategy:** Integration of small-scale livestock to diversify income.

Protected and Conservation Forest Areas (7.79 % of the total area)

- **Area:** 107.18 km² at elevations of 100-500 m above sea level with slopes of 8-25 %.
- **Purpose:** Soil and water conservation and biodiversity conservation.
- **Strategy:** Reforestation and ecosystem restoration to reduce land degradation.

K. RESEARCH RECOMMENDATIONS

1. Optimising Production in Food Zones

- **Development of Irrigation Networks:** Expansion of irrigation networks in Maliana Sub-District, which has the potential to become the main Rice production centre in Bobonaro District. Micro-irrigation and farm ponds should be prioritised to support intensive cropping patterns.
- **Management of Rainfed Rice Fields:** The use of drought-tolerant Rice varieties in areas with monomodal rainfall patterns. Farmers also need training in simple water management methods, such as rainwater harvesting, to increase agricultural production.
- **Commodity Diversification:** In addition to rice, these zones can be used for food crops such as corn, soybean and cassava as part of food diversification efforts.

2. Utilisation of Agroforestry and Protected Forest Potential

- **Agroforestry Development:**
  - **Industrial crops:** Planting high-value commodities such as Robusta Coffee, Arabica Coffee, Cacao and Coconut in Atabae Sub-District, Balibo Sub-District, Bobonaro Sub-District and Cailaco Sub-District.
  - **Horticulture:** Integrating fruit crops (Avocado, Mango) and vegetables (Tomato, Chili) with forest trees on sloping land to conserve soil.

- **Management of Protected Forests:**
  - Protected forests are focused on conserving biodiversity, reducing the impacts of climate change and managing land resources.
  - Production forests: Planting teak, mahogany and albizia to generate economic value while involving local communities in sustainable management.
- **Use of Weed Biomass:**
  Utilising *Chromolaena odorata* biomass for organic fertilizer or bioenergy to reduce pressure on forest ecosystems.

3. **Infrastructure and Technology Development**
   - **Supporting Infrastructure:**
     - **Farm ponds and rainwater reservoirs:** Constructed in rainfed rice and dryland agriculture zones to increase water supply during the dry season.
     - **Drainage channels:** Used to control runoff on sloping land, particularly in agroforestry zones.
   - **GIS and Remote Sensing Technology:**
     - Mapping land potential to support more accurate spatial planning.
     - Monitoring changes in land cover to assess the success of conservation strategies.
4. **Strengthening Community Capacity:**
   - **Training and Education:**
     - Training in soil conservation and water management for farmers in each zone.
     - Education on commodity diversification in agroforestry zones to increase income.
   - **Community Empowerment:** Formation of farmer groups based on zonation to support participatory implementation of strategies.
   - **Women's Empowerment:** Focusing training on the management of agroforestry products and weed biomass to enhance social inclusion and household income.
5. **Weed Management Strategy: Utilisation of *Chromolaena odorata***
   - **Biomass Utilisation:**
     - Processing *C. odorata* biomass into organic fertilizer to improve soil fertility.

- Producing biochar and briquettes as bioenergy for local community needs.

- **Development of Herbal Products:** The potential of *C. odorata* as a traditional medicinal ingredient can be explored further through collaboration between government and the pharmaceutical sector.
- **Multi-Stakeholder Collaboration**: Government, academia and the private sector are expected to collaborate in research and technological development related to weed utilisation.

6. Integrated Spatial Zoning

- **Protected and conservation forest:** Focused on areas with slope gradients > 45 % to maintain ecosystems.
- **Agroforestry zones:** Cover areas with slope gradients of 15-45 % for timber and horticultural cultivation.
- **Intensive agriculture zones:** Allocated to flat areas up to 15 % slope for main food production.

7. Policies and Incentives

- **Economic Incentives:**
  - Subsidies and incentives for farmers who adopt conservation technologies.
  - Microcredit to support enterprises based on agroforestry and weed utilisation.
- **Zoning Regulations:** Land use regulations based on the established zoning to ensure sustainable management.

8. Monitoring and Evaluation

- **Data-Based Monitoring:** Use of GIS technology to monitor the effectiveness of strategies and changes in land conditions.
- **Participatory Evaluation:** Involving local communities, stakeholders and government in the evaluation process so that strategies remain aligned with local needs.

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I. INTRODUCTION

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

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

In this new era, Timor-Leste faces significant challenges in optimally managing its natural resources to support sustainable development. The achievement of the Sustainable Development Goals (SDGs), particularly food security (SDG 2), clean water management (SDG 6) and climate change mitigation (SDG 13), has become a priority agenda.

To address these challenges, the identification of strategic regions is essential. Bobonaro District is one of the areas that offers substantial potential to support the achievement of national food security through optimal development of the agricultural sector.

Maliana Sub-District as a Core Irrigation Area

Bobonaro District (comprising Atabae Sub-District, Balibo Sub-District, Bobonaro Sub-District, Cailaco Sub-District, Lolotoe Sub-District and Maliana Sub-District) has diverse development potential. However, its flagship and priority potential is concentrated in **Maliana Sub-District**.

The Maliana area has geographical advantages that are ideal for irrigation-based intensive agriculture. The landscape is dominated by extensive flat land, supported by major rivers of sufficient size and an adequate irrigation network. These conditions make Maliana Sub-District a national priority area for the development of intensive irrigated rice fields, particularly for rice, which is a strategic element of food security in Timor-Leste.

Technical Basis: Vertisols as Soil Capital and Supporting Geology

The substantial potential in Maliana is strongly supported by its soil and geological conditions:

1. **Soil Capital (Edaphic):** Wilayah Bobonaro secara umum didominasi oleh **Tanah Vertisols (36,93%)**. This is a key asset. Vertisols have strong advantages in water-holding capacity and natural fertility, making them

highly suitable for the development of food crops such as rice. This potential is reinforced by the presence of very fertile **Mollisols (17.68 %),** as well as **Inceptisols (26.26 %)** and **Entisols (19.13 %).**

2. **Supporting Geology:** The dominant geological formations, (such as chaotic boulder fragments and unconsolidated deposits), are highly conducive to the development of modern irrigation infrastructure, including piped distribution and pumping systems, to maximise water management efficiency.

Opportunities for Integrated Development (Four Sectors)

With a focus on Maliana, but without neglecting other areas, the development strategy in Bobonaro District should encompass four integrated pillars:

1. **Agricultural Sector:** This is the main pillar. The focus is on developing intensive irrigated rice fields (especially rice) in Maliana Sub-District, taking advantage of the strengths of Vertisols and Mollisols.
2. **Forestry Sector:** In more sloping areas outside Maliana, agroforestry is a strategic solution. This system functions as a conservation base to reduce land degradation and increase carbon sequestration.
3. **Livestock Sector:** There is strategic potential for integrated farming systems, in which livestock are integrated with cropping activities to create efficient cycles (local feed supply and organic fertilizer).
4. **Fisheries Sector (Freshwater and Brackish Water):** There is dual potential in the fisheries sector. Coastal areas such as Atabae Sub-District can be developed for brackish water aquaculture (ponds). In addition, irrigation development in Maliana also creates opportunities for freshwater fisheries.

Evaluation Objectives in This Book

Accordingly, this study aims to comprehensively evaluate land suitability and map regional development potential in Bobonaro District. The primary focus is on the **agricultural sector** (with priority on irrigated rice fields), along with exploration of the **forestry sector (agroforestry), livestock and fisheries (freshwater and brackish water)** as integrated supporting sectors.

This book is expected to provide strategic and practical recommendations for local government and other stakeholders to manage natural resources sustainably in order to support Timor-Leste's national food security agenda in the new ASEAN era.

Historical and Context of Bobonaro

Bobonaro Sub-District, located at the western tip of Timor-Leste and bordering Nusa Tenggara Timur province in Indonesia, has a complex and dynamic demographic history. During the Portuguese colonial era, Bobonaro was a key administrative and military center. The town of Balibo, infamous for the 1975 tragedy involving five Australian journalists, was once a strategic Portuguese outpost. At that time, the population lived within a local feudal system while interacting with colonial power, with limited internal migration driven mainly by trade and agriculture.

The Indonesian occupation (1975–1999) brought major demographic shifts. Armed conflict, military operations, and displacement reduced the local population in some areas. Conversely, transmigration programs and infrastructure development introduced new ethnic diversity and altered population distribution. These historical dynamics continue to shape the socio-economic fabric of Bobonaro today, influencing its capacity to contribute to food security and sustainable development.

II. GENERAL OVERVIEW OF THE AREA

2.1 DEMOGRAPHY

Bobonaro District consists of 6 Sub-Districts: Sub-District Atabae, Sub-District Balibo, Sub-District Bobonaro, Sub-District Cailaco, Lolotoe Sub-District, and Maliana Sub-District. Geographically, Bobonaro District is located between 8°48'–9°15' S and 125°24'–125°55' E, with a distance of 149 km from Dili **(Figure 2.1)**.

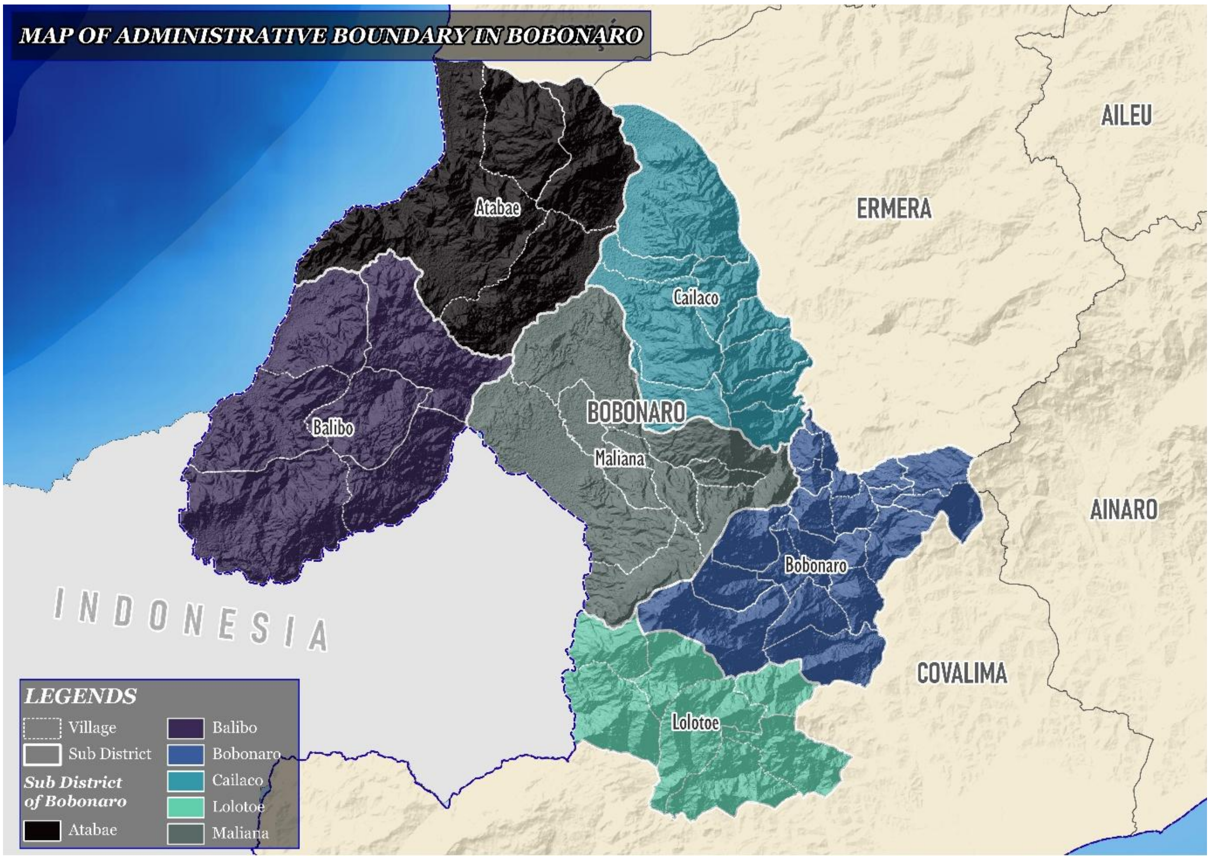


Figure 2.1 Administrative Area of Bobonaro District

Bobonaro District is one of the administrative areas in Timor-Leste, covering an area of 1.378,1 km² and inhabited by around 133.000 people. This region has diverse geographic characteristics and is spread across several administrative posts (sub-districts). Each sub-district has varying land areas and population sizes, reflecting differences in topography, natural resource potential, and the socio-economic dynamics of its communities. Details on the area of each sub-district are provided in **Table 2.1.**

Table 2.1 Area Data (ha) Bobonaro District

Sub-District	Area (ha)
Atabae	25.188,76
Balibo	29.597,30
Bobonaro	21.639,82
Cailaco	20.446,87
Lolotoe	16.872,81
Maliana	23.851,67

Bobonaro Sub-District, located at the western tip of Timor-Leste and bordering Nusa Tenggara Timur province in Indonesia, has a complex and dynamic demographic history. During the Portuguese colonial era, Bobonaro was a key administrative and military center. The town of Balibo, which became infamous for the 1975 tragedy involving five Australian journalists, was once a strategic Portuguese outpost. The population of Bobonaro during that time lived within a local feudal system while interacting with colonial power, with limited internal migration, primarily driven by trade and agriculture. The Indonesian occupation (1975–1999) brought major demographic shifts, as armed conflict, military operations, and displacement led to a decrease in the local population in some areas. On the other hand, transmigration programs and infrastructure development by the Indonesian government brought in people from outside Timor, creating new ethnic diversity and altering the population distribution.

2.2 SOIL TYPES

Soil information for the Timor-Leste region has been classified using the 1992 Soil Taxonomy key. This classification is carried out up to the Great Group/Soil Type/Soil Group level. There are 7 soil orders, 16 suborders, and 22 Great Groups (Soil Types).

Bobonaro District is predominantly covered by Vertisol soils, which span an area of 49,224.44 km² (36.93%), as shown in **Figure 2.2**, scattered across the entire study area, as depicted in **Figure 2.3**. In addition, Inceptisols cover 35,02.61 km² (12.82%), Entisols cover 25,501.68 km² (19.13%), and Molisols cover

23,565.75 km² (17.68%). Vertisols typically form in warm, humid, or semi-dry climates, and the vegetation growing on Vertisols generally includes grasslands, savannahs, open forests, or desert shrubs. Inceptisols are commonly used for intensive agriculture, but poor management can lead to reduced soil fertility. Entisols, on the other hand, are young soils still in the early stages of development, often found over parent material such as rocks or newly deposited material.

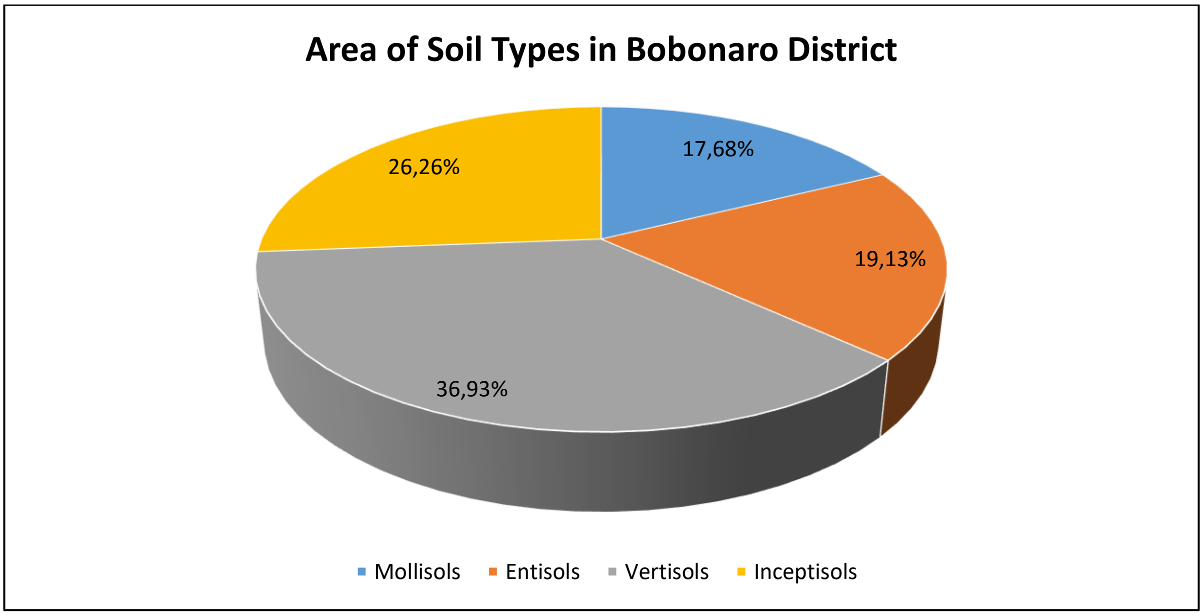


Figure 2.2 Soil Type Distribution in Bobonaro District

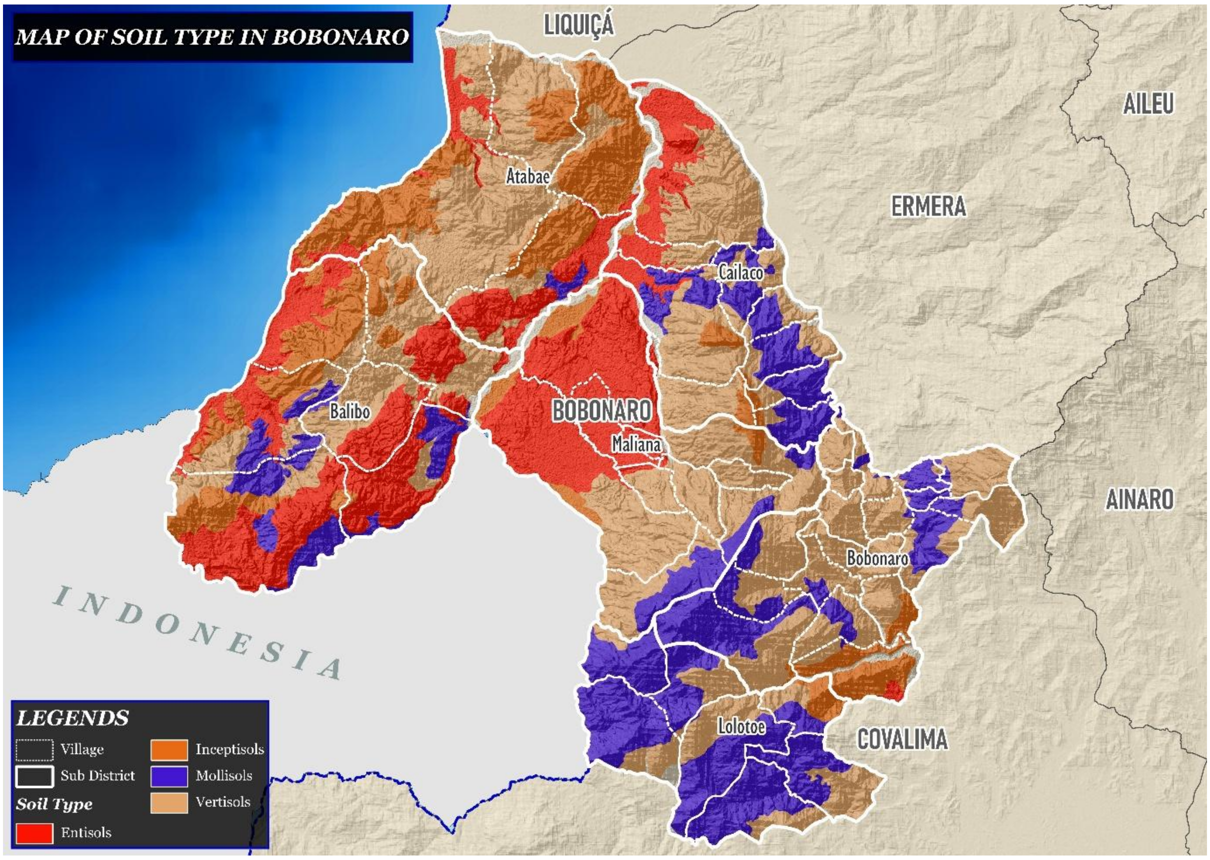


Figure 2.3 Soil Map of Bobonaro District

2.3 LAND USE

The development of agricultural commodities is a focal point for food improvement in Bobonaro District. This development must align with appropriate land use to enhance productivity as expected. Land use in Bobonaro District is varied across its sub-districts. Atabae Sub-District has agricultural land covering 2.26%, with river areas at 0.57%. Forest areas in this sub-district occupy 15.44%, and residential and industrial areas cover only 0.05%. This land use pattern shows that the potential for forestry development is very high, as almost all of its area is forested, and sustainable farming practices and proper conservation techniques must be implemented to prevent land degradation.

Balibo Sub-District shows a land use formation where forestry areas occupy 21.14%, the largest share of land use in comparison to other sub-districts, with river areas covering 0.26%. Although this sub-district has agricultural land, it is minimal, comprising only 0%. Based on this land use pattern, the development potential here is focused on forestry commodities, and forest areas should be utilized for growing economically valuable crops while ensuring sustainability.

Bobonaro Sub-District shows agricultural land use of 4.36%, followed by dry land at 0.57%. The forest area in this sub-district is 10.54%, with river areas at 0.25%, and residential and industrial areas at 0.02%. This pattern indicates that agricultural development should be optimized and intensive, with proper conservation applied, while the forest area must be managed sustainably due to its large coverage. Data on land area by land use type is presented in **Figure 2.4**.

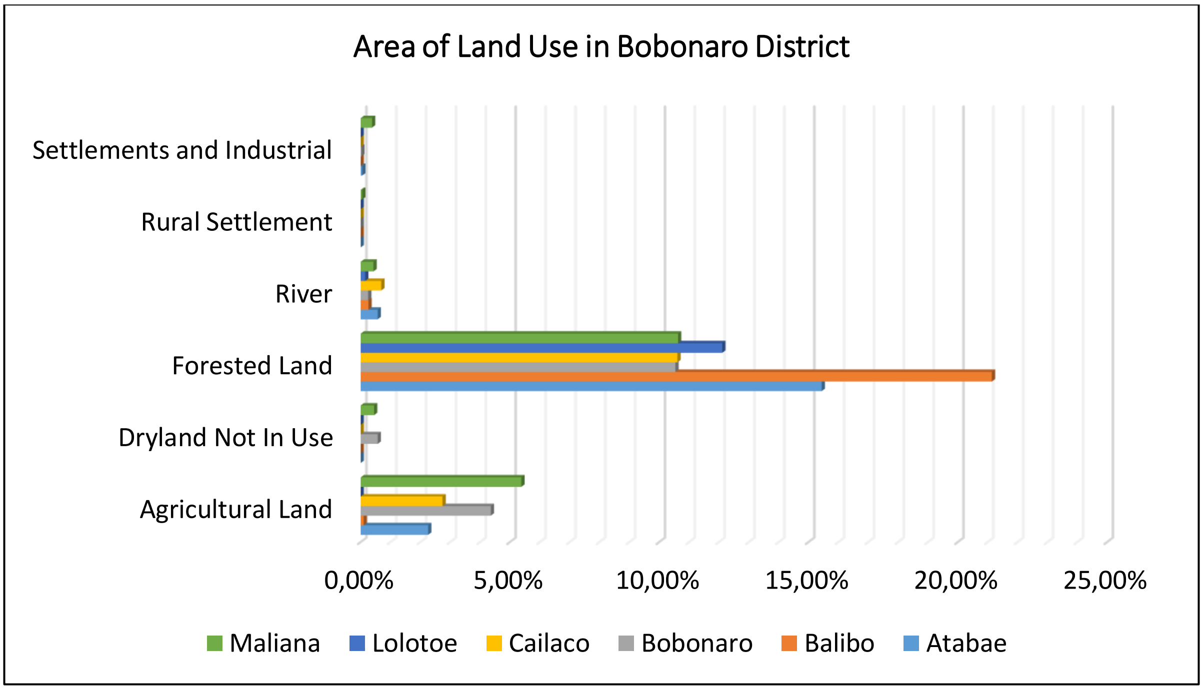


Figure 2.4 Land Use by Type (%) in Bobonaro District

Cailaco Sub-District has agricultural land covering 2.74%, followed by a relatively large forest area of 10.61%. River areas in this sub-district cover 0.69%, the largest compared to other sub-districts. This pattern suggests that agricultural land development should be efficient, with proper conservation, and sustainable forestry practices should be applied.

Lolotoe Sub-District has the same land use formation as Balibo Sub-District, with only forest land use at 12.11%, and river areas at 0.15%. This indicates that the focus for development is on the forestry sector, and high-value commodities should be planted in forested areas.

Maliana Sub-District has agricultural land covering 5.38%, dry land at 0.45%, forest areas at 10.63%, river areas at 0.43%, rural settlements at 0.05%, and residential and industrial areas at 0.38%, as shown in **Figure 2.5**. This land use pattern suggests that agricultural development should be as efficient as possible, and the forest area should be developed sustainably.

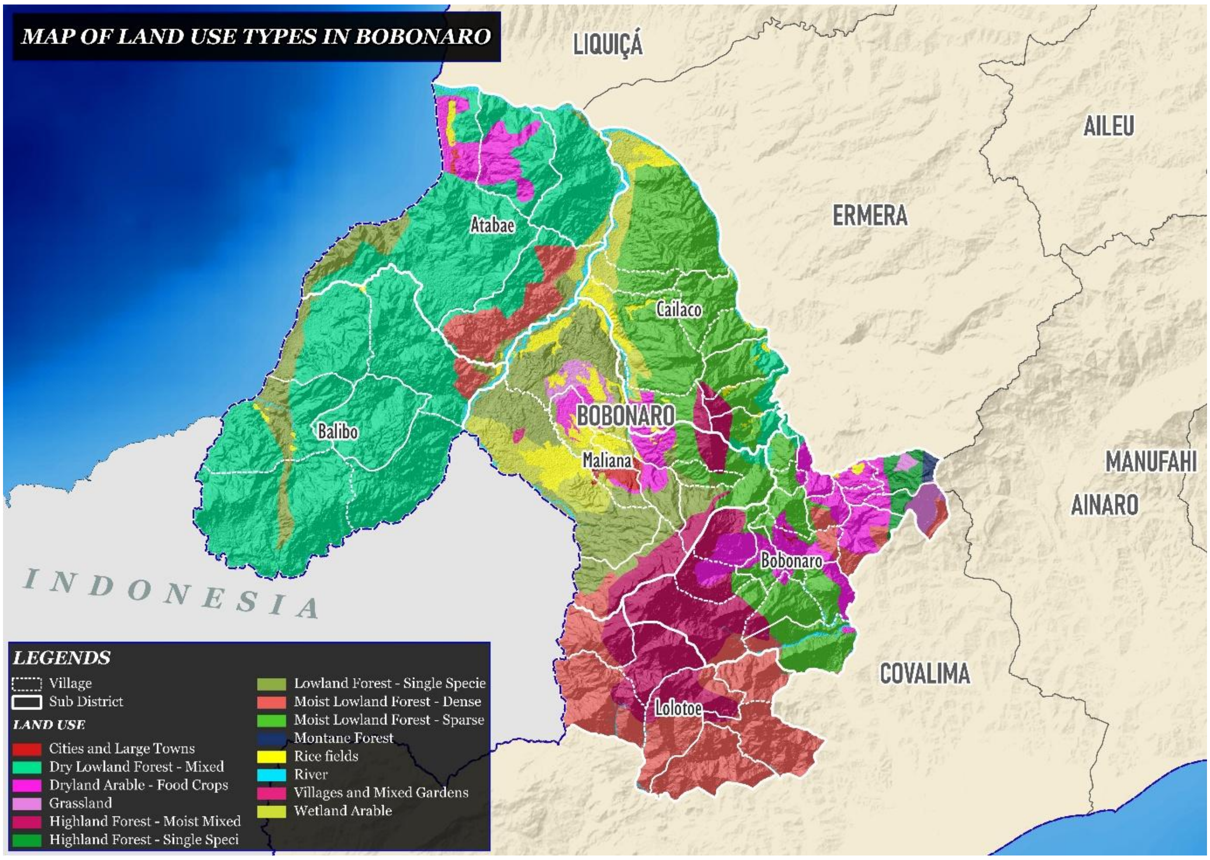


Figure 2.5 Land Use Map of Bobonaro District

2.4 EXISTING CONDITIONS

Bobonaro District has large areas of idle land across different regions that have not been optimally utilized, despite their significant potential for agricultural development. One of the main issues is the insufficient management of river water for irrigation systems, even though river water could be a key resource for supporting agricultural activities. Additionally, the excessive use of chemical fertilizers is a growing concern, as it may lead to long-term soil fertility decline and environmental pollution.

Furthermore, many dry lands located on steep slopes with minimal vegetation are at high risk of soil erosion. Erosion not only reduces soil fertility but also causes sedimentation in water bodies, which can harm aquatic ecosystems and reduce the availability of water for irrigation and other uses. Therefore, better conservation efforts are needed, such as planting cover crops, constructing terraces, and improving water management to address these issues and fully utilize land potential **(Figure 2.6)**.

In field observations and monitoring evaluations conducted by the Ministry Team under the leadership of Eng. Rofino Soares Gusmao, M.M, Director Geral dos Serviços Corporativos–MAPPF, significant potential for expanding rice paddies was identified, which could be maximized to increase food production **(Figure 2.7).** The team also identified substantial opportunities for developing commodities such as shallots and horticultural products in several promising areas. This effort is seen as a strategic step to not only increase agricultural productivity but also improve the welfare of local communities. Agricultural technology enhancement and training for local farmers are also planned to support the success of these initiatives and ensure sustainable results.

Figure 2.6 Condition of Mixed Garden Land in the Field

Figure 2.7 Productive Areas for Rice and Corn Development

2.5 *Chromolaena odorata*

Choromolaena odorata **(Figure 2.8.)** is a flowering weed from the Asteraceae family that grows in tropical and subtropical regions. This plant originates from North America, Mexico, and the Caribbean before spreading widely across Asia, Africa, and Australia through human activity and natural phenomena (Day et al., 2013). It has spread to developing countries such as Timor-Leste, where it has significant environmental and economic impacts.

C. odorata is commonly found in tropical lowlands up to 500 m above sea level, particularly in open land such as coconut plantations, rubber estates, home gardens, and grazing fields (Peniwiratri & Arbiwati, 2021). Morphologically, it has a cylindrical, hairy stem, simple serrated leaves, and composite flowers that are bluish when young, turning brown as they mature **(Figure 2.9).** Chemically, *C. odorata* contains active compounds such as flavonoids, tannins, alkaloids, saponins, and essential oils (Jamatia et al., 2024), which can be used as raw materials for traditional medicine for conditions such as diabetes, burns, hypertension, and skin infections (Jamatia et al., 2024).

Figure 2.8 Chromolaena odorata Plant
(Source: Zimbabweflora)

Chromolaena odorata was first found in Timor-Leste in the 1980s. Its rapid spread is attributed to slash-and-burn practices and the dry tropical climate that supports its growth (Day et al., 2013). *C. odorata* can grow in various soil types, including nutrient-poor land, and is typically found at altitudes of 500–2,000 m above sea level (Westaway et al., 2018). Its rapid spread indicates the plant's strong adaptability but also poses a serious threat to productive agricultural land.

Chromolaena odorata is an invasive weed that presents a significant threat to agriculture, livestock, and the environment in Timor-Leste. It grows densely and rapidly, inhibiting the growth of agricultural crops such as corn, coffee, and other horticultural products. This weed primarily affects newly cultivated lands that are a vital source of livelihood for rural communities (Day et al., 2013). With deep roots and wide branches, it absorbs soil nutrients faster than cultivated plants, leading to decreased crop yields and worsening food security. In livestock farming, the leaves of *Chromolaena odorata* contain toxins harmful to cattle and goats, as they can damage the liver when consumed in large quantities (Day et al., 2013; Jamatia et al., 2024).

Figure 2.9 Structure of Chromolaena odorata Flowers and Leaves
(Source: R.M. King & H. Rob)

The dominance of this weed in grazing lands reduces grass availability, thereby diminishing grazing capacity and lowering farmers' income (Westaway et al., 2018). Ecologically, it dominates native vegetation and disrupts the regeneration of local plants important for biodiversity (Mugwedi, 2020). Its biomass, which dries quickly, can increase the risk of fires during the dry season (Day et al., 2013), accelerate soil degradation, reduce environmental quality, and lower soil microbial content that plays a role in maintaining soil fertility.

Chromolaena odorata has various potential benefits, such as being an indicator of soil fertility. Studies show that mixing *C. odorata* biomass with manure can increase phosphorus levels in sandy soils and aid the growth of crops such as shallots. Its high organic content also makes it suitable for processing into environmentally friendly organic fertilizers. In Vietnam, *C. odorata* leaves are used to treat soft tissue wounds and leech bites, while in Africa, they serve as a natural antiseptic. *C. odorata* biomass can also be processed into high-quality vermicompost with the help of *Eisenia fetida* earthworms. This compost contains important nutrients like nitrogen, phosphorus, and potassium, making it a sustainable organic fertilizer alternative.

III. RESEARCH METHODS

This study was conducted in Bobonaro District, Timor-Leste, with the main objective of evaluating land suitability for agricultural development. Data were collected through field surveys, laboratory analysis, and the use of geographic information systems (GIS). The research was carried out from July to August 2024, focusing on direct field observations, soil sampling, interviews with local farmers, and GIS-based mapping. Each research phase was systematically organized to obtain accurate information that can serve as a basis for sustainable land management planning.

3.1 RESEARCH DESIGN

A. Methodological Approach

This study uses both quantitative and qualitative approaches. The quantitative approach aims to obtain numerical data analyzed statistically, while the qualitative approach is used to explore the understanding and experiences of farmers in managing agricultural land (Trigunasih, 2016). The research methods include field observations and laboratory analysis, including soil sampling and interviews with local communities.

B. Sampling Point Determination

The sampling points for this research were determined using the Homogeneous Land Unit (HLU) approach, obtained through overlaying various thematic maps, including land use, soil types, geology, and slope maps. The analysis and delineation of land units were performed using QGIS 3.10 software (Trigunasih et al., 2023). Soil sampling was conducted randomly and in a composite manner using the soil boring method. Each land unit was represented by one composite soil sample, which was collected at a depth of 0-30 cm for annual crops and 30-60 cm for perennial crops. Each soil sample weighed approximately 1 kg and was sent for further analysis in the laboratory.

C. Soil Morphology Observation

During the soil sampling process, environmental conditions around the sampling sites were observed and recorded using a soil observation form. Parameters observed included soil color, texture, structure, consistency, and drainage conditions. For more in-depth analysis, ring samples were used in the collection of undisturbed soil samples to measure bulk density (BD) and soil porosity, which are crucial in determining land fertility and water holding capacity (Sukarman et al., 2017).

D. Interviews and Questionnaires

In conjunction with the field surveys, structured interviews and questionnaires were administered to local farmers using purposive sampling or judgmental sampling methods, considering the respondents' experience and expertise in agriculture (Sekaran & Bougie, 2013). The collected data included cropping patterns, agricultural challenges, and existing land use systems in the study area.

E. Land Suitability Evaluation

Field survey results, climate data, and laboratory analysis were compiled and evaluated using an agroecosystem land suitability assessment system based on the criteria of Ritung et al. (2011). The classification method used follows the FAO (1976) matching system, which matches land characteristics with the growth requirements of the evaluated crops. The agricultural commodities analyzed included food crops, horticulture, industrial crops, forestry, spices and medicinal plants, livestock feed, and grazing.

3.2 RESEARCH PROCEDURE

A. Literature Review

The literature review stage aims to gather secondary data supporting this study. The data collected include administrative maps of the study area, geographic conditions, agricultural land areas, and data on agricultural commodity production. Climate data analyzed include temperature, rainfall, and dry months. In addition, previous relevant research on land suitability evaluation was reviewed to strengthen the theoretical foundation of this research.

B. Land Unit Analysis

The SLH analysis aims to define land units as the basis for field observation planning. The homogeneous land units produced were used as references for soil sampling and for the development of land suitability maps. The HLU analysis process includes:

a. Interpretation of Digital Elevation Model (DEM) maps to analyze landforms and slope gradients.

b. Satellite imagery analysis to verify actual land use patterns, especially in areas that have undergone land conversion, such as rice fields, settlements, and infrastructure.
c. Utilization of supporting data, such as slope, geology, and soil type maps, to strengthen land unit delineation.
d. Overlaying various thematic maps to generate homogeneous land units for soil sampling.

C. Field Survey

Field surveys were conducted to verify the suitability of homogeneous land units with actual field conditions. If discrepancies were found between map analysis results and field conditions, adjustments were made through re-delineation. Sampling points were determined based on HLU analysis and the current field conditions.

Additionally, interviews with local farmers were conducted to gather additional information on agricultural practices and challenges encountered in land management. Observations were made on various environmental factors affecting agricultural productivity, such as soil drainage, effective soil depth, erosion risk, flood risk, and surface rock content (Ritung et al., 2011).

Soil samples were collected using the soil boring method, with depths of 0-30 cm for annual crops and 30-60 cm for perennial crops. The collected soil samples were sent for further analysis in the laboratory to determine the physical and chemical properties that affect soil fertility. Climate data, such as temperature, rainfall, and dry months, were collected from local climate observation stations and presented in tabulated data. Results of the land suitability evaluation and characteristics of each land unit are presented in **Table 3.1**.

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

No	Parameter	Data Acquisition		Data Source
		Primary	Sekunder	
1	Temperature		√	Remote Sensing/ Climatology Timor-Leste
2	Rainfall		√	Remote Sensing/ Climatology Timor-Leste
3	Dry Months		√	Remote Sensing/ Climatology Timor-Leste

4	Humidity		√	Remote Sensing/ Climatology Timor-Leste
5	Drainage	√		Field Survey
6	Soil Texture	√		Laboratory Results
7	Coarse fragments	√		Field Survey
8	Effective Soil Depth	√		Field Survey
9	Cation exchange capacity (CEC)	√		Laboratory Results
10	Base saturation (BS)	√		Laboratory Results
11	Soil pH	√		Laboratory Results
12	Soil organic Carbon (SOC)	√		Laboratory Results
13	Total N	√		Laboratory Results
14	P_2O_5	√		Laboratory Results
15	K_2O	√		Laboratory Results
16	Salinity	√		Laboratory Results
17	Alkalinity	√		Laboratory Results
18	Slope gradient	√		Field Survey
19	Erosion hazard	√		Field Survey
20	Flood hazard	√		Field Survey
21	Surface rock cover	√		Field Survey
22	Rock outcrops	√		Field Survey

D. Laboratory Soil Analysis

Parameters used to determine soil characteristics from the analyzed samples in the laboratory include:

a. C-organic using the Walkley and Black method (%).
b. N-total using the Kjeldahl method (%).
c. Soil texture using the pipette method.
d. Soil pH using the potentiometer method (H_2O 1:2.5).
e. P-Available (ppm) and K-Available (ppm) using the Bray-1 method if the soil pH is below 7, and the Olsen method if the pH is above 7, with unit conversion to mg/100 g.
f. Salinity (dS/m) using the potentiometer method (H2O 1:2.5).
g. CEC (cmol) and BS (%) using NH_4OAc 1N pH 7 extraction.
h. Total P (mg /100 g) using the 25 % HCl method
i. Total K (mg/100 g) using the 25 % HCl method
j. Fertility Status determined by the method (PPT, 1995)
k. Erosion risk using the Universal Soil Loss Equation (USLE).

E. Land Suitability Analysis

Field observation results and laboratory analysis results were tabulated into agroecosystem land characteristic/quality data. Agroecosystem land suitability analysis was conducted by matching land characteristics/quality data with the growth requirements of the analyzed agricultural crops, which included food crops, horticulture, industrial crops, forestry, spices and medicinal plants, livestock feed, and grazing. This allowed for the classification of land suitability according to the criteria of Ritung et al. (2011). The classification was analyzed down to the land unit level.

Land suitability classes were classified into actual and potential land suitability. Actual land suitability for each homogeneous land unit was determined by matching the land characteristics/quality with crop growth requirements without improvements to limiting factors. Potential land suitability was determined by considering inputs and management actions applied to each homogeneous land unit, assuming improvements are made to address the limiting factors.

F. Agricultural Commodity Development Planning

Commodity planning was based on the evaluation of potential land suitability suitable for the developed agricultural commodities, with the highest land suitability for each crop as the main parameter. Other parameters included the primary land use for each homogeneous land unit and the feasibility of farming activities.

G. Land-Use Recommendations

Land use guidelines were prepared at the land unit level, based on the highest land suitability assessment, followed by lower suitability levels, addressing limiting factors, and improvement efforts for each homogeneous land unit in the 14 districts of Timor-Leste. The creation of digital maps using GIS greatly facilitated the interpretation of information. These maps contain information on agroecosystem land suitability, land use guidelines, and zoning for agricultural commodities.

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

H. Data Analysis Using Geographic Information System Technology

The land suitability information system consists of spatial data (homogeneous land unit maps) and attribute data (land suitability classes). Combining these two components generates the information system using QGIS 3.10 software, providing information on land suitability classes for food crops, horticulture, and plantation commodities based on suitability evaluations. The resulting land suitability maps, along with the associated database and resource information, are based on land suitability criteria aligned with their development potential, such as crop varieties, cultivation technologies, and land management.

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

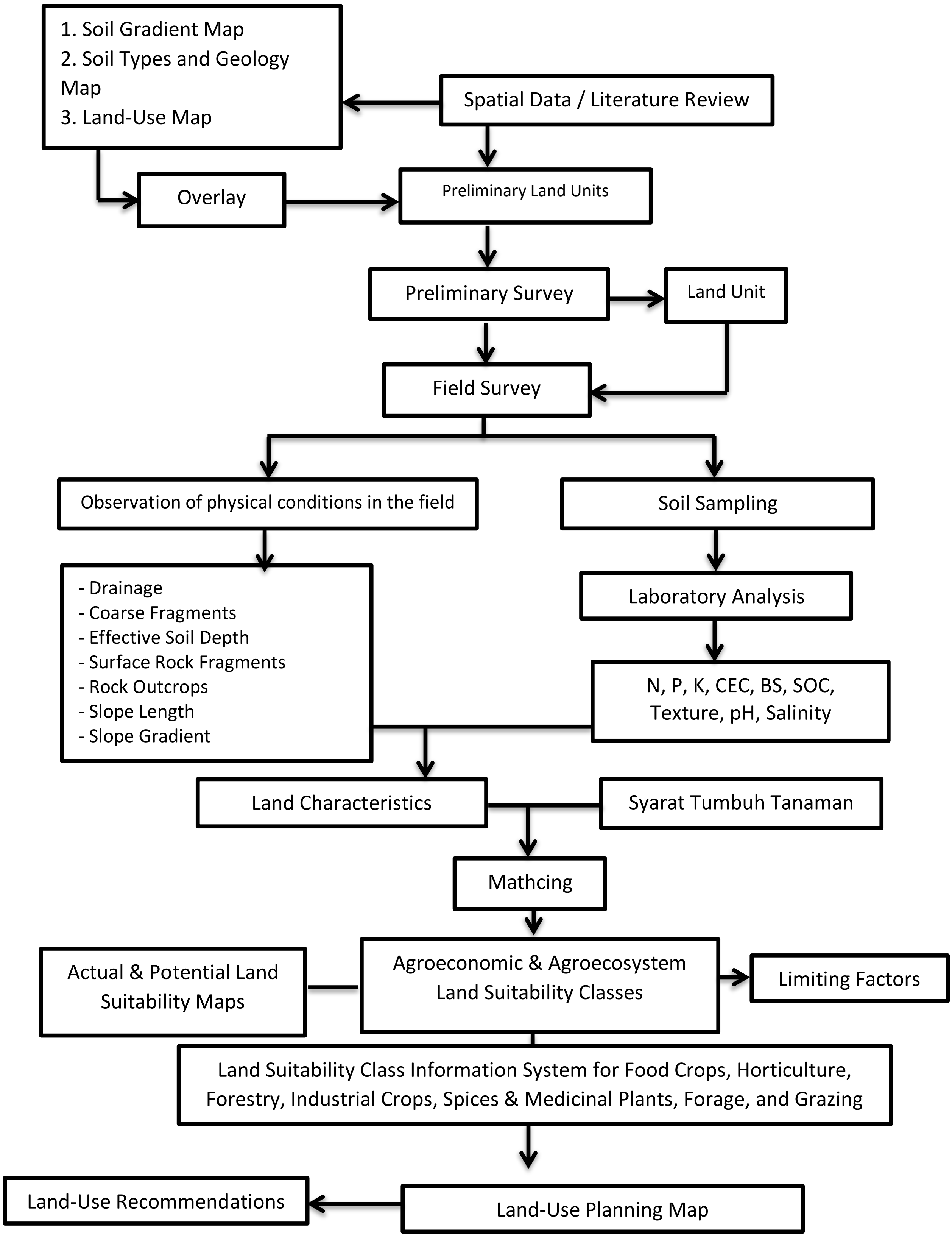


Figure 3.1 Research Process Flow Diagram

3.3 GEOGRAPHIC INFORMATION SYSTEM 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 can be outlined as follows:

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

From various definitions of GIS, several common keywords emerge, including spatially referenced data, data analysis (both spatial and attribute) to produce information, and specific purposes. Therefore, it can be concluded that compared to other systems, GIS has the ability to handle data and information from a geographical perspective. This is particularly relevant for development planning, as such planning is implemented within the context of a specific region (area).

The term “Geographic” is a part of the spatial concept. These terms are often used interchangeably, leading to the emergence of the third term, geospatial. All three terms carry the same meaning within the context of GIS. The term “Geographic” refers to an issue concerning the Earth’s surface, either two-dimensional or three-dimensional (Prahasta, 2005).

The term “geographic information” refers to information about places located on the Earth's surface, knowledge about the position where an object is located on the Earth’s surface, and information about the attributes present on the Earth’s surface, where the position is given or known (Prahasta, 2005).

GIS is a formal system consisting of various physical resources related to objects found on the Earth’s surface. Thus, GIS also refers to software that can be used for inputting, storing, manipulating, displaying, and outputting geographic information along with its attributes (Prahasta, 2005). **Figure 3.2** shows the components that form a GIS.

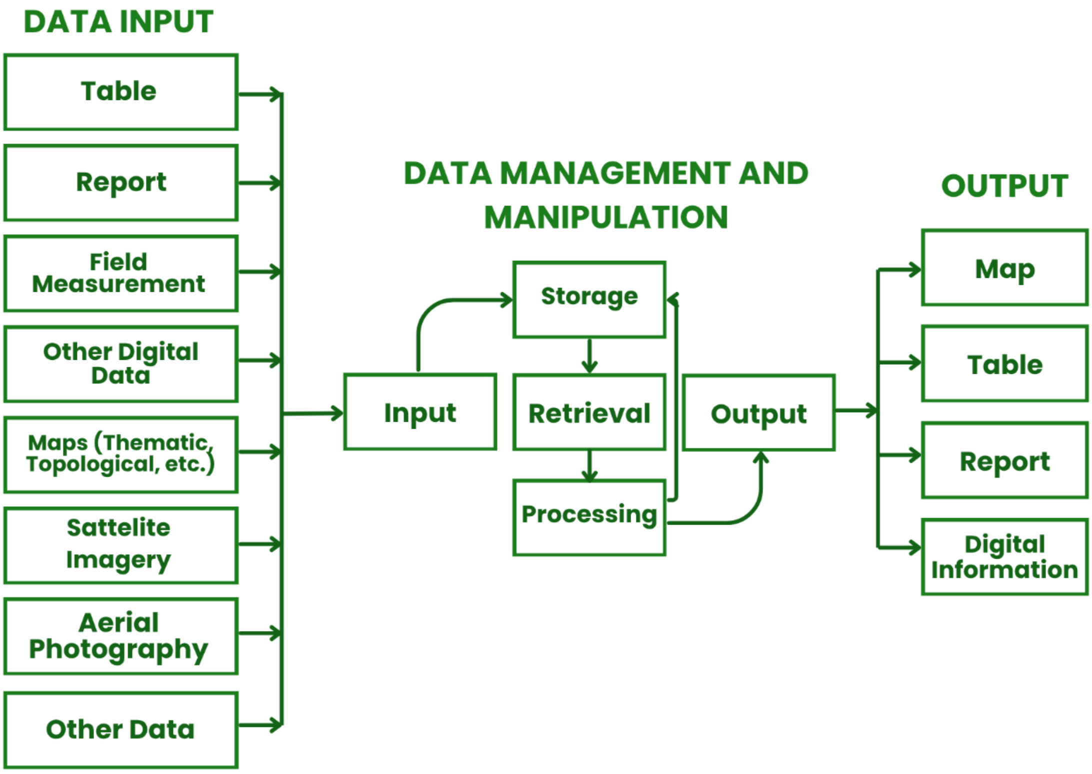


Figure 3.2 GIS Components
(Source: Prahasta, 2005)

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

1. Cartographic Capability
   With this capability, GIS users can create maps and technical drawings effectively and efficiently. This cartographic capability includes digitization, graphic visualization, interactive line manipulation, and plotting.
2. Data Management Capability
   GIS has the ability to store, process, and manipulate geographically referenced data. This management capability also includes processing attribute data, which involves storing and displaying specific attributes associated with a given geographic feature.
3. Analytical Capability
   Analytical capability refers to the ability to interpret and study the data and information collected for specific purposes. This analysis includes engineering function analysis, prediction/forecasting ability, computational operations, demographic analysis, socio-cultural analysis,

analysis of various regions and Districts, graphic and tabular presentations, overlay analysis, logical analysis, and selection analysis.

4. GIS and Multimedia Integration

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

A. Proses dan Komponen SIG

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

1. **Data Input**

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

2. **Data Transformation**

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

3. **Editing**

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

4. **Data Management**

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

5. **Query and Analysis**

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

a) Proximity Analysis

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

b) Overlay Analysis

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

6. Visualization

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

B. Komponen SIG

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

1. Hardware

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

2. Software

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

a. Tools for data input and manipulation.

b. A database management system (DBMS).

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

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

3. **Data**

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

4. **Human**

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

5. Methods

A good GIS has harmony between a well-prepared design plan and real-world rules. The modeling methods and implementation will vary according to each specific problem.

C. Pengolahan Data dalam SIG

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

1. Base Map Digitization

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

2. Data Import

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

3. Image Geometry Correction

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

4. Digital Image Processing

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

5. Satellite Image Classification

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

6. Spatial Information Updating

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

7. Field Survey

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

8. Re-interpretation and Editing

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

9. Edge Matching

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

10. Digital Cartography and Map Production

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

11. Database Design and Modeling

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

IV. LAND CHARACTERISTICS

4.1 TEMPERATURE

Air temperature is a key factor in land suitability evaluation, as it significantly affects the sustainability of natural resource management and regional development potential. In this study, temperature distribution was analyzed using a combination of field measurement data and geospatial data based on the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM), with the Braak formula approach. This analysis provides a comprehensive view of temperature variability, reflecting the complexity of topography, elevation, and microclimates in Bobonaro District.

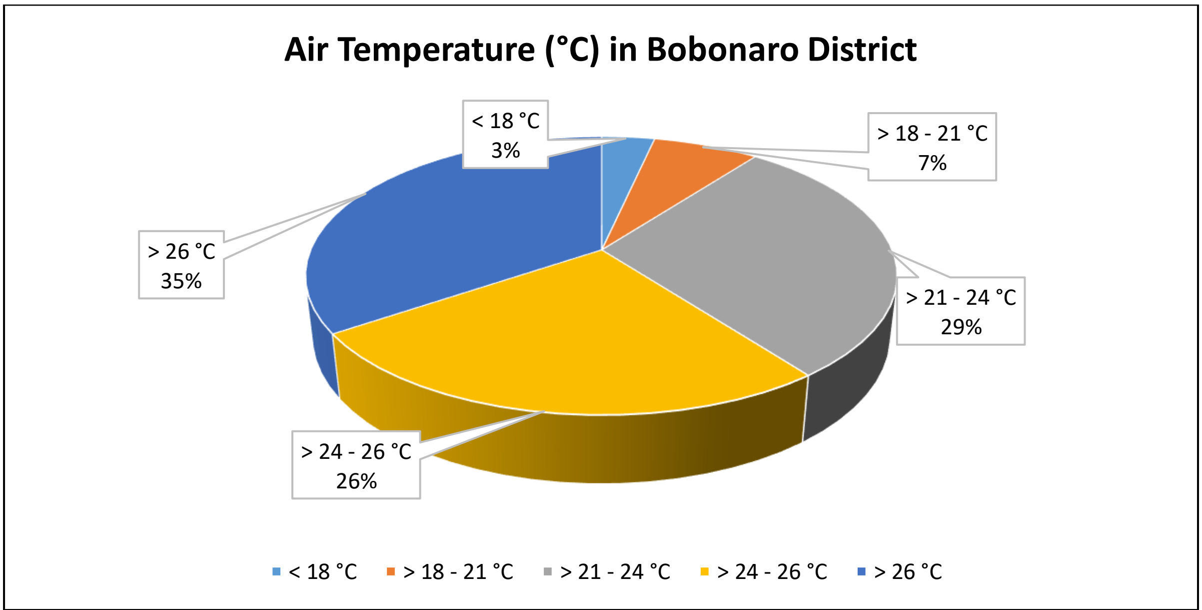


Figure 4.1 Air Temperature Data in Bobonaro District

Temperature distribution in Bobonaro District **(Figure 4.1)** shows that the region is predominantly characterized by temperatures >26°C (35%), followed by temperatures between 21-24°C (29%) and 24-26°C (26%). Meanwhile, areas with temperatures lower than 18-21°C (7%) and <18°C (3%) have a smaller coverage. This distribution pattern indicates that Bobonaro District has a generally warm to hot climate, with a few cooler areas. In agricultural contexts, air temperature is an important factor in determining the types of crops that can grow optimally. Areas with temperatures between 21-26°C cover more than half of Bobonaro, making them generally suitable for tropical crops such as rice, corn, root crops, and horticultural plants. However, temperatures >26°C, covering 35% of the region, present challenges regarding water availability and increased evapotranspiration, which can affect crop growth and land productivity. Conversely, areas with lower temperatures, though limited in proportion, can support the growth of crops that are more heat-sensitive, such as leafy vegetables or certain plantation crops. However, with limited coverage, the use of these areas for agriculture may be more specific to certain commodities.

Overall, Bobonaro District has temperature conditions that support agriculture, especially for tropical crops that are resilient to warm to hot temperatures. However, in areas with higher temperatures, effective land management strategies are needed, such as using heat-resistant crop varieties, implementing efficient irrigation systems, and employing soil conservation techniques to maintain soil fertility and moisture. With proper planning, agricultural potential in Bobonaro District can be maximized to support sustainable food production according to local climate conditions.

4.2 RAINFALL

Land characteristics in Bobonaro District, based on field observations, include rainfall, dry months, drainage, soil texture, slope gradient, and erosion risk. Field observations of rainfall indicate that the sub-districts vary in rainfall amounts. For example, Sub-District Atabae receives rainfall between 1500-2000 mm, which dominates 55% of the area; Sub-District Balibo has rainfall between 1500-2000 mm across its entire area (100%); Sub-District Bobonaro receives >2000 mm of rainfall, dominating 92% of its area; Sub-District Cailaco has rainfall between 1500-2000 mm, which dominates 73% of the area; Sub-District Lolotoe receives >2000 mm of rainfall across the entire area (100%); and Sub-District Maliana receives 1500-2000 mm of rainfall, which dominates 69% of the area. These data show that each sub-district has varying rainfall dominance, which also affects water availability. A complete representation of rainfall data distribution is presented in **Figure 4.2**.

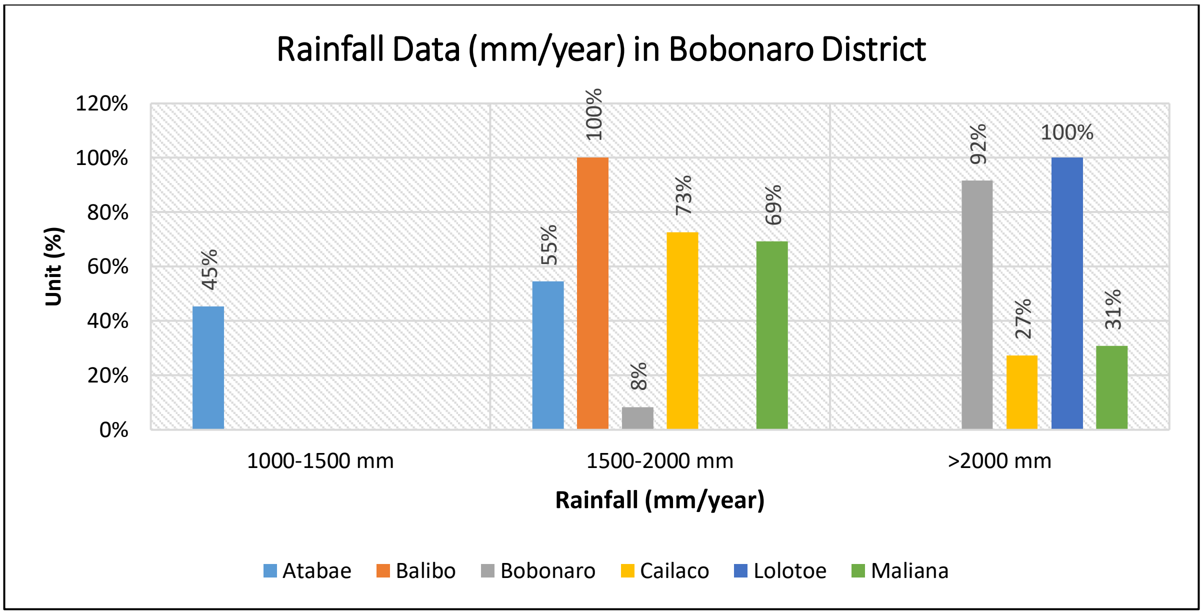


Figure 4.2 Rainfall Data (mm/year) in Bobonaro District

4.3 DRY MONTH

Land characteristics based on dry months in Bobonaro District show variations across sub-districts. Sub-District Atabae has 0-1 dry months dominating 55% of the area; Sub-District Balibo has 0-1 dry months dominating 50%; Sub-District Bobonaro has 3-4 dry months dominating 42%; Sub-District Cailaco has 0-1 dry months dominating 45%; Sub-District Lolotoe has 4-5 dry months dominating 71%; and Sub-District Maliana has 3-4 dry months dominating 42%. Based on the distribution of dry months in Bobonaro District, it can be concluded that the average number of dry months per sub-district is relatively short, with most areas experiencing 0-1 dry month. However, one sub-district, Lolotoe, has a prolonged dry period of 4-5 months, which can affect water availability. A complete distribution of dry month data is presented in **Figure 4.3**.

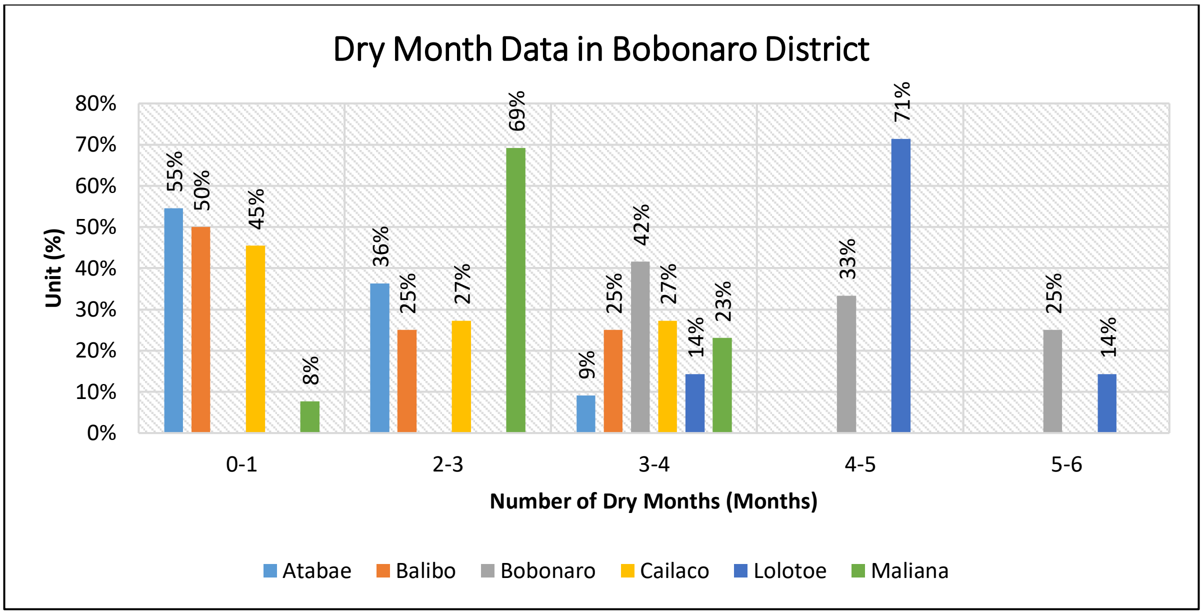


Figure 4.3 Dry Months Chart in Bobonaro District

4.4 DRAINAGE

Based on drainage characteristics observed in Bobonaro District, almost all sub-districts share similar drainage conditions within their respective areas. Four sub-districts have good drainage, with dominance such as Sub-District Atabae (82%), Sub-District Balibo (75%), Sub-District Bobonaro (83%), Sub-District Cailaco (64%), and Sub-District Lolotoe (86%). Sub-District Maliana, however, has different criteria, with impaired drainage dominating 54%. The better the drainage in an area, the more favorable the soil oxygen availability, which allows for better water movement, thus supporting plant water requirements. A complete representation of drainage data distribution is presented in **Figure 4.4**.

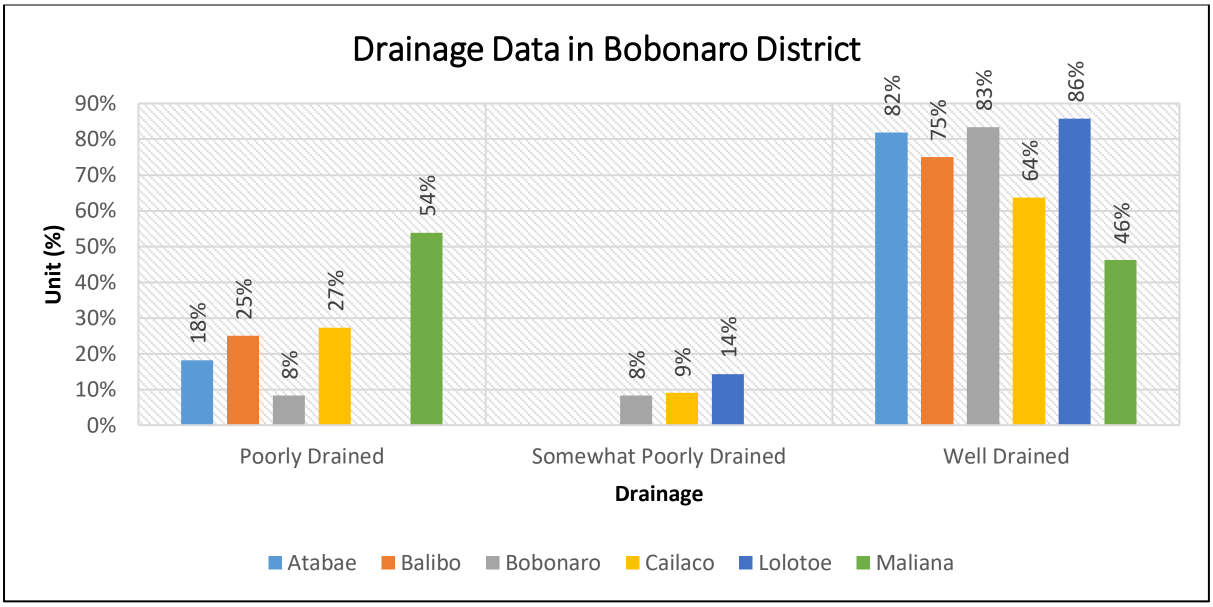


Figure 4.4 Drainage Data in Bobonaro District

4.5 SOIL TEXTURE

Soil texture characteristics in the sub-districts of Bobonaro District vary. Sub-District Atabae has a dominant soil texture of fine and moderate texture, each with a proportion of 27%; Sub-District Balibo has a dominant texture of somewhat fine to fine, comprising 50% of the area; Sub-District Bobonaro has a dominant fine texture, covering 50%; Sub-District Cailaco has two dominant textures somewhat fine and moderate each comprising 36% of the area; Sub-District Lolotoe has a dominant somewhat fine texture at 57%; and Sub-District Maliana has a dominant fine texture, covering 38% (**Figure 4.5**). Finer-textured soils tend to have higher organic matter content and better water retention capacity, while coarser textures improve soil aeration.

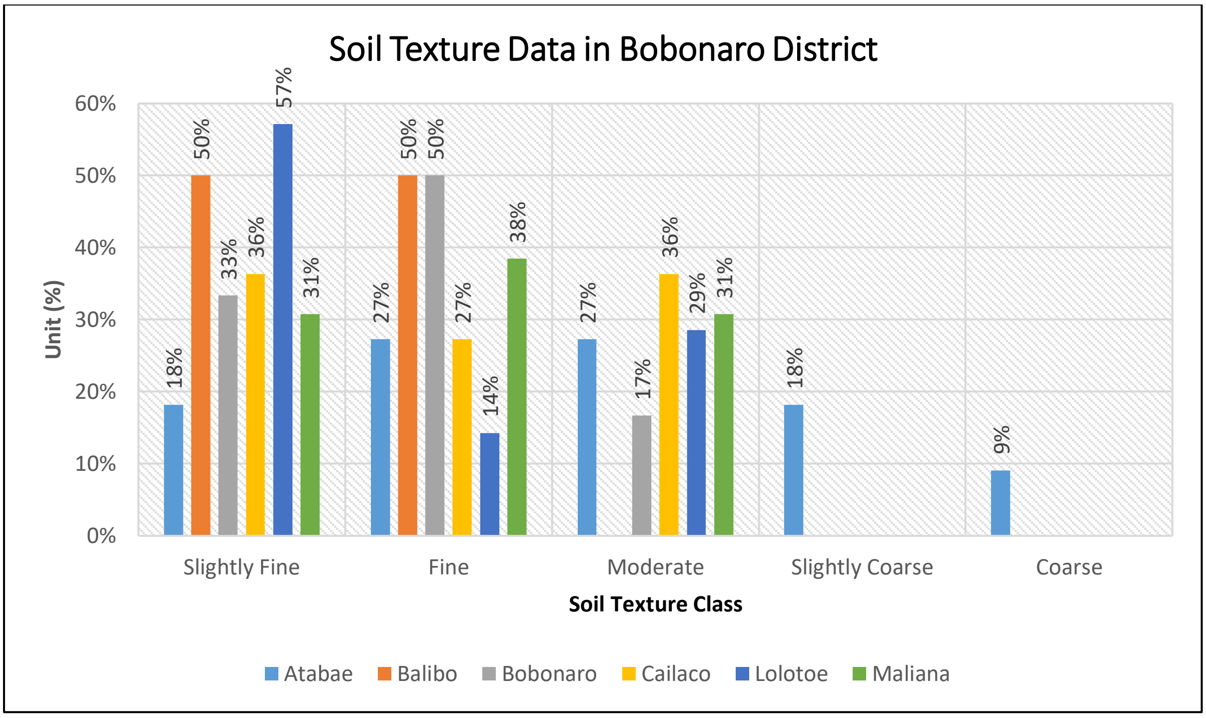


Figure 4.5 Soil Texture Data in Bobonaro District

4.6 COARSE FRAGMENT

Based on **Figure 4.6**, which shows the distribution of coarse material percentages in Bobonaro District, the <5% category dominates with 66%, indicating that most of the region has very low coarse material content. Soils with low coarse material content typically have finer textures, such as clay or loam, which usually offer better water retention and fertility for agriculture. The next categories are 5-10% and 15-20%, each covering 10% of the total area, indicating some regions with slightly higher coarse fragment content, but still within the range suitable for intensive agriculture. The 10-15% category comprises 4%, indicating that soils with moderate coarse material content are limited in the area. Areas with higher coarse material content, such as 20-25% (2%), 35-50% (5%), and >50% (3%), have a smaller coverage, suggesting that only a small portion of the area has rocky soil characteristics, which are less suitable for conventional agriculture. Areas with coarse fragment content between 25-35% were not recorded (0%), indicating that the transition between moderately textured soil to rocky soil is not significant in this region.

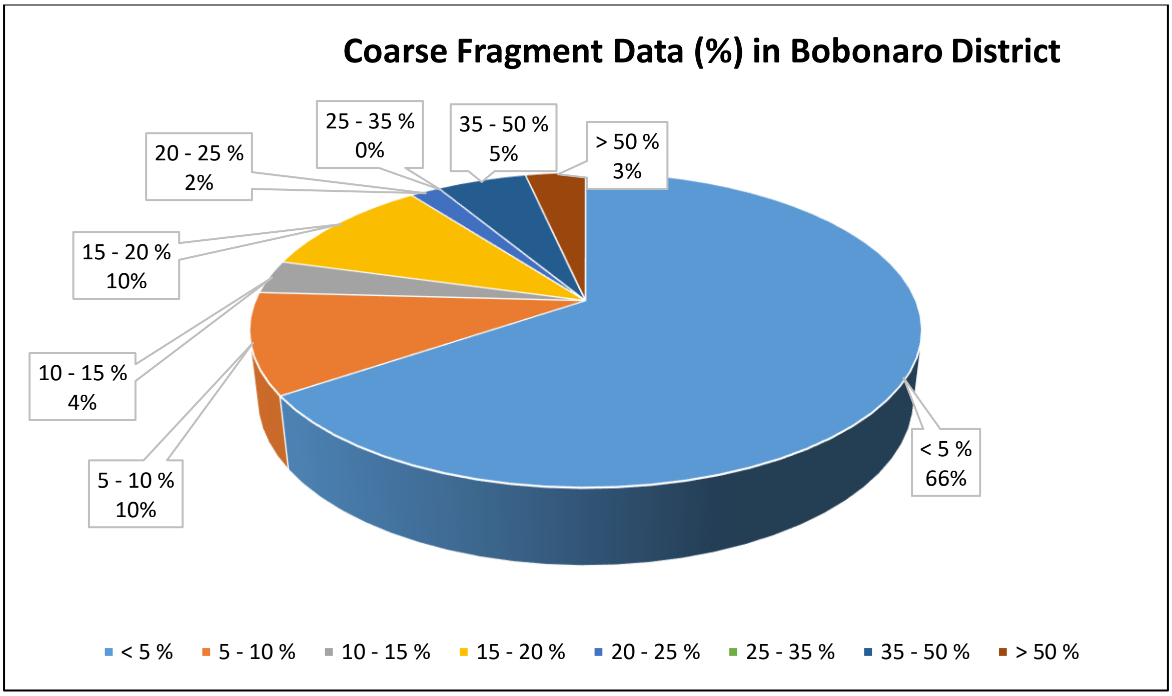


Figure 4.6 Coarse Fragment Data (%) in Bobonaro District

The dominance of soils with low coarse fragment content (<5%) indicates that Bobonaro District has good agricultural potential. These soils are generally more fertile, have better water retention, and support the growth of food crops like rice, corn, vegetables, and other horticultural plants. However, areas with higher coarse fragment content (>20%) require better land management strategies. Soils with high coarse material content usually have faster drainage, so efficient irrigation techniques and the use of organic matter are needed to maintain soil moisture. Additionally, soils with high coarse fragment content are more suitable for drought-tolerant crops, such as cassava and legumes.

Overall, Bobonaro District has good agricultural potential, particularly in areas with low coarse fragment content that support crop growth. However, land management strategies need to be adapted for areas with higher coarse fragment content to ensure productive use. With proper strategies, the land in this area can be optimized for sustainable agricultural production.

4.7 SURFACE ROCKS

Based on the distribution of surface rocks in Bobonaro District, **Figure 4.7** shows that areas with very low surface rock content (0-5%) dominate, covering 53% of the region. This indicates that most of the land has a relatively rock-free surface, which is generally easier to work with for agricultural activities and supports plant growth.

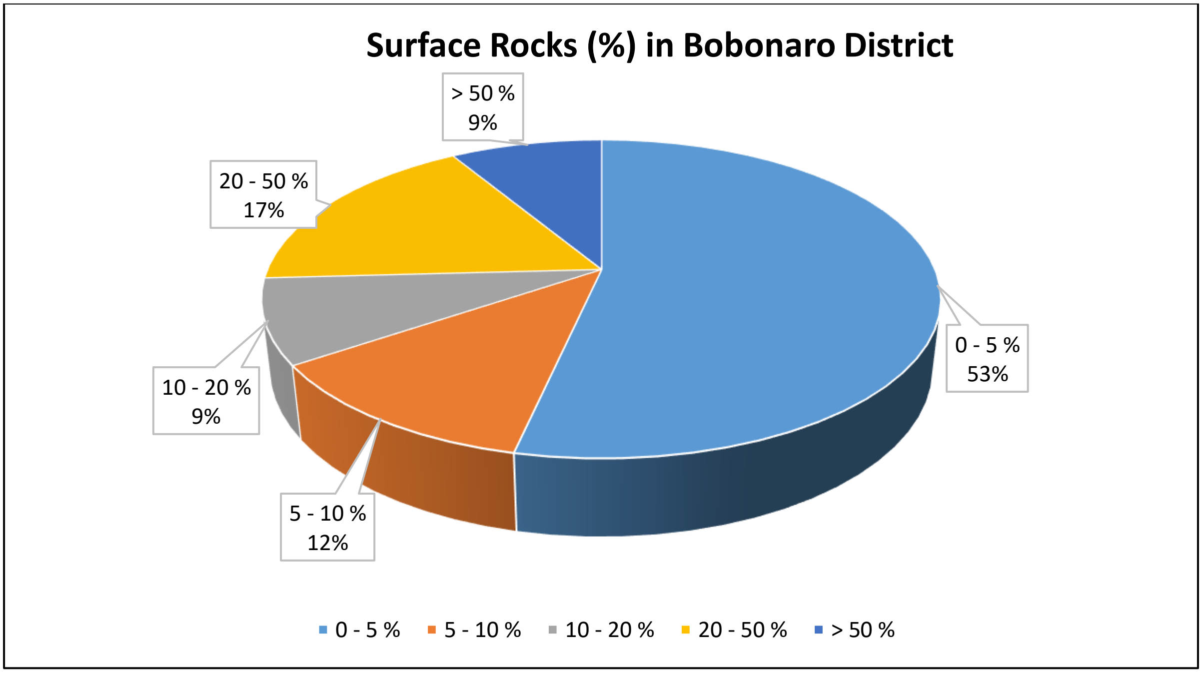


Figure 4.7 Surface Rocks Data (%) in Bobonaro District

The next category is 20-50% (17%), indicating areas with moderate to high surface rock content. These areas may be more rock, which can affect soil fertility and water availability for crops. Categories of 5-10% (12%) and 10-20% (9%) show areas with low to moderate surface rock content, which can still be managed for agriculture with proper techniques. Areas with very high surface rock content (>50%) cover 9%, indicating regions with more extreme rocky soil characteristics. These areas are less suitable for intensive agriculture but can be used for other purposes such as livestock grazing or conservation.

Areas with low surface rock content (0-5%) have very good agricultural potential as they are easier to cultivate and have better water retention capacity. Crops such as rice, corn, root crops, and vegetables can grow optimally in these areas. However, areas with higher surface rock content (10-50%) may require special approaches, such as adaptive agricultural technology, soil conservation techniques, and better irrigation systems to address rapid drainage issues. Areas with more than 50% surface rock are better suited for functions like forestry, livestock grazing, or conservation. Rocky areas with high percentages are generally difficult to manage mechanically and may have limitations in water and nutrient retention for crops.

Overall, Bobonaro District has good agricultural potential, particularly in areas with low surface rock content, which make up more than half of the region. However, for more rocky areas, specific land management strategies are required to ensure productive use. With proper planning, this area can be optimized for various agricultural activities and sustainable natural resource management.

4.8 ROCK OUTCROP

Based on the distribution of rock outcrops in Bobonaro District (**Figure 4.8**), areas with very low rock outcrop content (0-5%) dominate, covering 59%. This indicates that most of the land has minimal open rock exposure, which is generally more suitable for agricultural activities because it is easier to cultivate and has good water retention capacity.

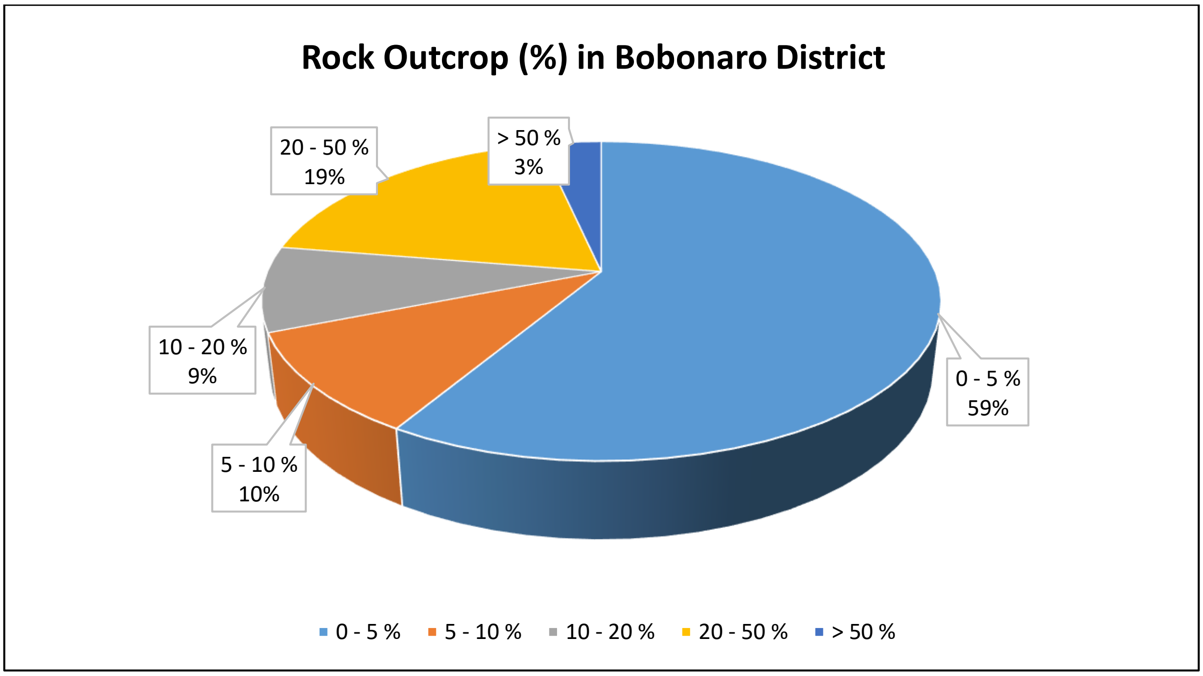


Figure 4.8 Rock Outcorp Data (%) in Bobonaro District

The next category is areas with rock outcrops between 20-50% (19%), indicating that nearly one-fifth of the region has moderate to high rock outcrop exposure. These areas may be rockier, which could limit water retention and soil fertility. Categories with rock outcrops between 5-10% (10%) and 10-20% (9%) show areas with low to moderate rock exposure, which can still be managed for agriculture with proper techniques. Areas with very high rock outcrop content (>50%) cover 3%, indicating a small portion of Bobonaro District with significant rock exposure.

Areas with high rock outcrop percentages are typically less suitable for intensive agriculture because of shallow, rocky soil, but they can be used for other functions such as extensive livestock farming, forestry, or environmental conservation. Areas with low rock outcrop exposure (0-5%) offer very good agricultural potential because they are easier to cultivate and more fertile. Crops such as rice, corn, root crops, and horticulture can grow optimally in these areas. However, areas with higher rock exposure (10-50%) may require specific strategies, such as soil conservation techniques, better irrigation systems, and organic fertilizers to improve soil fertility. Areas with rock outcrops over 50% are better suited for forestry, extensive livestock farming, or conservation.

Overall, Bobonaro District has good agricultural potential, particularly in areas with low rock outcrop exposure. However, areas with higher exposure require specific land management strategies to ensure they remain productive. With the right approach, the region can be optimized for various agricultural and natural resource management activities.

V. SOIL FERTILITY STATUS

Soil fertility is the ability of the soil to supply nutrients in appropriate quantities and balanced proportions in an environment suitable for plant growth (Yuwono, 2007). The aim of soil fertility is to enhance productivity, including fruit, seeds, leaves, flowers, tubers, and so on. Soil fertility varies depending on the soil-forming factors such as parent material, relief, organisms, and the time factors dominating the location. Soil is the primary focus in soil fertility, while plants serve as the main indicators of soil fertility quality (Yuwono, 2007).

Soil fertility evaluation is essential for determining the type and quantity of nutrients to be applied. This evaluation involves diagnosing soil nutrient issues and formulating fertilization recommendations. The diversity of soil characteristics or chemical properties supports the growth of crops as agricultural commodities and provides nutrients within the soil, distinguishing fertile soil from less fertile soil (Utomo et al., 2016). The assessment of soil fertility status is crucial to evaluate and monitor soil fertility so that the nutrients that limit plant growth can be identified. Soil fertility status is determined based on the characteristics of the soil and identifying the primary fertility constraints, as outlined by the Soil Research Center (PPT, 1995).

The evaluation of soil fertility status in Bobonaro District was conducted using several parameters, including cation exchange capacity (CEC), base saturation, soil organic carbon (SOC) content, soil P_2O_5 content, and soil K_2O content. The results of the soil fertility evaluation in Bobonaro District indicated three criteria: low fertility status (red), followed by medium (yellow), and high (green). The data are presented in Figure 5.1. In Munisípiu Bobonaro, soil fertility status is evaluated using several parameters, including Cation Exchange Capacity (CEC), Base Saturation (BS), soil C-organic, P_2O_5 content, and K_2O content. The results of the soil fertility evaluation in Munisípiu Bobonaro are classified into three categories: low (red), medium (yellow), and high (green). The data are presented in Figure 5.1.

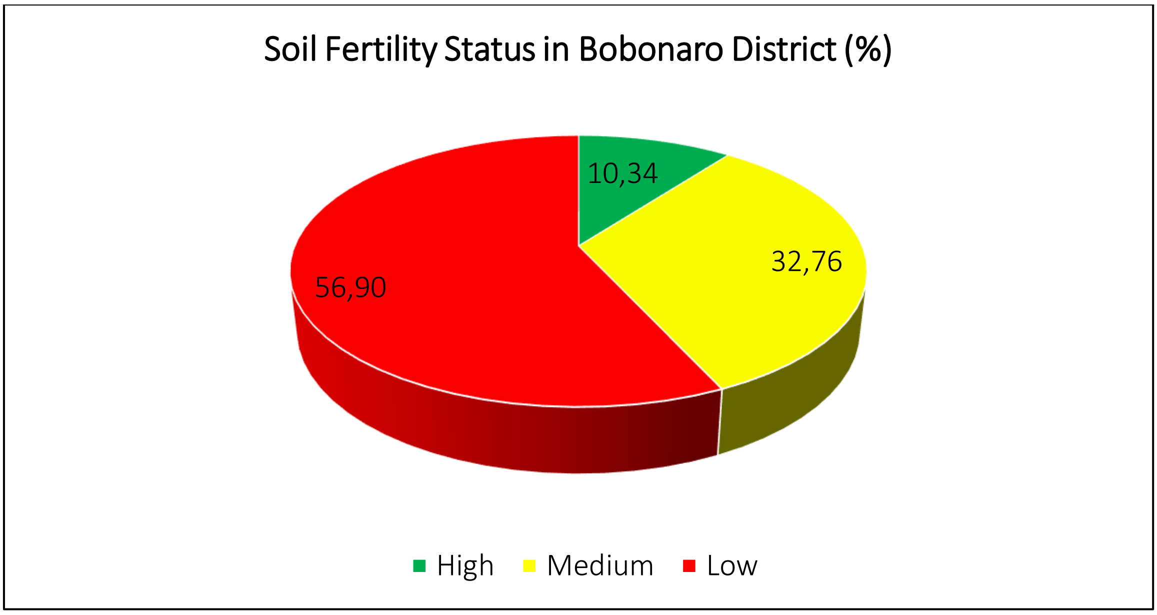


Figure 5.1 Soil Fertility Status in Bobonaro District

Figure 5.1 provides an overview of the total land area based on soil fertility levels. The analysis shows that 56.90% of the total land has low fertility, making it the dominant category in the area. Meanwhile, 32.80% of the land has moderate fertility, and only 10.30% has high fertility. This result indicates that more than half of Bobonaro's territory has soils with low fertility, which could pose challenges for agriculture and land management in the region. Therefore, specific strategies are needed to improve soil quality in areas with low fertility to enhance productivity.

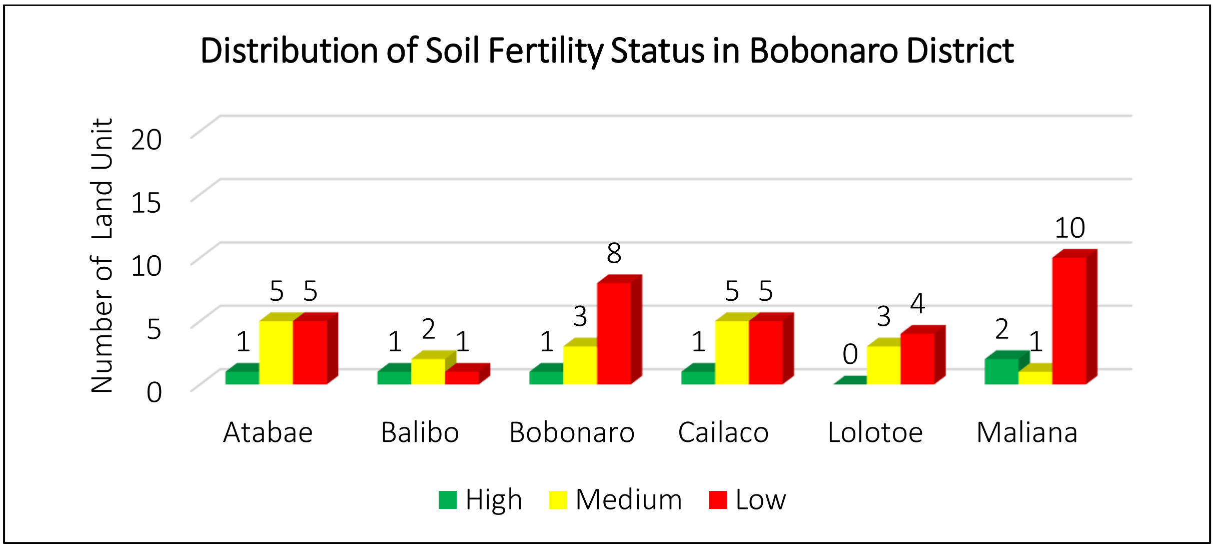


Figure 5.2 Distribution of Soil Fertility Status in Bobonaro District

Figure 5.2 shows the number of land units categorized by soil fertility level in the six Sub-Districts: Atabae, Balibo, Bobonaro, Cailaco, Lolotoe, and Maliana.

The Sub-District of Bobonaro has the highest number of land units with low fertility, with 8 units, followed by Maliana with 10 units, and Cailaco with 5 units. The Sub-District of Cailaco and Atabae have the highest number of land units with moderate fertility, each with 5 units. Land with high fertility is the least common across all Sub-Districts, with Atabae, Balibo, Bobonaro, and Cailaco each having only 1 land unit with high fertility. Lolotoe has no land with high fertility at all. This data shows that the Sub-Districts of Maliana and Bobonaro have the least fertile soils compared to the other Sub-Districts, as they have a dominant number of land units with low fertility. In contrast, Cailaco and Atabae have a higher proportion of land with moderate fertility, making them potential areas for agricultural development with improved management.

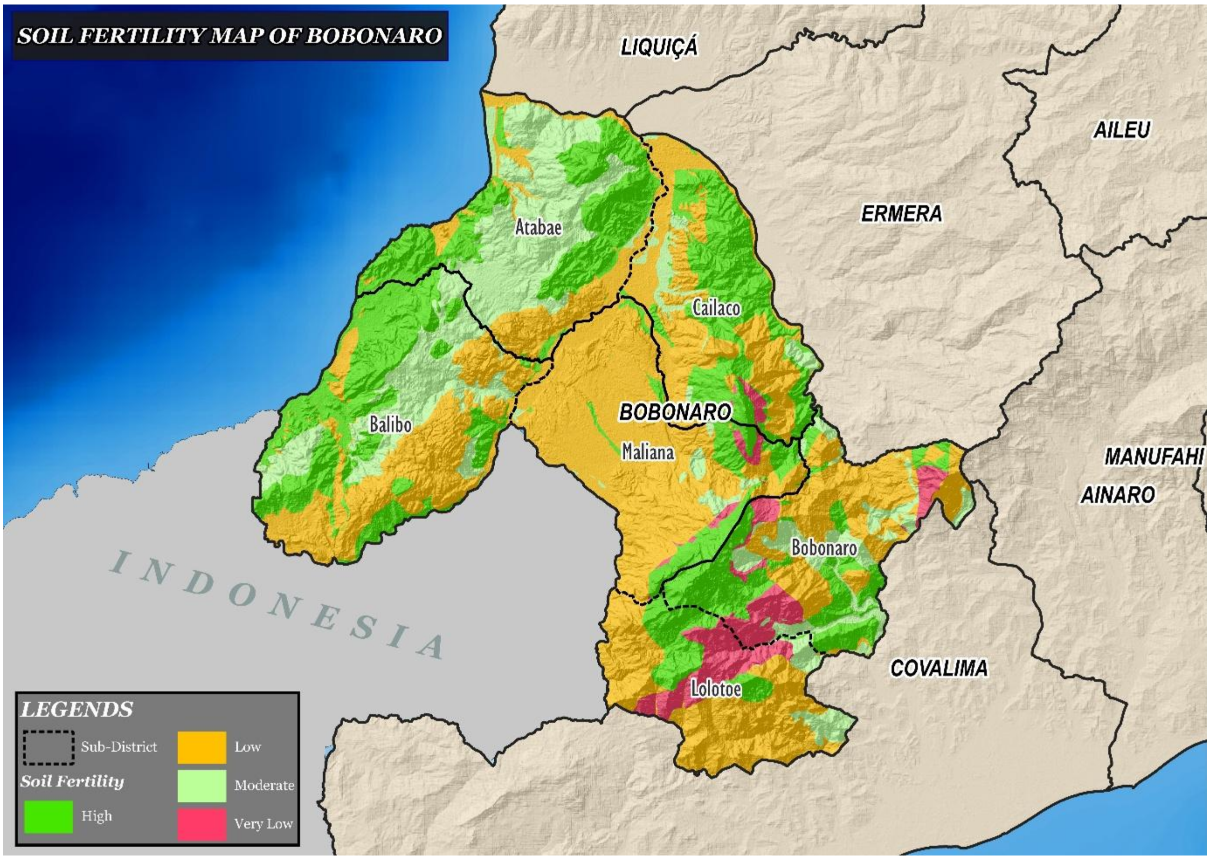


Figure 5.3 Soil Fertility Status Map in Bobonaro District

Figure 5.3 shows the distribution of soil fertility in Bobonaro District, categorized as high (green), medium (yellow), and low (red). The map indicates that most areas have soil with low fertility, particularly in the southern and central regions. Soil with moderate fertility is distributed in several areas, mainly in the northern and western regions. Soil with high fertility is scattered in smaller areas in a few parts of the region. The presence of rivers and the road network also affect soil fertility, with higher fertility soils typically located near water sources or areas closer to major transportation routes.

VI. EROSION AND CONSERVATION

6.1 SOIL EROSION

Soil erosion analysis plays a critical role in land suitability evaluation, particularly for the development of agricultural commodities. Soil erosion not only impacts land productivity but also affects ecosystem sustainability, environmental degradation, and the loss of the soil's capacity to retain nutrients and water. In agricultural land management, erosion analysis serves as a foundation for designing appropriate soil conservation strategies to mitigate negative impacts and ensure the long-term viability of land use.

According to the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1978), soil erosion is influenced by several key factors, including rainfall erosivity, soil erodibility, slope length and gradient, vegetation cover, and land management practices. In Timor-Leste, many of these factors contribute to high levels of erosion. The region's topography, characterized by steep slopes, low levels of land conservation, unstable soil structures due to geological influences, and limited vegetation cover, accelerates erosion rates. As stated by Morgan (2005), uncontrolled soil erosion can lead to the loss of the topsoil, which is the most fertile part of the soil, thereby limiting its productivity.

The analysis results show that soil erosion levels in Timor-Leste are classified into four categories: light (20%), moderate (21%), heavy (26%), and very heavy (33%). This data emphasizes that more than half of Timor-Leste is experiencing significant erosion, with the heavy and very heavy categories being predominant. This indicates the need for conservation-based land management strategies to prevent further soil degradation.

In Bobonaro District, the erosion levels are classified as very heavy at 30.95%, heavy at 38.55%, moderate at 21.24%, and light at 9.27%. The region is dominated by unstable soils such as Vertisols and Entisols, which have low retention capacity and are highly susceptible to erosion, especially under intense rainfall. The erosion data for Bobonaro District is presented in **Figure 6.1,** and the soil erosion distribution map is shown in **Figure 6.2.**

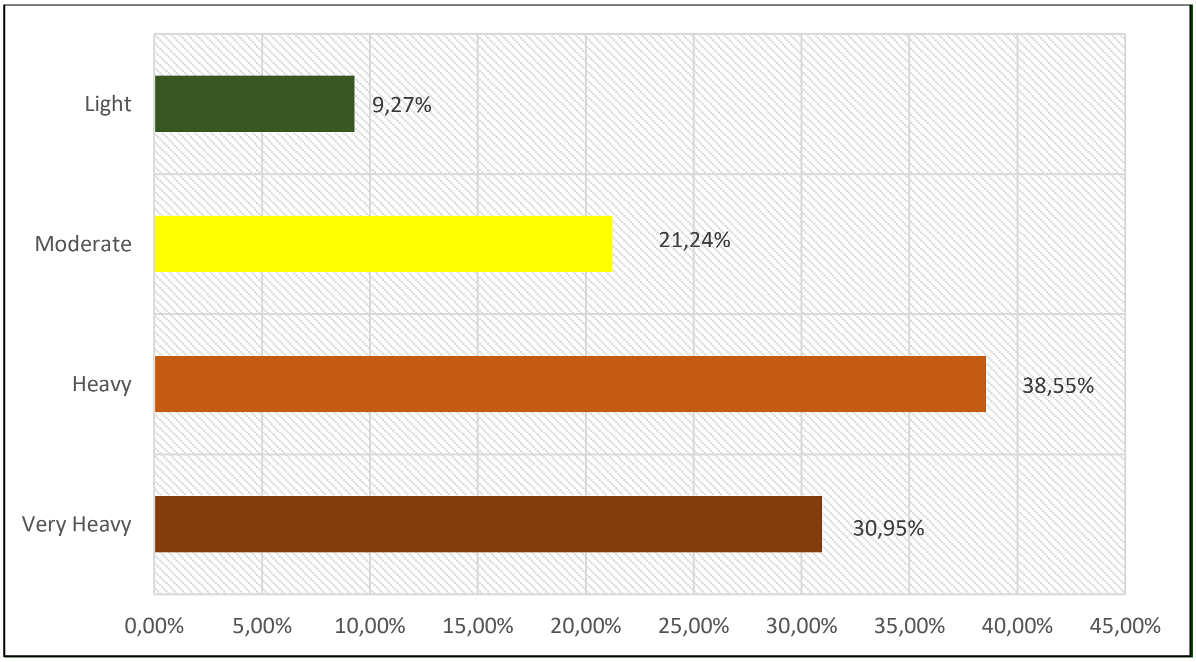


Figure 6.1 Soil Erosion Levels in Bobonaro District

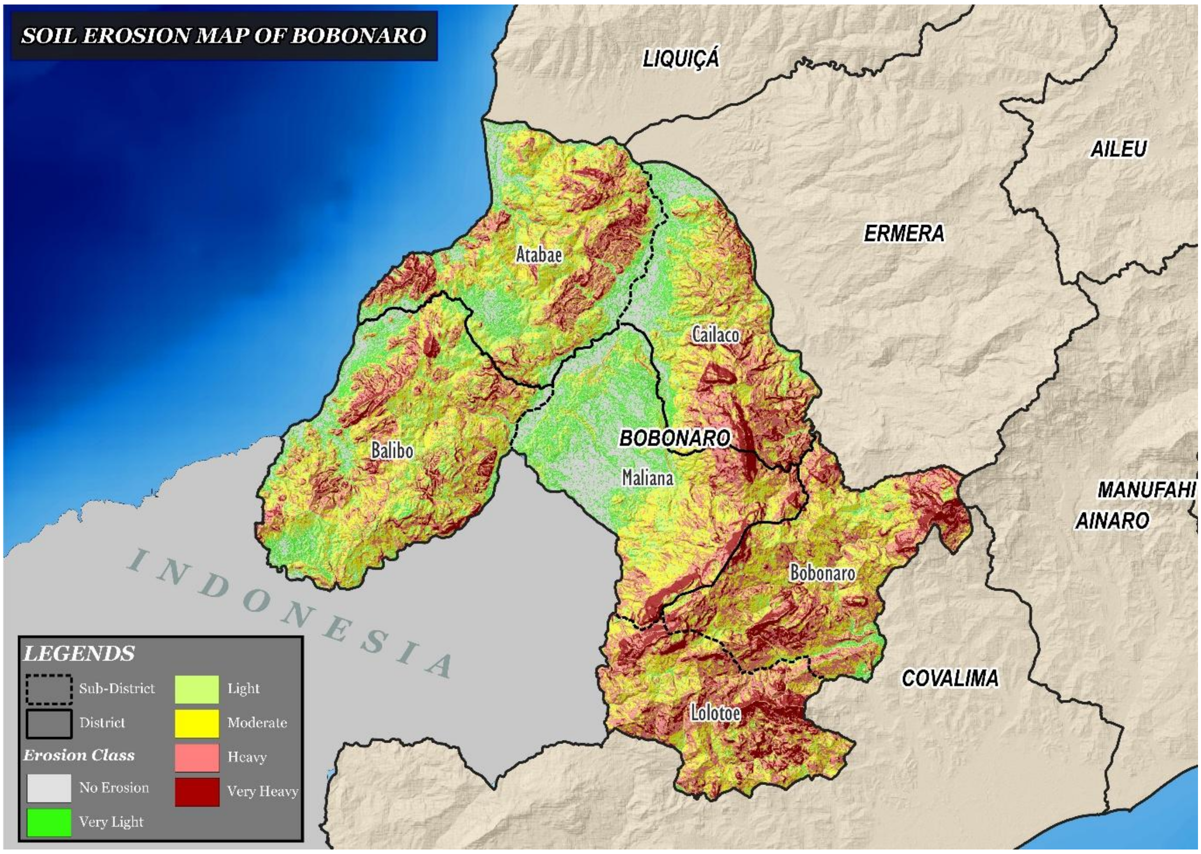


Figure 6.2 Soil Erosion Distribution Map in Bobonaro District

6.2 SOIL AND WATER CONSERVATION

Soil conservation is a long-term natural resource management practice aimed at maintaining land quality and productivity. Conservation plays a vital role in protecting soil from degradation, restoring degraded soils, improving infiltration, and preserving soil fertility.

In Bobonaro District, conservation efforts are based on slope gradient (as shown in **Figure 6.3**) and range from flat to very steep (0–45%). For slopes that are flat to gently sloping (0–15%), it is recommended for food crops, secondary crops, and horticulture. These commodities can be cultivated on land with a slope up to 40%, provided that terracing is implemented to facilitate water infiltration and reduce surface runoff and erosion. Such conditions are found in all six Sub-Districts in Bobonaro District (Atabae, Balibo, Bobonaro, Cailaco, Lolotoe, and Maliana). For slopes >45%, the land is recommended for tree crops (such as Ficus, mahogany, teak, Leucaena, and others), as the planting area becomes narrow with terraces, and soil erosion or landslides may occur with heavy rainfall.

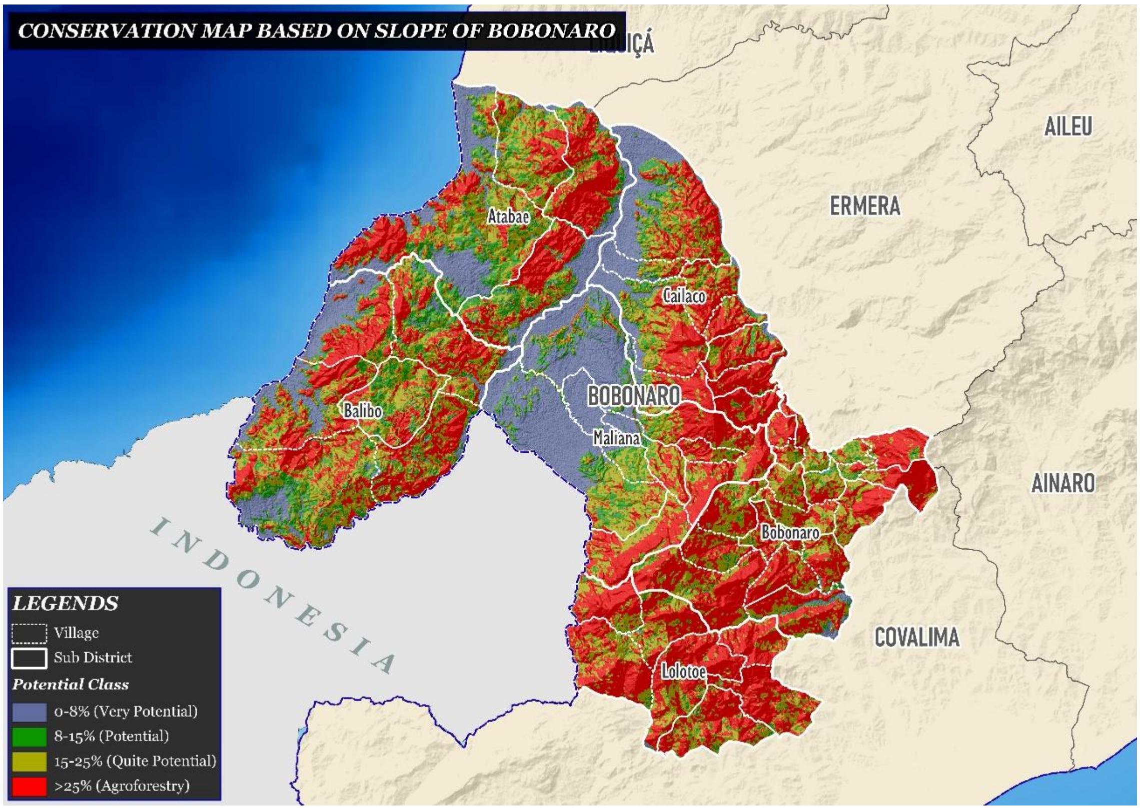


Figure 6.3 Conservation Map Based on Slope Gradient in Bobonaro District

Table 6.1 Slope Gradient Data in Bobonaro District

Sub-District	Slope Gradient (%)	Potential Class	Area (ha)	Area (%)
Atabae	25-45%	Agroforestry	18754,68	13,63
Atabae	>45%	Agroforestry	2107,96	1,53
Atabae	15-25%	Moderately Potential	1023,68	0,74
Atabae	8-15%	Potential	649,28	0,47
Atabae	0-8%	Highly Potential	2653,16	1,93

Balibo	25-45%	Agroforestry	27389,03	19,91
Balibo	>45%	Agroforestry	710,65	0,52
Balibo	15-25%	Moderately Potential	0,55	0
Balibo	0-8%	Highly Potential	1497,06	1,09
Bobonaro	25-45%	Agroforestry	11595,09	8,43
Bobonaro	>45%	Agroforestry	5254,77	3,82
Bobonaro	15-25%	Moderately Potential	3988,22	2,9
Bobonaro	8-15%	Potential	92,55	0,07
Bobonaro	0-8%	Highly Potential	709,19	0,51
Cailaco	25-45%	Agroforestry	10761,93	7,82
Cailaco	>45%	Agroforestry	1489,92	1,08
Cailaco	15-25%	Moderately Potential	3008,94	2,19
Cailaco	8-15%	Potential	837,54	0,61
Cailaco	0-8%	Highly Potential	4348,54	3,16
Lolotoe	25-45%	Agroforestry	5495,59	3,99
Lolotoe	>45%	Agroforestry	7371,45	5,36
Lolotoe	15-25%	Moderately Potential	3708,35	2,69
Lolotoe	8-15%	Potential	0,13	0
Lolotoe	0-8%	Highly Potential	297,29	0,22
Maliana	25-45%	Agroforestry	8119,54	5,9
Maliana	>45%	Agroforestry	2293,12	1,67
Maliana	15-25%	Moderately Potential	6127,39	4,45
Maliana	0-8%	Highly Potential	7311,63	5,31

Bobonaro District, which includes the Sub-Districts of Atabae, Balibo, Bobonaro, Cailaco, Lolotoe, and Maliana, has the following land areas with slopes >45%: 2,107.96 ha (1.53%); 710.65 ha (0.52%); 5,254.77 ha (3.82%); 1,489.92 ha (1.08%); 7,371 ha (5.36%); 2,293.12 ha (1.67%), with the largest area found in Lolotoe Sub-District. This indicates that areas with very steep slopes are suitable only for tree crops. The region also has gently sloping land (0–8%) covering 16,816.87 ha (12.22%), slopes of 8–15% covering 1,579.5 ha (1.15%), slopes of 15–25% covering 17,857.13 ha (12.97%), and slopes above 25%, which cover 101,343.73 ha (73.66%) (**Table 6.1**). This suggests that the land in Bobonaro District with the highest potential is smaller than the area used for agroforestry.

Agroforestry is one of the conservation efforts in the form of a land-use system combining forestry, agriculture, fisheries, and livestock towards integrated farming. This system optimizes land use by ensuring efficient and optimal space use (Sanudin & Priambodo, 2013). In Bobonaro District, other areas with gentle slopes (0–8%) also have rice fields, as the irrigation water quality is very good, requiring proper crop rotation to ensure sustainable production.

Land with steeper slopes is utilized for agroforestry. Agroforestry is a land management system that integrates trees, agricultural crops, and/or livestock on the same land to provide ecological interactions and diverse ecosystems. The integration of agroforestry components (trees, agricultural crops, and livestock) enhances soil fertility, improves the physical, biological, and chemical properties of the soil, provides specific habitats, increases biodiversity, reduces runoff, retains rainfall kinetic energy, binds soil particles, improves soil water holding capacity, and controls erosion.

Agroforestry is classified into several systems based on its components:

1. Agro-silviculture System: Integration of trees and specific food crops on the same land.
2. Silvopastoral System: Combination of tree cultivation and livestock grazing to support livestock maintenance.
3. Agrosilvopastoral System: Planting trees, food crops, pasture, and livestock on the same land. This system aims to optimize land production but requires intensive management at the subsystems level.
4. Home Garden System: Characterized by intensive cultivation of both perennial and seasonal crops, usually consisting of vegetables, cereals, fruit trees, grass, and livestock maintenance.
5. Other Systems: These include cultivation of multipurpose trees, beekeeping, and aquaculture, all of which can be utilized for various agricultural and non-agricultural purposes. The agroforestry conservation model is shown in **Figure 6.4**.

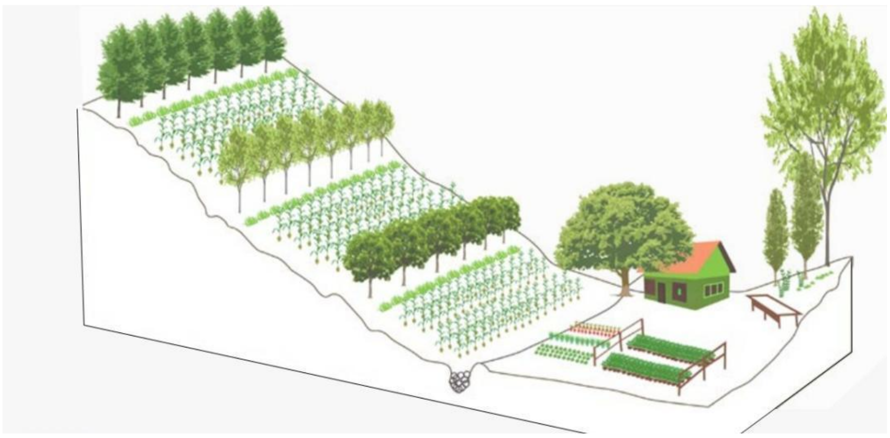


Figure 6.4 Agroforestry Conservation Model
Source: La et al., 2016

A. Importance of the Agroforestry Concept

Agroforestry plays a crucial role in the production of local commodities (firewood, timber, fruits, and livestock feed) and global commodities (coffee, tea, cocoa, rubber, and latex). It also plays a strategic role in helping countries combat poverty, food insecurity, and environmental sustainability. Agroforestry helps enhance farmers' resilience and household income by providing a diverse range of harvests at different times of the year. The combination of trees, crops, and livestock helps reduce environmental risks, create permanent ground cover that combats erosion, minimize flood damage, and enhance water storage for crops and pasture.

Agroforestry has several benefits, including:

1. Nutrisi Improving Food Security and Nutritional Enrichment
   Agroforestry provides plant species diversity to produce various food types, contributing to food security. The integration of agroforestry components improves agricultural productivity and enhances nutritional diversity for consumers.
2. Resilient Livelihoods
   The integration of trees, crops, and livestock can reduce production vulnerabilities to climate disasters and market shocks. Additionally, agroforestry can reduce pest attacks on monoculture systems by creating a better microclimate. Agroforestry mitigates the effects of climate disruptions, creating resilient livelihoods.
3. Climate Change Mitigation and Adaptation
   Integrating various agricultural crops helps mitigate the impacts of climate change on the agricultural sector. The use of trees in agroforestry systems plays a role in carbon sequestration, regulates the microclimate, reduces climate change rates, and positively influences plant growth.
4. Protecting the Environment
   Agroforestry systems regulate climate and environmental services. Perennial crops help improve air and water quality. Tree litter can be used as organic material to reduce chemical fertilizer use. The deep-rooted systems support nutrient cycling. Agroforestry components also support biodiversity by creating suitable environments for flora and fauna in agricultural landscapes.

5. Poverty Alleviation

   Agroforestry can enhance income diversification through the cultivation of commercial crops, timber sales, and livestock income. Diversification increases sustainable agricultural productivity, improving farmers' incomes, creating job opportunities, and contributing to poverty reduction and community well-being.

B. Agroforestry and Agro-Ecology in Bobonaro District

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

Paudel et al. (2022) describe common agroforestry models implemented in Bobonaro District.

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

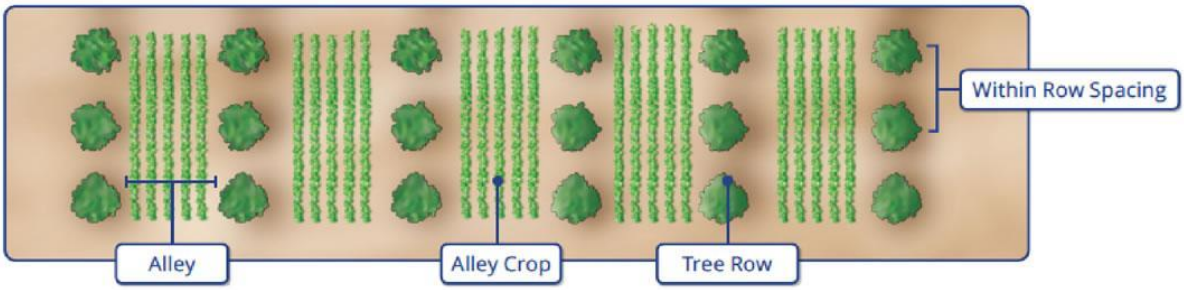


Figure 6.5 Alley Cropping System Concept
(Source: https://www.fs.usda.gov/nac/practices/alley-cropping.php)

2. Hedgerow Planting, the creation of boundaries/fences using trees/shrubs, primarily applied in steep hill areas to conserve soil. This concept is shown in **Figure 6.6.**

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

3. Random Planting of both woody plants and annual crops with irregular planting distances in flat lowlands. The random planting concept is shown in **Figure6.7.**

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

4. Alternating Row Planting with seasonal crops planted between rows on flat, wide land. Agroforestry models that can be applied in Bobonaro District, located at an elevation of 0–100 m above sea level with 500–1,500 mm of rainfall per year, include sandalwood (wood+fruit+vegetables) with supporting plants such as pineapple, mahogany, casuarina, candlenut, tomatoes, and eggplants.

Cogné & Lescuyer (2024) combine agro-ecological and socio-technical data to identify Agroforestry Systems (AFS) in Timor-Leste, which include home gardens integrating perennial plants, spices, and small livestock; combining crops and fallow land for the development of food crops and trees at specific distances; planting perennial crops (papaya, bananas, chili, etc.) along with timber trees (palms); forest gardens typically near water sources; and silvopastoral systems combining trees, shrubs, and livestock grazing on the same land. Bobonaro District has five agro-ecological zones (AEZs) based on elevation and North-South orientation. These zones have biophysical parameters such as elevation, average rainfall, and soil type that are important in selecting appropriate crops and agroforestry models for implementation in Bobonaro District (**Table 6.2**). The agro-climatic zones map for Bobonaro District is shown in **Figure 6.8.**

Table 6.2 Agro-Ecological Zones and Major Crop Types

Zone	Altitudes (m)	Rainfall (mm/year)	Main Crops
Zona A	<100	500-1500	Rice, Corn, Cassava, Coconut
Zona B	100-500	500-1500	Corn, Cassava, Rice, Sweet Potato, Cowpea
Zona C	500-1500	1500-3000	Red Beans, Coffee, Corn, Rice, Cassava, Sweet Potato, Cowpea
Zona D	500-1500	500-1500	Red Beans, Coffe, Corn, Rice, Cassava, Sweet Potato, Cowpea
Zona E	100-500	500-1500	Corn, Cassava, Rice, Sweet Potato, Cowpea

Agroforestry practices in Bobonaro District are traditionally referred to as Kuda Haur. Below are the recommendations for implementing agroforestry based on the agro-ecological zones in Bobonaro District (Godinho et al., 2023):

1. Zone A
   Suitable conservation practices include gabion check dams, ridge terracing, biopore holes, riverbank protection, rainwater reservoirs, and drainage systems. Suitable plants include mahogany, sandalwood, teak, and high-value timber species.
2. Zone B
   Conservation techniques applicable here include terracing with channels, bench terraces, rainwater reservoirs, drainage systems, grass planting, and check dams. Suitable crops include mahogany, sandalwood, cinnamon, coffee, cacao, and vanilla.
3. Zone C
   Suitable conservation techniques include terracing with channels, bench terraces, rainwater reservoirs, drainage systems, grass planting, and check dams. Suitable crops include mahogany, sandalwood, ebony, coffee, vanilla, and clove.

4. Zone D

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

5. Zone E

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

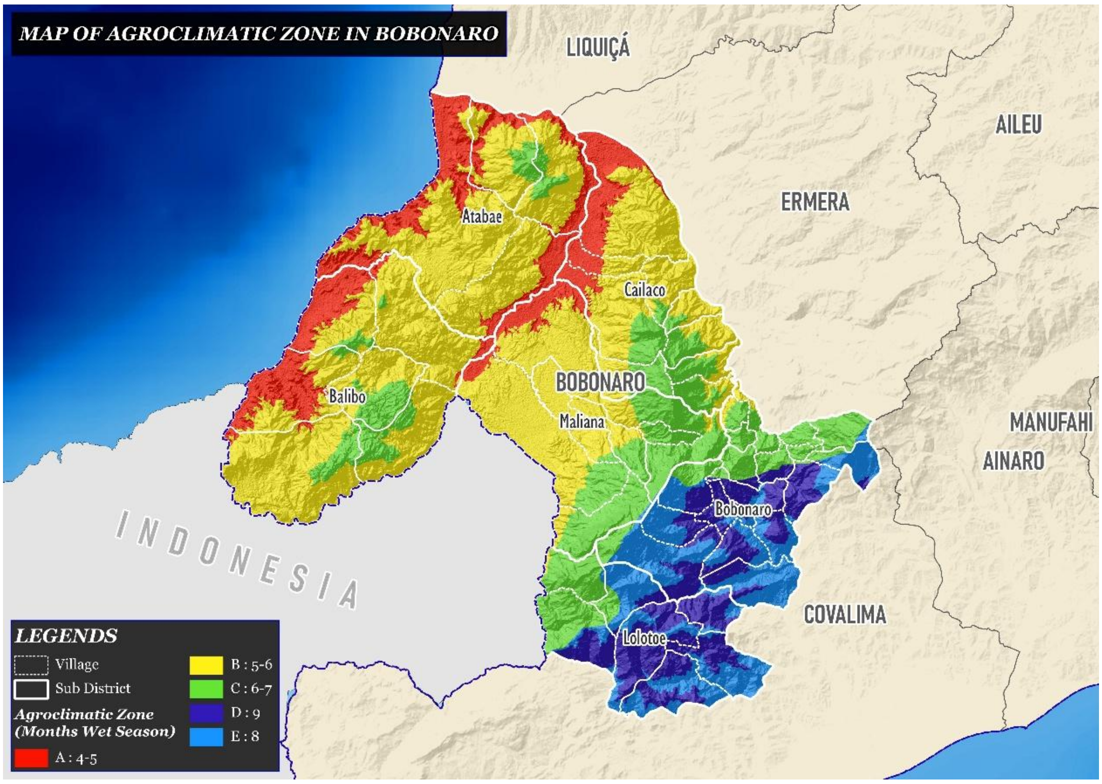


Figure 6.8 Agro-climatic Zones Map of Bobonaro District

C. Conservation Techniques in Bobonaro District

Soil conservation techniques are operational and managerial strategies aimed at maintaining and enhancing the production capacity of land susceptible to degradation. Conservation efforts include preventing or reducing erosion, preserving, and maintaining soil quality. Various soil and water conservation techniques have been implemented in many regions of Asia, such as converting agricultural land to forests or grasslands, terracing, mulching, and soil management (Huang *et al*., 2022).

1. Check Dam

A check dam is a small, low dam built in riverbeds or other water channels to reduce the speed of the water flow, decrease erosion, and encourage the deposition of eroded materials through the spillway. Check dams are beneficial for preserving agricultural land and reinforcing the dam structures in hilly and disaster-prone areas. There are several types of check dams, including.

a. **Brushwood**, A dam made from wood or branches, suitable for small river channels. It typically has an effective height of about 1 m above the ground surface, with a minimum foundation depth for the posts of 0.75-1 m. The brushwood conservation model is shown in **Figure 6.9**. Steps to construct a brushwood check dam include*:*
    1) Digging a trench about 5 cm wide, and setting wooden posts (150-200 cm) to a depth of one-third to half the length of the posts, with a distance of 30-50 cm between posts
    2) The center should be lower than the sides to form a gap that can accommodate maximum water flow
    3) Branches from trees (mahogany, rosewood, sesbania) and shrubs should be woven between the wood to reach the desired height
    4) The ends of the tied materials should extend into the riverbed at least 30 cm
    5) The back part of the dam must be filled with soil
    6) The sides of the brushwood dam, about 1.5-2.0 times the height of the dam, should be protected from erosion with galvanized wir
    7) Side walls must be built to direct the water flow to the dam
    8) Correct the steep gradient of the riverbed head

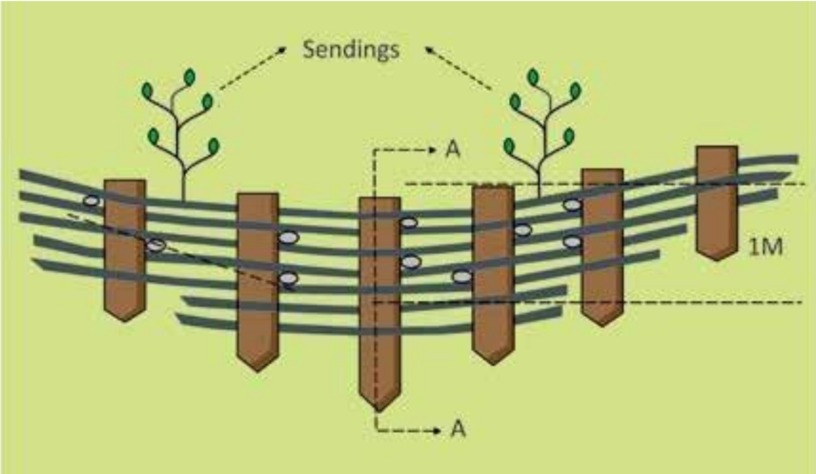


Figure 6.9 Brushwood Check Dam
(Source: Godinho *et al*., 2023)

b. **Loose Stone**, made from loose stones to block small to medium-sized river channels. A boulder dam uses large stones as a barrier, following the same principle as loose stone. These dams typically have an effective height of 1-2 meters, with a minimum foundation depth of half the effective height and a dam thickness of 0.5-1 m at the spillway. The loose stone model is shown in **Figure 6.10**. Steps to construct a loose stone or boulder check dam includer:
   1) Clear the site and mark the construction line using a rope
   2) Cut the sides of the riverbed with a 1:1 slope. The foundation of the wing walls must be >0.5 m. The height of the wing walls must match the depth of the spillway
   3) The dam's foundation must extend beyond the spillway
   4) For large dams, two wing walls with a foundation matching the height are built to force water flow into the spillway or gap, preventing damage to the riverbank.
   5) Boulder stones are used at the gap and downstream for the spillway. The center is kept low for water flow
   6) In case of large water flow volumes, use concrete at the gap or cover the entire dam with wire mesh
   7) Build an apron of stones below the dam
   8) Large stones are placed at the bottom of the dam, and stones approximately 50 x 30 cm are used throughout the dam

9) The upstream side of the dam should receive soil filling to increase its strength

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

c. **Gabion**, A dam made with hexagonal or square wire baskets filled with stones. The general specifications of gabions include a maximum effective height of <5 m, a maximum foundation depth of half the effective height, and a dam thickness of <1 m at the spillway. The gabion conservation model is shown in **Figure 6.11**. Steps to construct a gabion check dam include:
   1) The structure should extend at least 0.5 m into the riverbed and must be protected from floodwater with wing walls
   2) Wing walls with an appropriate foundation must be built above to direct the water flow to the spillway or gap, preventing damage to the riverbank. The space between the dam and wing walls should be filled with soil
   3) The dam foundation must extend beyond the spillway
   4) Large stones should be placed along the sides of the gabion box, while smaller stones fill the center. The stones used for construction should be larger than the wire mesh (mesh size 10 x 10 cm and 15 x 15 cm).
   5) If debris is present, concrete should be applied to the front of the dam to protect the wire mesh
   6) The spillway dimensions are calculated based on the maximum flow from the river catchment area
   7) An apron should be built below the dam

8) The back of the dam must be filled with soil to increase its strength
9) The gabion boxes should be tied with 12-gauge wire

Figure 6.11 Gabion Check Dam

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 directly control water flow and reduce significant soil loss. It alters the topography's continuity 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 creation of terraces combined with agroforestry trees can help gradually increase land cover and water infiltration, reduce nutrient loss, and enhance crop productivity. Terracing is not suitable for shallow soils. The conservation concept using terracing is shown in **Figure 6.12**, and the application of terracing is presented in **Figure 6.14**

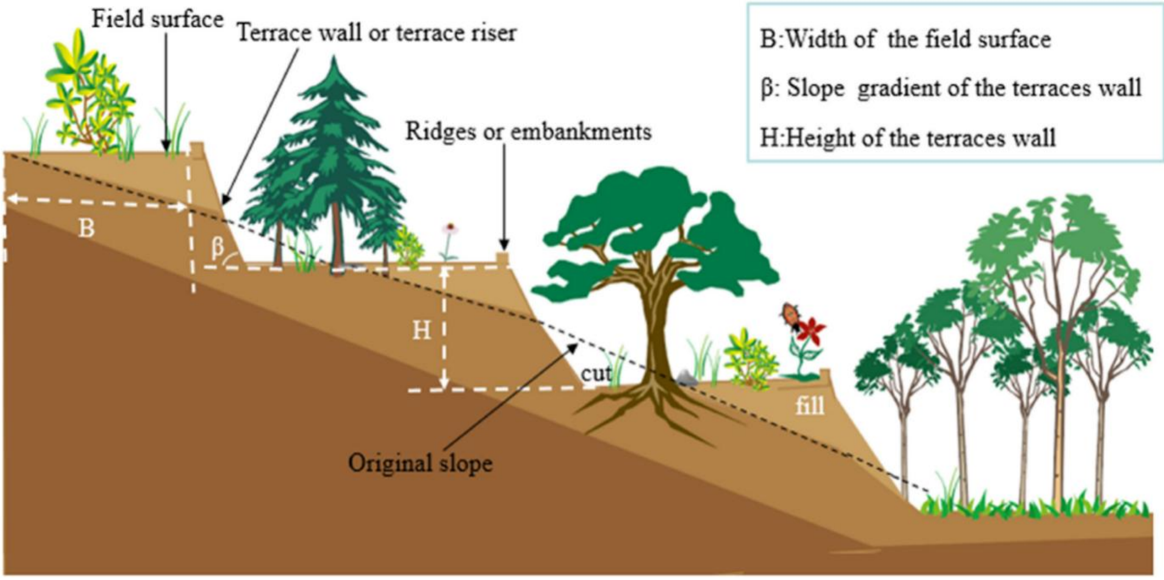
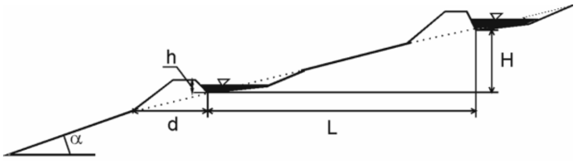


Figure 6.12 Terracing Conservation Concept
Sourcer: (Deng et al., 2021)

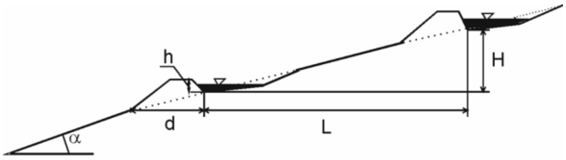
Several types of terraces based on their suitability with the slope include:

a. **Broad Channel Terraces**, these are typically built to capture and channel excess water on fields. This terrace type is suitable for wet areas with slopes of no more than 20%.

b. **Ridge Terraces**, built to capture and hold excess water by spreading it across the land between hilltops. These terraces are applied on gentle slopes (<3%) because the water spreads widely without requiring a high ridge. Ridge terraces have a water channel at the back of the ridge (guludan) to drain surface water into the spillway and increase water absorption into the soil. Ridge terraces divide the slope into smaller hydrological units, reducing water flow paths and affecting water circulation on the slope and throughout the catchment area. 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 have a parallel shape with the contour. These are built on permeable soil and areas with relatively low rainfall. Water flowing through them is retained by embankments and absorbed into the soil. Ridge terraces with water outflow have surface or subsurface drainage. In terraces with subsurface drainage, water is drained through wells or pumps to ditches, rivers, or reservoirs. These terraces are used in areas with high precipitation and soils with low absorption capacity. The concept of ridge terrace division is shown in **Figure 6.13.**



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



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

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

c. **Bench (Step) Terraces**, used on slopes of 20–50% to transform the land into a series of steps separated by vertical walls covered with stones or vegetation for protection. Step terraces can be flat, sloping inward/outward, and are typically built on rainfed paddy fields, dryland fields, and various agroforestry systems.
d. **Individual Terraces**, terraces built for individual plants, especially perennial crops. This type of terrace is typically constructed in orchards or fruit plantations.
e. **Orchard Terraces**, these are terraces for perennial crops, particularly plantation and fruit trees. Terraces are created with varying intervals according to planting distances.

Terraces are constructed manually using the cut-and-fill method, where soil from higher levels is cut and moved to lower levels. Terrace design specifications include

1) Terrace length, generally a maximum of 100 m in one drainage direction for humid tropical climates. The terrace length is limited by the land size and shape, the degree of cutting, and soil type.
2) Terrace width, optimal width ranges from 2.5-5 m (manual construction), and 3.5-8 m (machine/tractor construction). The width depends on soil depth, tillage tools, crop types, and other needs.
3) Terrace gradient, horizontal gradient ranges from 0.5-1% depending on climate and soil type.
4) Height and slope of sub-terraces, sub-terraces are made from compacted soil and protected by grass or stones. The height of sub-terraces should

not exceed 2 m. The vertical interval (VI) between two consecutive terraces can be calculated using the formula:

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

Where:

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 soil to enhance water infiltration, reduce flooding, convert organic waste into compost, reduce greenhouse gas emissions (CO_2 and methane), and utilize soil and plant roots. Biopore holes can increase water infiltration by up to 40 times, thus improving soil moisture and maximizing groundwater storage. In addition, biopores can improve soil fertility through the transformation of kitchen waste into compost.

Biopore construction can be done by digging or using a drill to create holes between 30–100 cm deep. The distance between holes should be about 0.5–1 m. Holes can be created around trees, typically with three holes positioned in an equilateral triangle around the tree. The edges of the hole should be reinforced with cement or short PVC pipe pieces to prevent erosion. Only organic waste (kitchen waste and/or garden waste) should be used. Waste should not be packed too tightly to avoid disrupting water infiltration. The compost generated typically takes 2–8 weeks. The concept of biopore infiltration hole application is shown in **Figure 6.15**

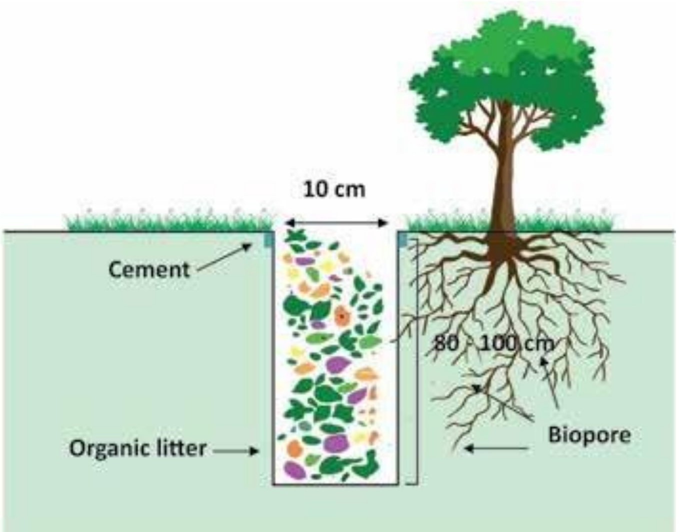


Figure 6.15 Biopore Infiltration Hole
(Source: Godinho et al., *2023*)

4. Riverbank Protection

Riverbank protection is a soil and water conservation technique applied along riverbanks to prevent landslides, reduce soil erosion, improve water quality, and suppress sedimentation. Riverbank protection can be applied to open areas along riverbanks that are prone to erosion and landslides, steep riverbanks, bare river boundaries, and areas with high rainfall. Riverbank management can involve planting grasses, shrubs, and trees with deep roots and dense canopies or installing bamboo frames. The concept of riverbank protection with vegetation is shown in **Figure 6.16**.

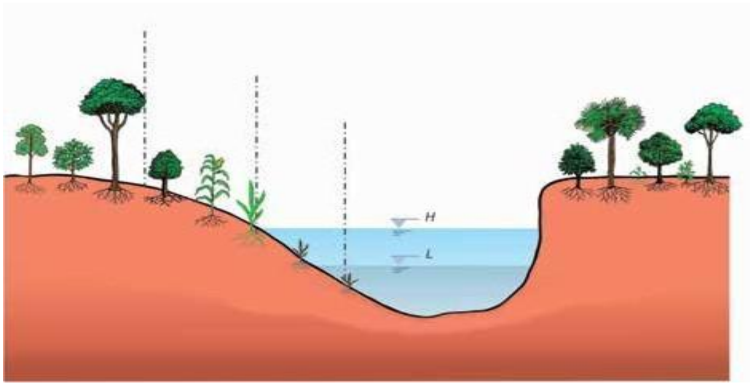


Figure 6.16 Riverbank Protection with Various Layers of Trees, Shrubs, and Grasses
(Source: Godinho et al., 2023)

5. Grass Planting

Grass planting is used to control soil erosion. The fibrous root system can form a dense mass of lateral roots that can reinforce, hold, capture, and stabilize the soil. Grasses with deep, strong, dense, and fibrous roots can penetrate and bind soil particles, effectively reducing sediment. Grasses can also serve as functional components in the system, promoting the formation of terraces even on steep slopes (Do et al., 2023).

Grass planting can be done in three ways:

a. Horizontal/Contour Grass Planting, this method is used on slopes <65 degrees and in areas prone to erosion. For slopes <30 degrees, the planting distance should be 1 x 1 m with 10 x 10 cm spacing. For slopes 30–45 degrees, the planting distance should be 50 x 50 cm with 10 x 10 cm spacing, and for slopes >45 degrees, the recommended planting distance is 30 x 30 cm with 10 x 10 cm spacing. The concept of horizontal/contour grass planting is shown in **Figure 6.17.**

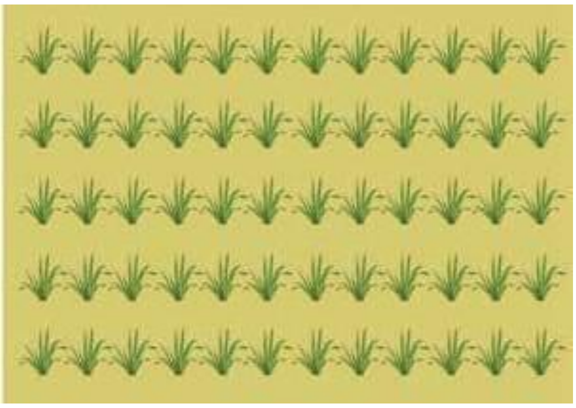


Figure 6.17 Horizontal Grass Planting
(Source: Godinho et al., 2023)

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

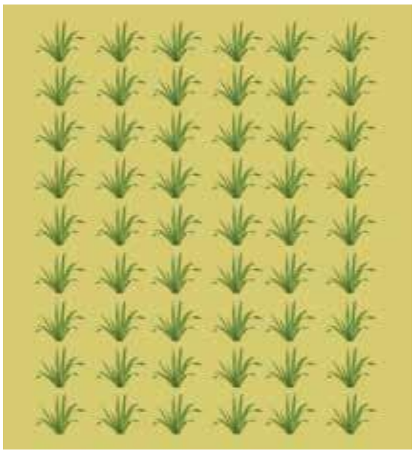


Figure 6.18 Vertical Grass Planting
(Source: Godinho et al., 2023)

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

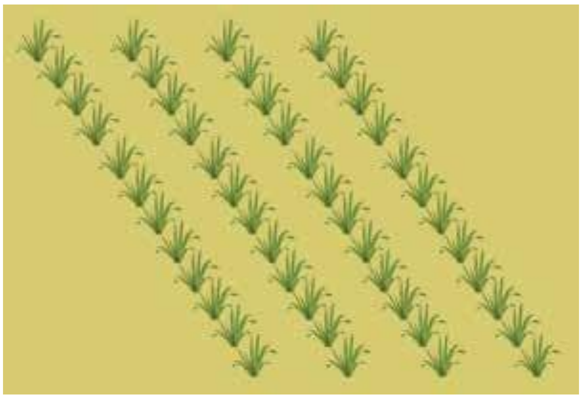


Figure 6.19 Diagonal Grass Planting
(Source: Godinho et al., 2023)

6. Rainwater Reservoir

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

Construction of rainwater reservoirs involves digging the soil, lining it with clay, and building a drainage channel. During excavation, the embankment or edges of the reservoir should be higher than the ground surface to prevent soil from entering the reservoir. Drainage channels should be built to prevent overflow of water from the reservoir. The distance between the drainage channel and the reservoir surface should be between 25 and 50 cm. The clay lining serves as a strengthening layer for the reservoir's walls, which should be at least 25 cm thick. The wall covering should be made at a 70–80-degree slope or in a tiered shape to prevent landslides. For sandy soils, the reservoir's wall should be lined with plastic, cement, or a mixture of lime and clay (1:1) to prevent rapid water seepage. Finally, the drainage channel should be directed towards the area to be irrigated, with a width between 15 and 25 cm and a depth of 10-15 cm. The rainwater reservoir construction concept is shown in **Figure 6.20.**

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

7. Drainage Channel Construction

Drainage channels are used to direct water to areas where it can be absorbed into the soil or collected. The construction of drainage channels is usually equipped with small waterfalls to prevent erosion and landslides. The construction of drainage channels begins with digging the soil to a minimum depth of 50 cm from the cultivation area, with a base width of 50 cm. The bottom of the channel on bench terraces should be sloped at 0.1–0.5% outward. In a 1-meter length of the drainage channel, grass should be planted 20 cm across the drainage channel. The next step is constructing the waterfall, where two or three split bamboo poles are installed across the waterfall to a depth of 0.5 m, with the outer part of the bamboo placed outside. Maintenance efforts include cleaning the channel of sediment, pruning weeds, and repairing damaged bamboo structures. The drainage channel concept is shown in **Figure 6.21.**

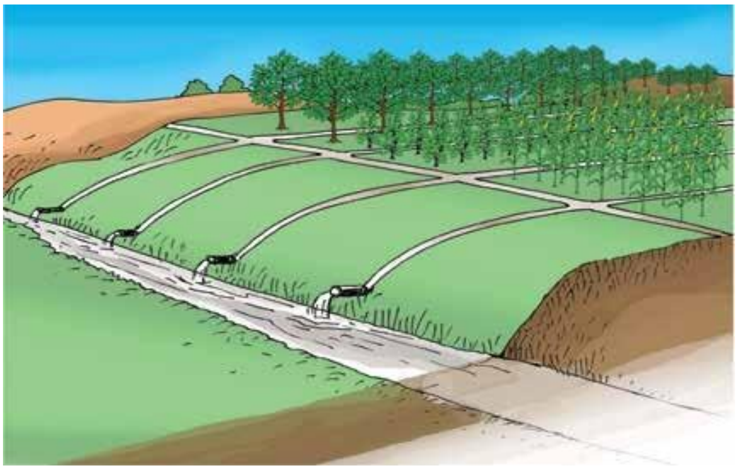


Figure 6.21 Drainage Channel
(Source: Godinho et al., 2023)

8. Wattle Fence / Live Check Dam

A wattle fence is a short barrier or fence made from vegetative materials placed along contours to capture debris moving down the slope, strengthen, and modify the slope. This conservation technique creates microhabitats for various plant species.

The wattle fence is built by clearing vegetation (wood or branches) for posts. Then, 100 cm posts are planted with a 100 cm distance along the fence line. Two 50 cm posts are placed between the main posts and should protrude about 20–30 cm above the ground surface. A trench (minimum depth 15 cm) is created along the contour between the posts. The lower ends of the plant cuttings are placed in the trench, and the cuttings are woven between the posts and the soil is packed back into the trench. The concept of wattle fence application is shown in **Figure 6.22**

Figure 6.22 Wattle Fence

9. Vegetative Actions

Vegetative actions are aimed at achieving better soil and water conservation efficiency through alternating planting of fruit trees, spices, and food crops. Conservation practices should minimize soil disturbances (minimal tillage), increase ground cover, and ensure crop rotation to improve agricultural sustainability (Huang et al., 2022).

a. **Conservation Forests**: In soil and water conservation, forested areas can reduce surface runoff erosion and maintain or restore soil fertility. Tree species and stand structure are the key factors determining the effectiveness of conservation. Native tree species and layered vegetation structures (e.g., trees + shrubs + spices) are prioritized for greening efforts.
b. **Hedge Plants:** Using hedge plants is also effective in controlling slope soil erosion, holding runoff, and improving soil fertility. Suitable hedge plants include *Vetiveria zizanioides*, *Leucaena leucocephala*, Guinea grass, *Gamal* (*Gliricidia sepium*), *Calliandra calothyrsus*, elephantgrass (*Pennisetum purpureum*), and others.
c. **Covering Areas,** cover intensity is divided into:
   1) Total cover, primarily for areas prone to erosion, mountains, near rivers, and reservoirs.
   2) Half cover, applied during specific seasons
   3) Rotational cover, applied in lightly eroded areas, divided into sub-areas for rotational cover
   4) Cover combined with planting, for areas with moderate erosion and very low vegetation cover.

   Additionally, vegetation cover can be enhanced with mulch, including leaves, compost, and manure, to cover the soil surface. Mulch helps prevent soil moisture loss due to evaporation, reduces soil erosion, and controls weeds. Suitable mulch materials include rice straw, corn residues, legume and vetiver grass residues, and plastic films (Huang et al., 2022).
d. **Crop Rotation,** crops planted in rotation generally yield higher results than continuous cropping. The benefits of crop rotation depend on seasonal weather conditions and long-term practices. Long-term crop diversification enhances agroecosystem productivity compared to monoculture systems and reduces input use. The combination of legumes

and brassicas tends to benefit the soil due to the combination of taproots and fibrous roots, fostering complex and diverse soil organisms (Quintarelli et al., 2022).

e. **Pond Construction,** according to Rustam (2010), a pond is an artificial structure designed to store and hold water with a small capacity, smaller than that of a reservoir or dam. Ponds are built by damming small rivers or outside rivers. A pond stores water during the rainy season and is then used during the dry season for fulfilling needs in a priority sequence for the population, livestock, and crops or fields. The pond's height and capacity depend on the volume of needs. An example of pond construction for conservation is shown in **Figure 6.23.**

Figure 6.23 Pond Construction Application

VII. AGRICULTURAL LAND SUITABILITY EVALUATION

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

7.1 LAND SUITABILITY FOR AGRICULTURE

The assessment of land suitability based on the current condition uses data from field surveys. This assessment reflects the land's capacity under existing conditions without additional intervention. Current land suitability, or suitability in its natural state, does not account for improvement efforts or management practices that can address existing constraints or limiting factors in each land unit or mapping unit. To determine the class of current land suitability, the evaluation is first made on each land quality based on the most limiting factor or the poorest land characteristic, and then the suitability class is determined according to 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 can become moderately suitable (S2) or even highly suitable (S1) after improvements such as fertilization are applied. The assessment of potential land suitability is conducted by improving the land qualities that act as limiting factors, so that the suitability is expected to improve. Through technology, lands that naturally have low suitability (current land suitability) can be upgraded to a higher suitability class (potential land suitability) with improvements. However, not all land qualities or characteristics can be improved with current technologies, or may require high management levels to improve.

In land-use planning, the primary focus is on potential land suitability, as this assessment provides an overview of the land's maximum potential for various uses after improvements are made. Thus, potential land suitability assists in planning land use effectively and sustainably, as well as determining the necessary improvements to achieve optimal results. The improvements of current land characteristics to make them suitable according to management levels are presented in **Table 7.1.**

Table 7.1 Types of Improvements to Convert Current Land Suitability to Potential Suitability Based on Management Level

No	Land Quality/ Characteristic	Type of Improvement	Management Level
1	**Radiation regime** (sunshine duration)	No improvement possible	-
2	**Temperature regime**		
	Average annual temperature	No improvement possible	-
	Average temperature of the coldest month	No improvement possible	-
	Average temperature of the hottest month	No improvement possible	-
3	**Air humidity regime**		
	Relative humidity	No improvement possible	-
4	**Water availability**		
	Dry months	Irrigation system	Moderate, High
	Rainfall	Drainage system	Moderate, High
5	**Rooting media**		
	Drainage	Improvement of drainage system, such as construction of drainage channels	
	Texture	Addition of organic matter	
	Effective depth	No improvement possible Generally, improvement is not possible, except for soft and thin hardpan layers, which can be broken up during soil cultivation.	
6	**Nutrient retention**		
	CEC pH	Liming or addition of organic matter	Moderate, High
7	**Nutrient availability**		
	Total nitrogen (N)	Urea and ZA fertilization	Moderate, High
	Phosphorus (P_2O_5)	SP36 and TSP fertilization	
	Pottasium (K_2O)	KCl fertilization	
8	**Diversity**		
	Salinity	Addition of organic matter	Moderate, High
9	**Erosion hazard**	Erosion reduction efforts, construction of terraces, contour planting, cover crop planting	Moderate, High

10	**Flood hazard** Period Frequency	Construction of water barriers and drainage channels for improved water management.	High
11	**Toxicity** Aluminum saturation Pyrite layer	 Liming Water management system regulation, groundwater level must be above the pyritic layer	 Moderate, High Moderate, High
12	**Ease of cultivation**	Soil moisture management to facilitate soil cultivation	Moderate, High
13	**Terrain/Mechanism potential**	No improvement possible	-

Descriptions:

- Moderate management level: Management can be carried out at the farmer level with moderate agricultural techniques or investment.
- High management level: Management can only be carried out with relatively large capital, generally undertaken by the government or large or medium-sized companies.

Table 7.2 Assumptions for Improving Current Land Quality to Potential Land Quality Based on Management Level

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

Descriptions:

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

7.2 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 for the land suitability classification system uses four categories: order, class, subclass, and unit (Hardjowigeno, 2015). Land suitability is systematically presented in **Table 7.3.**

Table 7.3 Land Suitability Classification (FAO, 1976)

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

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

Land Suitability Order

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

Suitable Order (S)

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

Not Suitable Order (N)

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

Land Suitability Class

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

Highly Suitable Class (S1)

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

Moderately Suitable Class (S2)

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

Marginally Suitable Class (S3)

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

Not Suitable Class (N1)

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

Permanently Not Suitable Class N2:

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

Sub-classes of Suitability

Reflect the type and intensity of limiting factors that hinder land use or the type of improvements required. Each class may consist of one or more sub-classes, depending on the type of constraints present. These limiting factors are indicated by small letter symbols placed after the class symbol. For example, class S2 with the limiting factor of effective depth (s) can become sub-class S2s. A sub-class may have one, two, or at most three limiting factor symbols, where the most dominant factor is written first. For example, in the sub-class S2ts, the topography (t) is the most dominant limiting factor, and the effective depth (s) is the second or additional limiting factor.

Suitability Unit

Suitability at the unit level is a more detailed subdivision of sub-classes based on the intensity of the limiting factors affecting the land. All units within a sub-class have a similar level of suitability within that class and share the same types of limiting factors at the sub-class level.

Table 7.4 Structure of Land Suitability Classification (FAO, 1976)

No	Ordo	Kelas	Sub-kelas	Unit
		S1	-	
			S2s	S2r-1
1.	S	S2	S2e	S2e-2
			S2se	Dsb..
		S3	Dsb.	
		N1	N1s	-
2.	N		N1e	-
		N2	Dsb.	

The difference between one unit and another usually lies in its production capacity or in the additional aspects of management required, and is often a more detailed distinction of the limiting factors. Detailed knowledge of these limitations facilitates interpretation and planning in farm management. Units are marked by adding Arabic numerals separated by hyphens after the sub-class symbol. For example, S2e-1, S2e-2, and so on. The number of units within a sub-class is unlimited. The symbol for the unit level is given by adding Arabic numerals separated by a hyphen from the sub-class symbol. For example, S2e-1, S3e-2, and so forth. The number of units in one sub-class is unlimited.

7.3 LAND SUITABILITY EVALUATION RESULTS

Land suitability evaluation 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 analysis in the laboratory. This approach allows for the identification of both the potential and limitations of 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 bio-physical conditions of the land, such as slope gradient, cover vegetation, 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 collected is analyzed based on the growth requirements of each type of crop in its current state, as well as 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 commodity development priorities, identifying limiting factors, and designing relevant technical solutions.

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

Bobonaro District in Timor-Leste has significant potential for the development of the agricultural and forestry sectors. With its diverse topography and fertile soil, this region is suitable for various strategic agricultural commodities, such as irrigated rice, maize, and cowpea. However, the success of land utilization is influenced by bio-physical factors, such as slope gradient, soil depth, rainfall, and the presence of surface rocks.

Through land suitability evaluation, appropriate commodities and constraints that need to be addressed can be identified. The rice fields in Bobonaro are evaluated as suitable for irrigated rice, although there are limitations in organic matter content, base saturation (BS), and nutrients such as potassium (K_2O) and phosphate (P_2O_5). To improve productivity, the addition of organic fertilizer and chemical fertilizers such as urea, SP-36, and KCl is required.

In addition to rice, maize and horticultural crops such as chili, eggplant, and bitter melon also grow well on land with a slope of less than 15%. For industrial crops such as robusta coffee and coconut, special management practices, such as the creation of terraces and deep planting holes, are necessary to address issues of erosion and surface rocks.

Forest plants such as agathis, albizia, and melaleuca are suitable for land with steep slopes and serve as vegetation to prevent erosion. Agroforestry approaches, which combine industrial crops, horticulture, and spice plants, can be an effective strategy to maximize land use while preserving environmental sustainability.

With the application of appropriate management strategies, Bobonaro's potential can be optimally utilized to improve the well-being of the community and maintain environmental sustainability.

A. Land Suitability Evaluation of Atabae Sub-District

Atabae Sub-District has extensive agricultural potential for the development of various agricultural commodities, including food crops, horticulture, industrial crops, and livestock feed. Based on the land suitability evaluation, most of the area is classified as moderately suitable (S2) to marginally suitable (S3). The food crops that can be developed include irrigated rice, upland rice, maize, mung beans, cassava, sweet potatoes, and taro. Horticultural vegetables include shallots, chili, caisim, cucumber, eggplant, tomato, cabbage, and long beans; horticultural fruits include guava, breadfruit, longan, watermelon, rambutan, jackfruit, pineapple, and passion fruit; horticultural flowers include rose, aster, and sunflower. Spices and medicinal plants include lemongrass, aromatic ginger, turmeric, galangal, jatropha, candlenut, cardamom, and sesame. Industrial crops suitable for the area include coconut, robusta coffee, cocoa, clove, tea, tobacco, and melinjo. For livestock feed, elephant grass, setaria, legumes, and grazing land are available.

The main limiting factors in agricultural development in this area include the length of the dry season, soil texture, rainfall intensity, slope gradient, erosion level, drainage, nutrient availability (total N, P_2O_5, K_2O), soil depth, surface rocks, and rock outcrops. Improvement measures that can be undertaken include optimizing irrigation systems, building drainage channels, adding organic matter, applying NPK fertilizers, clearing surface rocks, and creating planting holes between rock outcrops. To address soil texture and poor drainage, intensive soil cultivation, raised beds, and the addition of ameliorants can be applied. Slope gradient and erosion can be mitigated with terracing, planting vetiver grass, and using cover crops. Nutrient deficiencies can be corrected through crop rotation with legumes and balanced fertilization.

However, there is a permanent limiting factor in low temperature, which cannot be improved technically, meaning commodities such as wheat, potatoes, carrots, garlic, and cashew are not recommended for development. Overall, Atabae Sub-District has land suitability potential that supports sustainable agriculture. With proper land management and adaptation to environmental conditions, this area has great potential to increase productivity. Additional information on other commodities that can be developed in this area is listed in **Table 7.5.**

B. Land Suitability Evaluation of Bobonaro Sub-District

Bobonaro Sub-District has extensive agricultural potential for the development of various agricultural commodities, including food crops, horticulture, industrial crops, and livestock feed. Based on the land suitability evaluation, most of the area is classified as moderately suitable (S2) to marginally suitable (S3). The food crops that can be developed include irrigated rice, upland rice, cassava, soybean, peanut, and taro. Horticultural vegetables include shallots, chili, eggplant, tomato, cabbage, and long beans; horticultural fruits include guava, watermelon, papaya, mango, durian, rambutan, and passion fruit; horticultural flowers include rose, aster, and sunflower. Spices and medicinal plants include vetiver root, lemongrass, vanilla, aromatic ginger, turmeric, galangal, and cardamom. Industrial crops suitable for the area include sugarcane, coconut, oil palm, robusta coffee, cocoa, and melinjo. For livestock feed, elephant grass, setaria, legumes, and grazing land are available.

The main limiting factors in agricultural development in this area include the length of the dry season, soil texture, rainfall intensity, slope gradient, erosion level, drainage, nutrient availability (total N, P_2O_5, K_2O), soil depth, surface rocks, and rock outcrops. Improvement measures that can be undertaken include optimizing irrigation systems, building drainage channels, adding organic matter, applying NPK fertilizers, clearing surface rocks, and creating planting holes between rock outcrops. To address soil texture and poor drainage, intensive soil cultivation, raised beds, and the addition of ameliorants can be applied. Slope gradient and erosion can be mitigated with terracing, planting vetiver grass, and using cover crops. Nutrient deficiencies can be corrected through crop rotation with legumes and balanced fertilization.

However, there is a permanent limiting factor in low temperature, which cannot be improved technically, meaning commodities such as wheat, potatoes, carrots, garlic, and cashew are not recommended for development. Overall, Bobonaro Sub-District has land suitability potential that supports sustainable agriculture. With proper land management and adaptation to environmental conditions, this area has great potential to increase productivity. Additional information on other commodities that can be developed in this area is listed in **Table 7.5.**

C. Land Suitability Evaluation of Cailaco Sub-District

Cailaco Sub-District has extensive agricultural potential for the development of various agricultural commodities, including food crops, horticulture, industrial crops, and livestock feed. Based on the land suitability evaluation, most of the area is classified as moderately suitable (S2) to marginally suitable (S3). The food crops that can be developed include irrigated rice, upland rice, maize, mung beans, cowpeas, sorghum, and cassava. Horticultural vegetables include shallots, chili, eggplant, tomato, cabbage, and long beans; horticultural fruits include guava, longan, melon, durian, rambutan, and passion fruit; horticultural flowers include rose, aster, and sunflower. Spices and medicinal plants include aromatic ginger, lemongrass, galangal, and nutmeg. Industrial crops suitable for the area include coconut, oil palm, robusta coffee, tobacco, and melinjo. For livestock feed, elephant grass, setaria, legumes, and grazing land are available.

The main limiting factors include the length of the dry season, soil texture, rainfall, slope gradient, erosion, drainage, soil depth, surface rocks, rock outcrops, and low nutrient availability (N, P_2O_5, K_2O). Improvement measures that can be undertaken include the construction of irrigation and drainage systems, adding organic matter, applying NPK fertilizers, clearing rocks, adaptive planting holes, soil cultivation, raised beds, ameliorants, terracing, planting vetiver grass, and crop rotation with legumes.

However, low temperature is a permanent limiting factor that cannot be overcome technically, meaning commodities such as wheat, potatoes, carrots, garlic, and cashew are not recommended. Overall, Cailaco Sub-District has prospects for sustainable agriculture with opportunities to increase productivity through proper and adaptive land management. Additional information on other commodities that can be developed in this area is listed in **Table 7.5.**

D. Land Suitability Evaluation of Lolotoe Sub-District

Lolotoe Sub-District has extensive agricultural potential for the development of various agricultural commodities, including food crops, horticulture, industrial crops, and livestock feed. Based on the land suitability evaluation, most of the area is classified as moderately suitable (S2) to marginally suitable (S3). The food crops that can be developed include irrigated rice, maize, cassava, soybean, sweet potatoes, and taro. Horticultural vegetables include shallots, eggplant, bitter melon, tomato, cabbage, and long beans; horticultural fruits include melon, papaya, mango, durian, rambutan, pineapple, and passion fruit; horticultural flowers include rose, aster, and sunflower. Spices and medicinal plants include aromatic ginger, turmeric, galangal, jatropha, candlenut, and sesame. Industrial crops suitable for the area include coconut, oil palm, robusta coffee, tobacco, and melinjo. For livestock feed, elephant grass, setaria, legumes, and grazing land are available.

The main limiting factors include the length of the dry season, soil texture, rainfall, slope gradient, erosion, drainage, soil depth, surface rocks, rock outcrops, and low nutrient availability (N, P_2O_5, K_2O). Improvement measures that can be undertaken include constructing irrigation and drainage systems, adding organic matter, applying NPK fertilizers, clearing rocks, adaptive planting holes, soil cultivation, raised beds, ameliorants, terracing, planting vetiver grass, and crop rotation with legumes.

However, low temperature is a permanent limiting factor that cannot be overcome technically, meaning commodities such as wheat, potatoes, carrots, garlic, and cashew are not recommended. Overall, Lolotoe Sub-District has prospects for sustainable agriculture with opportunities to increase productivity through proper and adaptive land management. Additional information on other commodities that can be developed in this area is listed in **Table 7.5.**

E. Land Suitability Evaluation of Maliana Sub-District

Maliana Sub-District has extensive agricultural potential for the development of various agricultural commodities, including food crops, horticulture, industrial crops, and livestock feed. Based on the land suitability evaluation, most of the area is classified as moderately suitable (S2) to marginally suitable (S3). The food crops that can be developed include irrigated rice, maize, cassava, soybean, sweet potatoes, and taro. Horticultural vegetables include shallots, eggplant, bitter melon, tomato, cabbage, and long beans; horticultural fruits include melon, papaya, mango, durian, rambutan, pineapple, and passion fruit; horticultural flowers include rose, aster, and sunflower. Spices and medicinal plants include aromatic ginger, turmeric, galangal, jatropha, candlenut, and sesame. Industrial crops suitable for the area include coconut, oil palm, robusta coffee, tobacco, and melinjo. For livestock feed, elephant grass, setaria, legumes, and grazing land are available.

The main limiting factors include the length of the dry season, soil texture, rainfall, slope gradient, erosion, drainage, soil depth, surface rocks, rock outcrops, and low nutrient availability (N, P_2O_5, K_2O). Improvement measures that can be undertaken include constructing irrigation and drainage systems, adding organic matter, applying NPK fertilizers, clearing rocks, adaptive planting holes, soil cultivation, raised beds, ameliorants, terracing, planting vetiver grass, and crop rotation with legumes.

However, low temperature is a permanent limiting factor that cannot be overcome technically, meaning commodities such as wheat, potatoes, carrots, garlic, and cashew are not recommended. Overall, Maliana Sub-District has prospects for sustainable agriculture with opportunities to increase productivity through proper and adaptive land management. Additional information on other commodities that can be developed in this area is listed in **Table 7.5.**

F. Land Suitability Evaluation of Balibo Sub-District

Bobonaro Sub-District has extensive agricultural potential for the development of various agricultural commodities, including food crops, horticulture, industrial crops, and livestock feed. Based on the land suitability evaluation, most of the area is classified as moderately suitable (S2) to marginally suitable (S3). The food crops that can be developed include irrigated rice, upland rice, cassava, soybean, peanut, and taro. Horticultural vegetables include shallots, chili, eggplant, tomato, cabbage, and long beans; horticultural fruits include guava, watermelon, papaya, mango, durian, rambutan, and passion fruit; horticultural flowers include rose, aster, and sunflower. Spices and medicinal plants include vetiver root, lemongrass, vanilla, aromatic ginger, turmeric, galangal, and cardamom. Industrial crops suitable for the area include sugarcane, coconut, oil palm, robusta coffee, cocoa, and melinjo. For livestock feed, elephant grass, setaria, legumes, and grazing land are available.

The main limiting factors include the length of the dry season, soil texture, rainfall intensity, slope gradient, erosion level, drainage, nutrient availability (total N, P_2O_5, K_2O), soil depth, surface rocks, and rock outcrops. Improvement measures that can be undertaken include optimizing irrigation systems, building drainage channels, adding organic matter, applying NPK fertilizers, clearing surface rocks, and creating planting holes between rock outcrops. To address soil texture and poor drainage, intensive soil cultivation, raised beds, and the addition of ameliorants can be applied. Slope gradient and erosion can be mitigated with terracing, planting vetiver grass, and using cover crops. Nutrient deficiencies can be corrected through crop rotation with legumes and balanced fertilization.

However, there is a permanent limiting factor in low temperature, which cannot be improved technically, meaning commodities such as wheat, potatoes, carrots, garlic, and cashew are not recommended for development. Overall, Atabae Sub-District has land suitability potential that supports sustainable agriculture. With proper land management and adaptation to environmental conditions, this area has great potential to increase productivity. Additional commodities are listed in **Table 7.5.**

Table 7.5 Land Suitability Evaluation Matrix for Bobonaro District

Commodities	Sub-District	Limiting Factor	Potential Land Suitability / Land Improvement Efforts
		FOOD COMMODITIES	
Irrigated Rice	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Drainage, Coarse Fragment, BS, pH, SOC **S3:** Temperature, Texture, N-total, P_2O_5, K_2O, Surface Rock **N:** Effective Depth, Slope, Erosion, Rock outcrop	**S2:** Texture, Coarse Fragment, Slope, Erosion, Effective Depth, Surface Rock, Rock outcrop **S3:** Temperature
Dryland Food Commodities			
Corn	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Temperature, pH, SOC **S3:** Rainfall, Drainage, Coarse Fragment, N-total, P_2O_5, K_2O **N:** Effective Depth, Slope, Erosion, Surface Rock, Rock outcrop	**S2:** Temperature, Coarse Fragment, Effective Depth, Slope, Erosion, Surface Rock, Rock outcrop
Mung bean	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Temperature, P_2O_5 **S3:** Rainfall, Drainage, Coarse Fragment, Effective Depth, N-total, K_2O, Surface Rock **N:** Slope, Erosion, Rock outcrop	**S2:** Temperature, Coarse Fragment, Effective Depth, Slope, Erosion, Surface Rock, Rock outcrop
Cowpea	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Coarse Fragment, Effective Depth, BS, pH, P_2O_5 **S3:** Drainage, SOC, N-total, K_2O **N:** Slope, Erosion, Surface Rock, Rock outcrop	**S2:** Coarse Fragment, Effective Depth, Slope, Erosion, Surface Rock, Rock outcrop
Shorgum Cassava	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Temperature, Coarse Fragment, SOC **S3:** Drainage, Texture, N-total, P_2O_5, K_2O, Surface Rock	**S2:** Temperature, Rainfall, Texture, Coarse Fragment, Slope, Erosion, Effective Depth, Rock outcrop, Surface Rock

		N: Rainfall, Effective Depth, Slope, Erosion, Rock outcrop	
Upland Rice	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** SOC **S3:** Drainage, Coarse Fragment, N-total, P_2O_5, K_2O **N:** Effective Depth, Slope, Erosion, Surface Rock, Rock outcrop	**S2:** Coarse Fragment, Slope, Erosion, Effective Depth, Surface Rock, Rock outcrop
Wheat	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** BS, SOC **S3:** Texture, N-total, P_2O_5, K_2O, Surface Rock **N:** Temperature, Rainfall, Effective Depth, Slope, Erosion, Rock outcrop	**S2:** Rainfall, Texture, Slope, Erosion, Effective Depth, Surface Rock, Rock outcrop **N:** Temperature
Soybean **Peanut**	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Temperature, Effective Depth **S3:** Drainage, Coarse Fragment, N-total, P_2O_5, K_2O, Surface Rock **N:** Slope, Erosion, Rock outcrop	**S2:** Temperature, Coarse Fragment, Effective Depth, Slope, Erosion, Surface Rock, Rock outcrop
Sweet potato	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Temperature, Rainfall, Texture, SOC **S3:** Drainage, N-total, P_2O_5, K_2O **N:** Bulan Kering, Effective Depth, Slope, Erosion, Surface Rock, Rock outcrop	**S2:** Temperature, Texture, Slope, Erosion, Surface Rock, Rock outcrop, Effective Depth **S3:** Dry Month
Taro	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Temperature, Rainfall, Texture, Coarse Fragment, pH **S3:** Drainage, Effective Depth, SOC, N-total, P_2O_5, K_2O, Surface Rock **N:** Slope, Erosion, Rock outcrop	**S2:** Temperature, Texture, Coarse Fragment, Effective Depth, Slope, Erosion, Surface Rock, Rock outcrop
VEGETABLE HORTICULTURAL COMMODITIES			
Potato **Carrot**	• Atabae • Balibo • Bobonaro • Cailaco	**S2:** Texture, Coarse Fragment, Effective Depth, SOC	**S2:** Texture, Coarse Fragment, Effective Depth, Erosion, Slope, Surface Rock, Rock outcrop

	• Loloto • Maliana	**S3:** Rainfall, Drainage, N-total, P_2O_5, K_2O **N:** Temperature, Slope, Erosion, Surface Rock, Rock outcrop	**N:** Temperature
Shallot	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Temperature, Texture, Coarse Fragment, Effective Depth **S3:** Drainage, CEC, SOC, N-total, P_2O_5, K_2O **N:** Rainfall, Slope, Erosion, Surface Rock, Rock outcrop	**S2:** Temperature Rainfall, Texture, Coarse Fragment, Effective Depth, Erosion, Slope, Surface Rock, Rock outcrop
Garlic	• Atabae • Balibo • Bobonaro • Cailaco • Loloto • Maliana	**S2:** Effective Depth, SOC **S3:** Drainage, Coarse Fragment, N-Total, P_2O_5, K_2O, Surface Rock **N:** Temperature, Rainfall, Slope, Erosion, Rock outcrop	**S2:** Rainfall, Coarse Fragment, Effective Depth, Erosion, Slope, Surface Rock, Rock outcrop **N:** Temperature
Chili **Bell Pepper** **Green Bean** **Broccoli**	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Temperature, Coarse Fragment, Effective Depth **S3:** Rainfall, Drainage, CEC, KB, SOC, N-total, P_2O_5, K_2O **N:** Slope, Erosion, Surface Rock, Rock outcrop	**S2:** Temperature Coarse Fragment, Effective Depth, Erosion, Slope, Surface Rock, Rock outcrop
Caisim	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Temperature, Dry Month, Texture, pH, SOC, P_2O_5 **S3:** Drainage, Coarse Fragment, Effective Depth, N-total, K_2O, Surface Rock **N:** Rainfall, Slope, Erosion, Rock outcrop	**S2:** Temperature, Rainfall, Dry Month, Texture, Coarse Fragment, Effective Depth, Slope, Erosion, Surface Rock, Rock outcrop
Snow Pea	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Rainfall, Effective Depth, SOC, P_2O_5 **S3:** Temperature, Drainage, Coarse Fragment, N-Total, K_2O, Surface Rock **N:** Slope, Erosion, Rock outcrop	**S2:** Coarse Fragment, Effective Depth, Erosion, Slope, Surface Rock, Rock outcrop **S3:** Temperature

Cucumber	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Effective Depth, SOC, P_2O_5 **S3:** Rainfall, Drainage, Coarse Fragment, N-Total, K_2O, Surface Rock **N:** Slope, Erosion, Rock outcrop	**S2:** Coarse Fragment, Effective Depth, Erosion, Slope, Surface Rock, Rock outcrop
Eggplant Bitter melon Vegetable Tomato	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** P_2O_5, K_2O **S3:** Effective Depth, N-Total **N:** Slope, Erosion	**S2:** Effective Depth, Slope, Erosion
Cabbage Long bean	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Temperature, Texture, SOC, K_2O **S3:** Rainfall, Effective Depth, N- Total **N:** Slope, Erosion	**S2:** Temperature, Texture, Effective Depth, Slope, Erosion
FRUIT HORTICULTURAL COMMODITIES			
Guava Soursop Breadfruit Longan	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Rainfall, CEC, SOC, P_2O_5 **S3:** Drainage, Coarse Fragment, N-total, K_2O, Surface Rock **N:** Effective Depth, Slope, Erosion, Rock outcrop	**S2:** Coarse Fragment, Effective Depth, Slope, Erosion, Surface Rock, Rock outcrop
Watermelon Melon	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Texture, SOC **S3:** Rainfall, Drainage, Coarse Fragment, Effective Depth, N-total, P_2O_5, K_2O, Erosion **N:** Slope, Erosion, Surface Rock, Rock outcrop	**S2:** Texture, Coarse Fragment, Effective Depth, Slope, Erosion, Surface Rock, Rock outcrop
Banana	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Temperature, Rainfall, Coarse Fragment, P_2O_5, Erosion **S3:** Drainage, SOC, N-total, K_2O **N:** Dry Month, Effective Depth, Slope, Surface Rock, Rock outcrop	**S2:** Temperature, Coarse Fragment, Effective Depth, Slope, Erosion, Surface Rock, Rock outcrop **S3:** Dry Month
Papaya	• Atabae • Balibo • Bobonaro	**S2:** Temperature, CEC, SOC, P_2O_5	**S2:** Temperature, Coarse Fragment, Slope, Erosion,

	• Cailaco • Lolotoe • Maliana	**S3:** Rainfall, Drainage, Coarse Fragment, N-total, K_2O **N:** Effective Depth, Slope, Erosion, Surface Rock, Rock outcrop	Effective Depth, Surface Rock, Rock outcrop
Orange	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Texture, CEC, SOC **S3:** Drainage, Coarse Fragment, N-total, P_2O_5, K_2O, Surface Rock **N:** Dry Month, Effective Depth, Slope, Erosion, Rock outcrop	**S2:** Texture, Coarse Fragment, Effective Depth, Rock outcrop, Slope, Erosion, Surface Rock **S3:** Dry Month
Avocado	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Temperature, Rainfall, Texture, CEC, SOC, P_2O_5 **S3:** Drainage, Coarse Fragment, N-total, K_2O, Slope, Surface Rock **N:** Dry Month, Effective Depth, Erosion, Rock outcrop	**S2:** Temperature, Texture, Coarse Fragment, Effective Depth, Rock outcrop, Slope, Erosion, Surface Rock **S3:** Dry Month
Mango	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Rainfall, SOC, P_2O_5 **S3:** Drainage, Coarse Fragment, N-total, K_2O, Surface Rock **N:** Effective Depth, Slope, Erosion, Rock outcrop	**S2:** Coarse Fragment, Effective Depth, Slope, Erosion, Surface Rock, Rock outcrop
Durian Rambutan	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Temperature, CEC, SOC, P_2O_5 **S3:** Rainfall, Drainage, Coarse Fragment, N-total, K_2O, Erosion, Surface Rock **N:** Effective Depth, Erosion, Rock outcrop	**S2:** Temperature, Coarse Fragment, Effective Depth, Slope, Erosion, Surface Rock, Rock outcrop
Custard Apple Snake fruit Jackfruit	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Temperature, Rainfall, CEC, SOC **S3:** Drainage, Coarse Fragment, N-total, P_2O_5, K_2O **N:** Effective Depth, Slope, Erosion, Surface Rock, Rock outcrop	**S2:** Temperature, Coarse Fragment, Effective Depth, Slope, Erosion, Surface Rock, Rock outcrop

Strawberry **Pineapple**	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Temperature, Rainfall, Coarse Fragment, Effective Depth, CEC **S3:** Drainage, SOC, N-total, P_2O_5, K_2O **N:** Slope, Erosion, Surface Rock, Rock outcrop	**S2:** Temperature, Coarse Fragment, Effective Depth, Slope, Erosion, Surface Rock, Rock outcrop
Grape	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Temperature, Texture, SOC, P_2O_5 **S3:** Drainage, Coarse Fragment, N-total, K_2O, Surface Rock **N:** Dry Month, Effective Depth, Slope, Erosion, Rock outcrop	**S2:** Temperature, Texture, Coarse Fragment, Effective Depth, Slope, Erosion, Surface Rock, Rock outcrop **S3:** Dry Month
Passion Fruit	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Rainfall, Texture, Erosion **S3:** Temperature, Drainage, SOC, N-total, P_2O_5, K_2O **N:** Dry Month, Coarse Fragment, Effective Depth, Slope, Surface Rock, Rock outcrop	**S2:** Texture, Coarse Fragment, Effective Depth, Surface Rock, Rock outcrop, Slope, Erosion **S3:** Temperature, Dry Month
FLOWER HORTICULTURAL COMMODITIES			
Rose **Aster** **Sunflower**	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Temperature, Rainfall, Drainage, Texture, SOC **S3:** Coarse Fragment, N-total, P_2O_5, K_2O **N:** Effective Depth, Slope, Erosion, Surface Rock, Rock outcrop	**S2:** Temperature, Texture, Coarse Fragment, Slope, Erosion, Effective Depth, Surface Rock, Rock outcrop
SPICE AND MEDICINAL COMMODITIES			
Ginger	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Texture, CEC, N-total **S3:** Temperature, Coarse Fragment, Effective Depth, P_2O_5, K_2O, Rock outcrop **N:** Rainfall, Dry Month, Slope, Erosion, Surface Rock	**S2:** Texture, Coarse Fragment, Effective Depth, Slope, Erosion, Rock outcrop, Surface Rock **S3:** Temperature, Dry Month
Vetiver root **Lemongrass** **Vanilla**	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe	**S2:** Temperature, Rainfall, Drainage, N-total	**S2:** Temperature, Coarse Fragment, Effective Depth, Slope, Erosion, Rock outcrop, Surface Rock

	• Maliana	**S3:** Coarse Fragment, Effective Depth, P_2O_5, K_2O, Rock outcrop **N:** Slope, Erosion, Surface Rock	
Candlenut	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Temperature, Dry Month, CEC, N-total, P_2O_5 **S3:** K_2O, Slope, Surface Rock, Rock outcrop **N:** Effective Depth, Erosion	**S2:** Temperature, Dry Month, Slope, Erosion, Effective Depth, Surface Rock, Rock outcrop
Cinnamon	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Rainfall, CEC, N-total **S3:** Temperature, Coarse Fragment, Effective Depth, P_2O_5, K_2O, Slope, Rock outcrop **N:** Dry Month, Erosion, Surface Rock	**S2:** Coarse Fragment, Effective Depth, Slope, Erosion, Rock outcrop, Surface Rock **S3:** Temperature, Dry Month
Nutmeg	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Temperature, CEC, N-total **S3:** Coarse Fragment, P_2O_5, K_2O, Slope, Surface Rock **N:** Rainfall, Dry Month, Effective Depth, Erosion, Rock outcrop	**S2:** Temperature, Rainfall, Coarse Fragment, Slope, Erosion, Effective Depth, Surface Rock, Rock outcrop **S3:** Dry Month
Pepper	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** CEC, N-total **S3:** Rainfall, Coarse Fragment, Effective Depth, P_2O_5, K_2O, Surface Rock **N:** Dry Month, Slope, Erosion, Rock outcrop	**S2:** Coarse Fragment, Effective Depth, Slope, Erosion, Surface Rock, Rock outcrop **S3:** Dry Month
Jathropa	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Temperature, Drainage, CEC, N-total, P_2O_5 **S3:** Rainfall, Coarse Fragment, Effective Depth, K_2O, Rock outcrop **N:** Slope, Erosion, Surface Rock	**S2:** Temperature, Coarse Fragment, Effective Depth, Slope, Erosion, Rock outcrop, Surface Rock
Aromatic Ginger Turmeric Galangal	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Rainfall, Coarse Fragment, CEC, P_2O_5, K_2O **S3:** Effective Depth, N-total, Rock outcrop	**S2:** Coarse Fragment, Effective Depth, Slope, Erosion, , Rock outcrop, Surface Rock

		N: Slope, Erosion, Surface Rock	
Cardamom	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Rainfall, Texture, P_2O_5 **S3:** Effective Depth, N-Total, K_2O **N:** Dry Month, Slope, Erosion, Surface Rock, Rock outcrop	**S2:** Texture, Slope, Erosion, Effective Depth, Rock outcrop, Surface Rock **S3:** Dry Month
Sesame	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S3:** Erosi, Kedalaman solum, Surface Rock, Rock outcrop, N-Total, P_2O_5, K_2O **N:** Rainfall, Dry Month	**S2:** Rainfall, Kedalaman solum, Surface Rock, Rock outcrop **S3:** Dry Month
		INDUSTRIAL COMMODITIES	
Rubber	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Temperature, P_2O_5, Salinitas **S3:** Rainfall, BS, pH-tanah, N- Total, K_2O, Slope, Erosion **N:** Dry Month, Effective Depth, Surface Rock, Rock outcrop	**S2:** Temperature, Slope, Erosion, Effective Depth, Surface Rock, Rock outcrop **S3:** Dry Month
Coconut Oil Palm	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Temperature, Rainfall, BS, N-total **S3:** Drainage, Coarse Fragment, K_2O, Slope, Surface Rock **N:** Dry Month, Effective Depth, Erosion, Rock outcrop	**S2:** Temperature, Coarse Fragment, Slope, Erosion, Surface Rock, Effective Depth, Rock outcrop **S3:** Dry Month
Arabica Coffee	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Dry Month, SOC, N-total, P_2O_5 **S3:** Temperature, Rainfall, pH, K_2O, Slope, Surface Rock, Rock outcrop **N:** Effective Depth, Erosion	**S2:** Dry Month, Slope, Erosion, Effective Depth, Rock outcrop, Surface Rock **S3:** Temperature
Robusta Coffee	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Temperature, Texture, N-total **S3:** Rainfall, Drainage, Coarse Fragment, pH, P_2O_5, K_2O, Surface Rock	**S2:** Temperature, Texture, Coarse Fragment, Slope, Erosion, Surface Rock, Effective Depth, Rock outcrop **S3:** Dry Month

		N: Dry Month, Effective Depth, Slope, Erosion, Rock outcrop	
Cocoa Clove	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Temperature, pH, N-total, P_2O_5 **S3:** Coarse Fragment, K_2O, Surface Rock **N:** Dry Month, Effective Depth, Slope, Erosion, Rock outcrop	**S2:** Temperature, Coarse Fragment, Slope, Erosion, Surface Rock, Effective Depth, Rock outcrop **S3:** Dry Month
Tea	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Drainage, P_2O_5 **S3:** Temperature, Rainfall, Coarse Fragment, BS, pH, N-total, K_2O, Surface Rock **N:** Dry Month, Effective Depth, Slope, Erosion, Rock outcrop	**S2:** Coarse Fragment, Slope, Erosion, Surface Rock, Effective Depth, Rock outcrop, Surface Rock, **S3:** Temperature, Dry Month
Tobacco	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Coarse Fragment, P_2O_5, K_2O **S3:** Rainfall, Effective Depth, BS, pH, N-total, Rock outcrop **N:** Dry Month, Slope, Erosion, Surface Rock	**S2:** Coarse Fragment, Effective Depth, Slope, Erosion, Surface Rock, Rock outcrop **S3:** Dry Month
Sugarcane	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Temperature, Rainfall, N-total **S3:** Rainfall, Coarse Fragment, P_2O_5, K_2O, Surface Rock **N:** Effective Depth, Slope, Erosion, Rock outcrop	**S2:** Temperature, Coarse Fragment, Slope, Erosion, Surface Rock, Effective Depth, Rock outcrop
Cashew	• Atabae • Balibo • Bobonaro • Cailaco • Loloto • Maliana	**S2:** Rainfall, P_2O_5 **S3:** N- Total, K_2O, Slope, Erosion **N:** Temperature, Dry Month, Effective Depth, Surface Rock, Rock outcrop	**S2:** Slope, Erosion, Effective Depth, Surface Rock, Rock outcrop **S3:** Dry Month **N:** Temperature
Melinjo	• Atabae • Balibo • Bobonaro • Cailaco • Loloto • Maliana	**S2:** Temperature, N-total, P_2O_5 **S3:** Coarse Fragment, K_2O, Slope, Surface Rock	**S2:** Temperature, Coarse Fragment, Slope, Erosion, Surface Rock, Effective Depth, Rock outcrop **S3:** Dry Month

		N: Dry Month, Effective Depth, Erosion, Rock outcrop	
Kapok Cotton	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** pH, N-total **S3:** Temperature, Rainfall, K_2O, Slope, Surface Rock, Rock outcrop **N:** Effective Depth, Erosion	**S2:** Slope, Erosion, Surface Rock, Effective Depth, Rock outcrop **S3:** Temperature
Quinine	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** pH-tanah, K_2O, Surface Rock, Erosion **S3:** Temperature, Texture, N- Total, Slope **N:** Effective Depth	**S2:** Texture, Slope, Erosion, Surface Rock **S3:** Temperature, Effective Depth
GRAZING AREAS AND LIVESTOCK FEED			
Livestock Feed Group: Elephant Grass Setaria	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**N**: Lereng **S3:** Rock outcrop, Erosi **S2:** Surface Rock, Rainfall, N-total, P_2O_5, K_2O	**S2:** Lereng, Rock outcrop, Surface Rock
Legumes	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**N**: Erosi, Lereng **S3:** Rock outcrop **S2:** Surface Rock, Rainfall, N-total, P_2O_5, K_2O	**S2:** Lereng, Rock outcrop, Surface Rock
Grazing	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2:** Dry Month, : N- Total, P_2O_5 **S3**: Temperature, Surface Rock **N:** Slope, Erosion, Rock outcrop	**S2:** Dry Month, Slope, Erosion, Surface Rock, Rock outcrop **S3:** Temperature

VIII. FORESTRY POTENTIAL

8.1 LAND SUITABILITY EVALUATION 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, utilizing geospatial data, field observations, and laboratory analysis of soil physical and chemical properties. This approach allows for the identification of the potential and limitations of land for the development of various agricultural, horticultural, and forestry commodities.

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

Subsequently, the obtained data are analyzed based on the actual growing requirements of each plant species and their potential suitability after implementing land improvement practices such as fertilization, organic matter addition, or soil conservation techniques. This process yields comprehensive information to determine commodity development priorities, identify limiting factors, and design relevant technical solutions.

This scientific approach serves as the basis for land suitability evaluation in Bobonaro District. The analysis results provide strategic guidance to maximize land productivity while maintaining the sustainability of natural resources in each area. In Table 8.1, the results of land suitability evaluation list several crops in the same column, indicating that these crops share similar growing requirements and limiting factors. Crops placed in different columns have different growing requirements and limiting factors, necessitating a tailored management approach for each crop commodity.

A. Land Suitability Evaluation of Atabae Sub-District

The development of forestry commodities in Atabae Sub-District shows promising potential, particularly with the suitability of species such as melaleuca, pine, sandalwood, (S2), mahogany, teak, agathis, albizia, leucaena, acacia, and eucalyptus, which are classified as marginally suitable (S3) for the district's biophysical conditions. Although the land faces challenges such as limited soil depth, surface rock outcrops, and coarse fragments, management can still be carried out through forestry technical approaches.

Altingia species have potential for development, although temperature constraints may limit their growth. Nonetheless, the region still holds significant opportunities for forestry development, particularly if appropriate species selection and proper land conservation techniques are implemented. **Table 8.1** lists alternative species that could be developed, while **Table 11.1** provides recommendations for forestry development in Atabae Sub-District as part of a land-use diversification and optimization strategy.

B. Land Suitability Evaluation of Balibo Sub-District

The development of forestry commodities in Balibo Sub-District shows promising potential, particularly with the suitability of species such as melaleuca, pine, sandalwood, (S2), mahogany, teak, agathis, albizia, leucaena, acacia, and eucalyptus, which are classified as marginally suitable (S3) for the district's biophysical conditions. Despite the land facing constraints such as limited soil depth, surface rock outcrops, and coarse fragments, management can still be implemented through forestry technical approaches.

Altingia species have potential for development, although temperature may limit their growth. However, the overall region presents adequate potential for forestry development, especially if suitable species are selected and proper land conservation practices are employed. **Table 8.1** lists potential alternative species, while **Table 11.1** contains recommendations for forestry development in Balibo Sub-District as part of the land-use diversification and optimization strategy.

C. Land Suitability Evaluation of Bobonaro Sub-District

The development of forestry commodities in Bobonaro Sub-District shows promising potential, particularly with the suitability of species such as melaleuca, pine, sandalwood, (S2), mahogany, teak, agathis, albizia, leucaena, acacia, and eucalyptus, which are classified as marginally suitable (S3) for the district's biophysical conditions. Although the land faces challenges such as limited soil depth, surface rock outcrops, and coarse fragments, management can still be carried out through forestry technical approaches.

Altingia species have potential for development, although temperature may limit their growth. Nevertheless, the region presents considerable opportunities for forestry development if appropriate species are selected and proper land conservation techniques are implemented. **Table 8.1** lists alternative species that could be developed, and **Table 11.1** provides recommendations for forestry development in Bobonaro Sub-District as part of a land-use diversification and optimization strategy.

D. Land Suitability Evaluation of Cailaco Sub-District

The development of forestry commodities in Cailaco Sub-District shows promising potential, particularly with the suitability of species such as melaleuca, pine, sandalwood, (S2), mahogany, teak, agathis, albizia, leucaena, acacia, and eucalyptus, which are classified as marginally suitable (S3) for the district's biophysical conditions. Despite the challenges of limited soil depth, surface rock outcrops, and coarse fragments, the area can still be managed through forestry technical approaches.

Altingia species have potential for development, although their growth is constrained by temperature. Nevertheless, the area still offers opportunities for forestry development, particularly with suitable species selection and land conservation measures. **Table 8.1** lists potential alternative species, while **Table 11.1** provides recommendations for forestry development in Cailaco Sub-District as part of a land-use diversification and optimization strategy.

E. Land Suitability Evaluation of Lolotoe Sub-District

The development of forestry commodities in Lolotoe Sub-District shows promising potential, particularly with the suitability of species such as melaleuca, pine, sandalwood, (S2), mahogany, teak, agathis, albizia, leucaena, acacia, and eucalyptus, which are classified as marginally suitable (S3) for the district's biophysical conditions. While the land faces challenges such as limited soil depth, surface rock outcrops, and coarse fragments, management can still be carried out through forestry technical approaches.

Altingia species have potential for development, although temperature constraints may limit their growth. However, the region still holds potential for forestry development, particularly with appropriate species selection and the application of proper land conservation techniques. **Table 8.1** lists alternative species that could be developed, and **Table 11.1** provides recommendations for forestry development in Lolotoe Sub-District as part of a land-use diversification and optimization strategy.

F. Land Suitability Evaluation of Maliana Sub-District

The development of forestry commodities in Maliana Sub-District shows promising potential, particularly with the suitability of species such as melaleuca, pine, sandalwood, (S2), mahogany, teak, agathis, albizia, leucaena, acacia, and eucalyptus, which are classified as marginally suitable (S3) for the district's biophysical conditions. Although the land faces challenges such as limited soil depth, surface rock outcrops, and coarse fragments, the area can still be managed through forestry technical approaches.

Altingia species have potential for development, although their growth may be limited by temperature. Nonetheless, the region offers significant opportunities for forestry development, especially with the selection of suitable species and proper land conservation techniques. **Table 8.1** lists potential alternative species, while **Table 11.1** provides recommendations for forestry development in Maliana Sub-District as part of a land-use diversification and optimization strategy.

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

Commodities	Sub-District	Limiting Factors	Potential Land Suitability / Land Improvement Efforts
FORESTRY COMMODITIES			
Teak	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2 :** Temperature, Rainfall, Surface Rocks, Rock Outcrops **S3 :** Coarse Fragment, N-Total, K_2O, Slope **N :** Dry Month, Effective Depth, Erosion	**S2 :** Temperature, Coarse Fragment, Effective Depth, Slope, Erosion, Surface Rocks, Rock Outcrops **S3 :** Dry Month
Mahoni	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2 :** Temperature, Surface Rocks, Rock Outcrops **S3 :** N- Total, K_2O, Slope **N :** Dry Month, Effective Depth, Erosion	**S2 :** Temperature, Coarse Fragment, Effective Depth, Slope, Erosion, Surface Rocks, Rock Outcrops **S3 :** Dry Month
Agathis	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2 :** Temperature, Surface Rocks, Rock Outcrops **S3 :** N- Total, K_2O, Slope **N :** Rainfall, Dry Month, Effective Depth, Erosion	**S2 :** Temperature, Coarse Fragment, Effective Depth, Slope, Erosion, Surface Rocks, Rock Outcrops **S3 :** Dry Month
Altingia	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2 :** Surface Rocks, Rock Outcrops **S3 :** Temperature, N- Total, K_2O, Slope **N :** Dry Month, Effective Depth, Erosion	**S2 :** Slope, Effective Depth, Erosion, Surface Rocks, Rock Outcrops **S3 :** Temperature, Dry Month
Sengon	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2 :** Rainfall, Surface Rocks, Rock Outcrops **S3 :** N- Total, K_2O, Slope **N :** Dry Month, Effective Depth, Erosion	**S2 :** Slope, Effective Depth, Erosion, Surface Rocks, Rock Outcrops **S3 :** Temperature, Dry Month
Leucaena	• Atabae • Balibo • Bobonaro	**S2 :** pH-soil, Surface Rocks, Rock Outcrops	**S2 :** Rainfall, Effective Depth, Slope, Erosion, Surface Rocks, Rock Outcrops

Acasia	• Cailaco • Lolotoe • Maliana	**S3 :** N- Total, K_2O, Slope **N :** Rainfall, Dry Month, Effective Depth, Erosion	**S3 :** Dry Month
Eucalyptus	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2 :** Surface Rocks, Rock Outcrops **S3 :** N- Total, K_2O, Slope **N :** Dry Month, Effective Depth, Erosion	**S2 :** Slope, Effective Depth, Erosion, Surface Rocks, Rock Outcrops **S3 :** Dry Month
Melaleuca	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2** : Rainfall, pH-soil, Surface Rocks, Rock Outcrops **S3** : N- Total, K_2O, Slope **N :** Effective Depth, Erosion	**S2** : Slope, Effective Depth, Erosion, Surface Rocks, Rock Outcrops
Pine	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**S2** : Rainfall, Dry Month, Surface Rocks, Rock Outcrops **S3** : N- Total, K_2O, Slope **N :** Effective Depth, Erosion	**S2** : Dry Month, Slope, Effective Depth, Erosion, Surface Rocks, Rock Outcrops
Sandalwood	• Atabae • Balibo • Bobonaro • Cailaco • Lolotoe • Maliana	**N :** Rock Outcrops **S3 :** Lereng, Surface Rocks, N-total, P-Available, K-Available **S2 :** Coarse Fragment, Slope, C-Organic	**S2 :** Coarse Fragment, Surface Rocks, Rock Outcrops

Note: Sufficiently Suitable (S2); Marginally Suitable (S3); Not Suitable (N)

8.2 LAND IMPROVEMENT PRACTICES

The productivity and sustainability of agriculture in the district depend heavily on the proper and integrated management of land limiting factors. Despite challenges such as limited soil depth, surface rock outcrops, and coarse fragments, management can still be carried out through forestry technical approaches. Improvement practices include the application of intensive silvicultural techniques, such as creating deep planting holes filled with organic matter to improve soil structure and expand the root zone, as well as clearing surface rocks and breaking rocks to support root growth.

In addition to physical constraints, the chemical properties of the soil show significant limitations. Organic carbon levels are low, which impacts soil structure and microbial activity. Key nutrients such as nitrogen, phosphorus, and potassium are also insufficient to support plant growth. Therefore, soil fertility improvement through the addition of organic matter and balanced fertilization becomes a strategic measure to enhance production capacity and support forestry commodities that are adaptive to marginal conditions.

Although most of the constraints are permanent, land management can still be carried out through adaptive and locally-based technical approaches. Strategies that can be applied include erosion control, site selection at appropriate altitudes, planting under protective cover to reduce thermal stress, and the use of superior varieties that are more tolerant to extreme temperatures. This integrated approach enables the optimization of land functions sustainably, supporting vegetation rehabilitation, and enhancing the ecological function of the area, such as controlling runoff, increasing water infiltration, and preserving biodiversity. Thus, marginal lands in Bobonaro District still hold strategic value for conservation-based and adaptive forestry development.

8.3 FORESTRY CROP DEVELOPMENT ZONING

The zoning for forestry crop development in Bobonaro District reflects a systematic effort to manage forest resources sustainably. Bobonaro District has biophysical characteristics that support the development of agroforestry and protected forest zones, with both covering 56.48% of the total area. These zones not only play a role in maintaining ecological balance but also form a key foundation in supporting food security, natural resource protection, and the improvement of local community welfare.

A. Agroforestry

Agroforestry systems have been widely implemented in Bobonaro District, covering an area of 667.78 km², or approximately 48.43% of the total administrative area. The largest distributions are found in Balibo Sub-District (16.40%), Atabae Sub-District (9.90%), Bobonaro Sub-District (9.47%), Cailaco Sub-District (5.60%), Lolotoe Sub-District (4.61%), and Maliana Sub-District (2.56%), as shown in **Figure 11.1 in Chapter XI**. This distribution reflects variations in biophysical conditions, accessibility levels, and land-use intensity. The agroforestry system in this region serves as an integrated approach combining production, environmental conservation, and socio-economic empowerment of local communities.

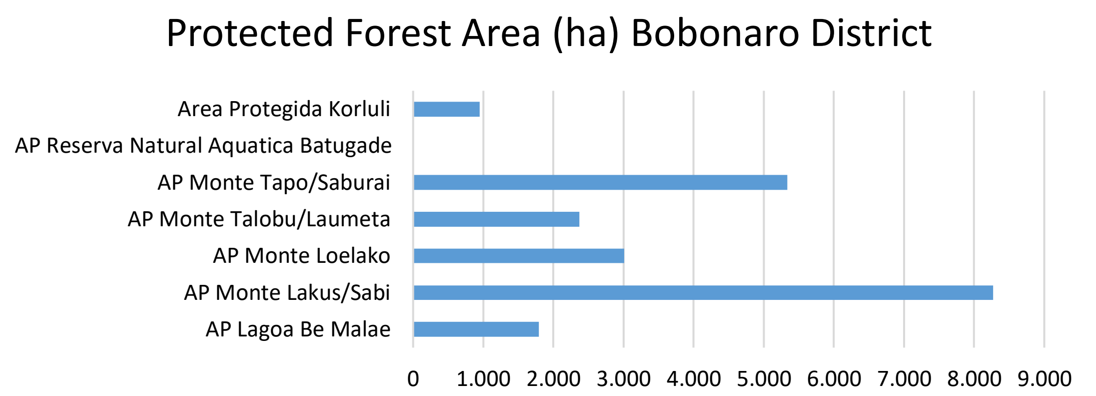
Coffee is a flagship commodity in Bobonaro's agroforestry system, generally cultivated using a multistrata method under hard tree cover. This system provides ecological benefits such as erosion control, increased soil moisture, and organic material accumulation from leaf litter. The layered vegetation structure creates a stable habitat and supports biodiversity conservation. Economically, coffee has a high market value both domestically and internationally, particularly when cultivated sustainably. Environmentally friendly practices open opportunities for premium pricing in global markets, while socially, coffee development promotes job creation, strengthens farmer institutions, and enhances community capacity in farm management.

The land suitability evaluation shows that this area is quite supportive of robusta coffee cultivation. Biophysical factors such as altitude, average temperature, soil texture, and water availability are within the optimal range for coffee growth. However, technical management is still required to improve productivity sustainably, as described in **Table 7.5 in Chapter VII**. With an adaptive agroforestry approach, coffee not only becomes an economically valuable commodity but also an instrument for conservation and community empowerment, relevant for sustainable development in Bobonaro.

B. Protected Forest Areas

Bobonaro District has protected forest areas covering 107.18 km², or about 7.79% of the total area. Bobonaro Sub-District (2.23%), Cailaco Sub-District (0.71%), Lolotoe Sub-District (3.62%), and Maliana Sub-District (1.24%), as shown in **Figure 11.1 in Chapter XI**. This zoning serves as a conservation area that supports the protection of river catchment areas, maintains landscape stability, and provides natural habitats for biodiversity. Its ecological role is crucial, especially in areas facing high environmental pressure and having biophysical conditions vulnerable to degradation.

In addition to these zones, Bobonaro District also includes established protected forest areas, such as the Area Protegida (AP) Monte Lakus/Sabi, Monte Tapo/Saburai, Monte Loelako, Monte Talobu/Laumeta, Lagoa Be Malae, Korluli, and Reserva Natural Aquatica Batugade. Each area has its own ecological characteristics and is an important habitat for various species of flora and fauna. These areas also play a role in erosion control, water conservation, and climate change mitigation. Besides their ecological value, the protected forest areas in Bobonaro have the potential to be developed as environmental education locations and community-based ecotourism. Information about the size and distribution of these areas is visually presented in **Figure 8.1**, supporting the integrated and sustainable natural resource management planning.



	AP Lagoa Be Malae	AP Monte Lakus/Sabi	AP Monte Loelako	AP Monte Talobu/Laumeta	AP Monte Tapo/Saburai	AP Reserva Natural Aquatica Batugade	Area Protegida Korluli
Hutan Lindung (ha)	1789,98	8269,99	3012,63	2373,42	5338,55	0,00	950,25

Figure 8.1 Protected Forest Area (ha) in Bobonaro District

C. Mangrove

Mangroves are a crucial coastal ecosystem for environmental balance and community life. The potential for mangrove development in Bobonaro District is highly limited, with coverage found only in two administrative sub-districts: Atabae (0.06%) and Balibo (0.10%). Although the area is relatively small, the presence of mangroves in these two areas holds important ecological and social value. Mangroves are characteristic coastal vegetation that grows in the intertidal zone, serving as natural protection against coastal erosion, saltwater intrusion, and tropical storm impacts. In addition, the mangrove ecosystem provides essential habitats for various fish species and plays a role in maintaining the food chain in coastal areas.

Mangrove development in these areas aims to strengthen environmental resilience, improve the welfare of coastal communities, and support climate change mitigation efforts through the carbon-sequestering ability of mangroves. In Atabae and Balibo Sub-Districts, mangrove management also has the potential to be developed as a source of local economic activity, particularly through sustainable fisheries and conservation-based ecotourism. With a participatory approach involving local communities and policy support from the government, mangrove development in Bobonaro is expected to become a model for adaptive, inclusive, and sustainable coastal ecosystem restoration practices, even within a limited scope.

8.4 SANDALWOOD DEVELOPMENT POTENTIAL

Sandalwood (*Santalum album* L.) is a high-value tree species that plays an important role in ecology, economy, and culture. The essential oil derived from its wood is widely used in the perfume, cosmetics, and pharmaceutical industries. In addition, sandalwood holds symbolic value in various traditions in Asia, including Timor-Leste. Sandalwood is also used as a primary material in crafting, carving, and creating high-value artworks, making it a competitive commodity with sustainable market prospects.

The land suitability evaluation indicates that the potential for sandalwood development in Bobonaro District falls within the marginally suitable (S3) class. This means that the land is still suitable for sandalwood cultivation, but there are biophysical constraints that require technical intervention. Recommended actions include selecting suitable planting sites, maintaining host trees to support growth, and applying adaptive silviculture techniques. With proper management and conservation-based practices, these limitations do not pose a barrier to making sandalwood a flagship commodity for the region.

As part of national policy, the Timor-Leste government has implemented a sandalwood tree inventory program to strengthen sustainable resource management and provide investment certainty. This program aims to map the number, distribution, and condition of sandalwood trees across various regions, including Bobonaro, as a basis for data-driven development planning. With government policy support, high economic value, and promising market potential, sandalwood development in Bobonaro has strong prospects. If managed sustainably, sandalwood can not only provide livelihoods for local communities but also serve as a symbol of cultural preservation and successful conservation of local natural resources.

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 de Oe-Cusse Ambeno (RAEOA), and Viqueque. The country experiences two seasons: the dry season, which lasts from June to November, and the rainy season, which occurs from December to May. The country's mountainous topography and proximity to the Australian continent cause it to be influenced by the dry easterly monsoon winds, resulting in some areas experiencing drought. Furthermore, low rainfall limits vegetation growth across various regions of the country.

The mountainous topography and low rainfall not only affect vegetation growth and agricultural life but also impact the availability of forage for the livestock sector. The development of livestock is highly dependent on the potential of land resources, the appropriateness of land use, and management methods. These factors are crucial in providing sufficient forage, which typically consists of grasses and legumes.

Forage can come from both natural sources and cultivated crops, including grazing lands (Priyanto, 2016). Optimal utilization of grazing land depends heavily on anthropogenic factors and the biophysical conditions of the land. Therefore, the application of various technological and institutional innovations is needed to ensure effective and optimal land resource use (Suryana and Rahman, 2006).

In general, the livestock sector in Timor-Leste faces several challenges. One of the main causes is the traditional and extensive livestock management system, which results in suboptimal production. The low level of awareness, knowledge, and technological mastery among farmers also hinders progress, particularly in the provision of quality forage in terms of both type and availability. Livestock are generally kept as household savings, to be sold in times of emergency. Additionally, some communities still use livestock as labor for land cultivation with traditional management systems.

The success of livestock enterprises relies on three main factors: breeding, feed, and management (Aman *et al.*, 2019). These three factors are interdependent: neglecting any one of them will prevent optimal outcomes, even if the other factors are well-managed. Livestock productivity, especially 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 a critical role in livestock development because it directly impacts production, productivity, and animal health. The quality of forage is influenced by factors such as the variety of forage, genotype, harvest maturity, season, and management practices applied (Adesogan *et al*., 2015).

One initial step in developing the livestock sector in Timor-Leste is the optimization of land use for sustainable forage production. To optimize land use, there must be alignment between the land characteristics and the types of forage to be cultivated. Therefore, land suitability evaluation becomes an essential approach for assessing the potential and carrying capacity of land resources (Harahap *et al*., 2019). This evaluation assesses not only the land's potential but also its suitability for various uses based on the management practices applied (Nugroho *et al*., 2014). The evaluation requires environmental data and soil quality for a specific area. The assessment is conducted by identifying various land characteristics such as topography, climate, soil condition and quality, and other physical environmental properties (Iswan *et al*., 2019). This evaluation process provides information on 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 addressed (Jawang *et al*., 2018).

9.2 RESEARCH METHODS

The research was conducted using survey and descriptive analysis methods in specific study areas selected purposively, namely the KTS (Karau Timor Susubeen) center and recommended livestock areas. The 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 factors, as well as biophysical land observations and soil characteristics for forage suitability. Further analysis of biophysical and soil properties was carried out according to laboratory standards. Secondary data used included the Timor-Leste Agricultural Census 2019.

The interview data obtained were analyzed using a simple tabulation method based on the Miles and Huberman analysis model, which includes data reduction, data presentation, conclusion drawing, and verification. Biophysical land and soil characteristics data were analyzed and presented using Geographic Information System (GIS) techniques, utilizing GIS software and various approaches depending on the data form and the objectives (Rusdi *et al*., 2015).

A. Research Procedure

1. Observation of Livestock Production and Socio-Economic Aspects

Observations were conducted through interviews using parameters such as livestock type, population, land area, management system (housing system), feed and nutrition management, water sources, breeding system, animal health management, livestock products, marketing, infrastructure, farmer characteristics, and traditions/customs.

2. Livestock Forage Land Suitability

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

9.3 GENERAL OVERVIEW

A. General Existing Conditions

The livestock sector plays an important role in supporting the livelihoods of many households in Bobonaro District. The distribution of households engaged in livestock farming shows significant differences across Sub-Districts. Balibo Sub-District has the highest number of households involved in livestock farming, with 436 households (35.28%). Meanwhile, Lolotoe Sub-District has the lowest number of households, with only 11 households (0.89%) engaged in livestock farming.

Nevertheless, the contributions of these households remain important for fulfilling local needs while preserving the livestock farming traditions that have been a part of local life. These differences illustrate that each Sub-District has its own contribution to the sustainability of the livestock sector in Bobonaro. The number of agricultural households involved in livestock farming is presented in **Figure 9.1.**

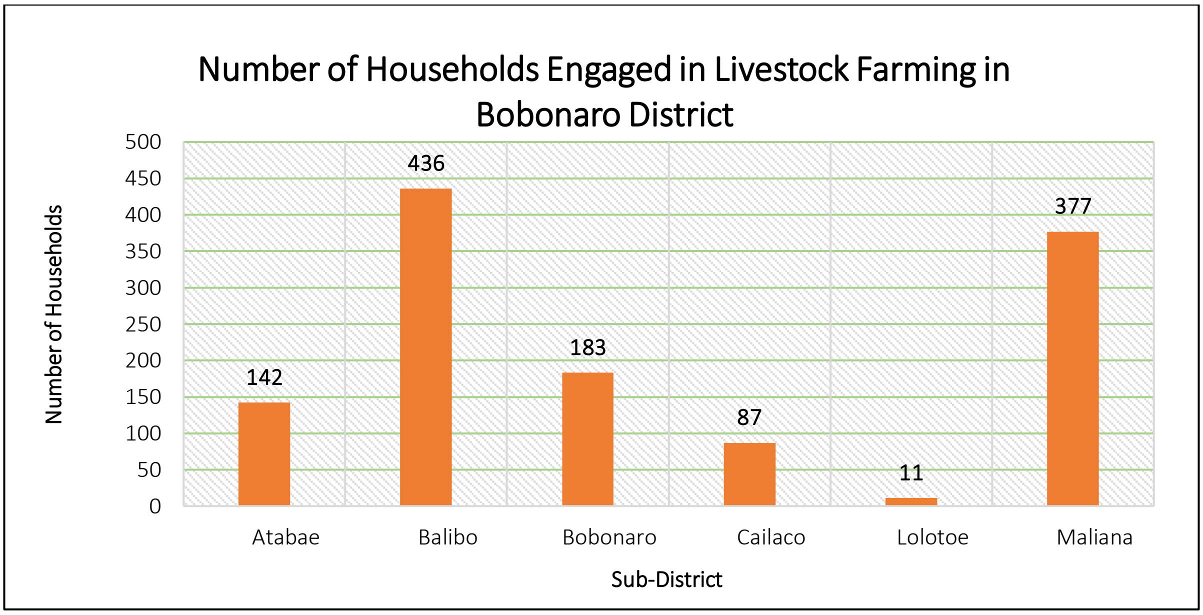


Figure 9.1 Number of Households Engaged in Livestock Farming
(Source: Agriculture Timor-Leste Agriculture Census, 2019)

Figure 9.2 and Figure 9.3 show that majority of livestock in Bobonaro District are large livestock, particularly cattle. Bobonaro Sub-District has the highest number of cattle-keeping households, with 2,062 households (23%) and a total population of 7,960 cattle. In contrast, Atabae Sub-District has the smallest number of cattle-keeping households, with 862 households (10%) and 8,347 cattle.

Horses are most commonly kept in Bobonaro Sub-District, with 331 households (64%) and a population of 549 horses. In contrast, Lolotoe Sub-District has the lowest number of horse-keeping households, with only 121 households (23%) and 168 horses.

For buffalo, Cailaco Sub-District dominates with 364 households (37%) and 1,770 buffalo. In contrast, Lolotoe Sub-District has the lowest number of buffalo-keeping households, with only 16 households (2%) and 73 buffalo (Figures 9.2

and 9.3). In terms of dairy cattle, Cailaco Sub-District has the highest number of dairy cattle-keeping households, with 37 households (64%).

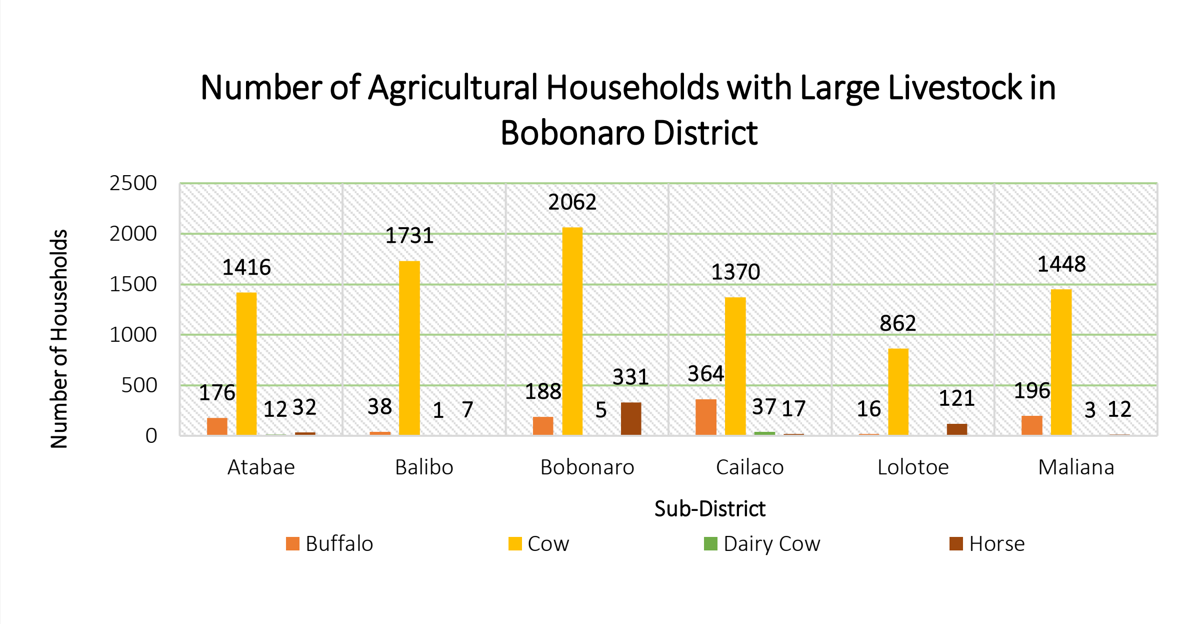


Figure 9.2 Number of Agricultural Households with Large Livestock
(Source: Timor-Leste Agriculture Census, 2019)

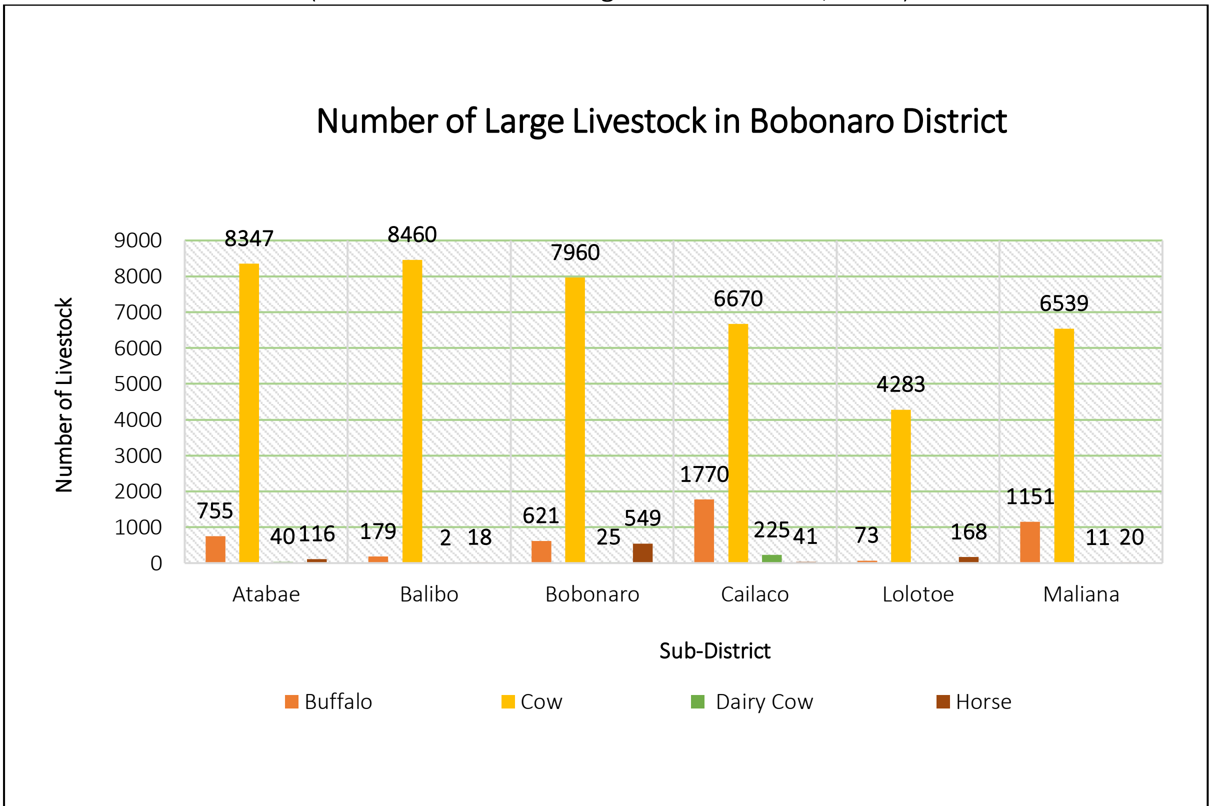


Figure 9.3 Number of Large Livestock
(Source: Timor-Leste Agriculture Census, 2019)

Figures 9.4 and 9.5 show that pigs are a significant small livestock species in Bobonaro District. Bobonaro Sub-District has the highest number of pig-keeping households, with 2,804 households (23%) and 8,727 pigs. In contrast, Lolotoe Sub-District has the lowest number of pig-keeping households, with only 1,120 households (9%) and 2,381 pigs.

Goat-keeping households show more variation across Sub-Districts. Cailaco Sub-District has the highest number of goat-keeping households, with 1,181 households (27%) and 4,866 goats, while Lolotoe Sub-District has the smallest number, with only 83 households (2%) and 305 goats.

For other livestock, such as sheep and rabbits, household contributions are smaller compared to goats and pigs. Bobonaro Sub-District has the highest number of sheep-keeping households, with 49 households (49%), while Lolotoe Sub-District has the lowest, with only 2 households (2%). For rabbits, there are only a few households scattered across some Sub-Districts, such as 2 households (67%) in Bobonaro and 1 household (33%) in Cailaco, while other Sub-Districts do not report any rabbit-keeping households.

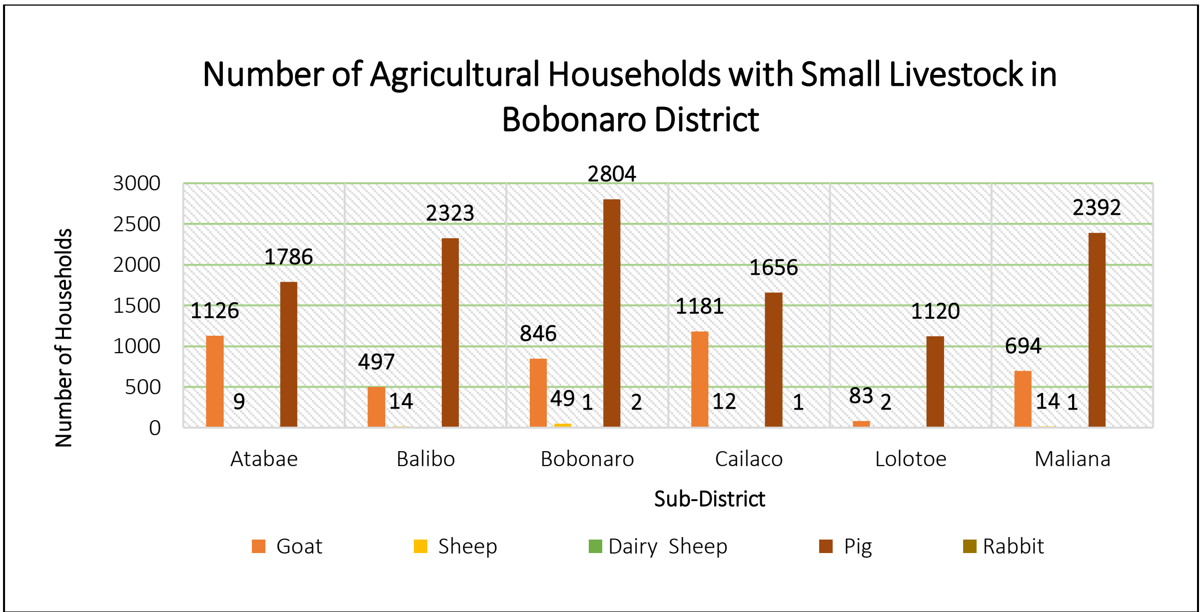


Figure 9.4 Number of Households That Keep Small Livestock
(Source: Timor-Leste Agriculture Census, 2019)

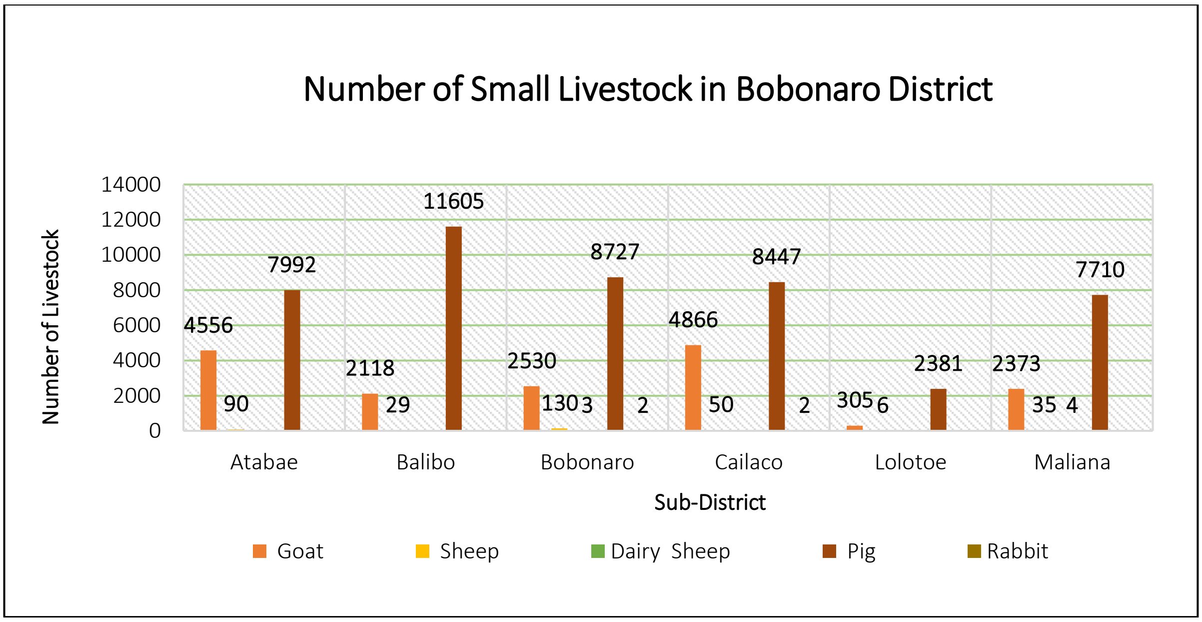


Figure 9.5 Number of Small Livestock
(Source: Agriculture Timor-Leste Agriculture Census, 2019)

The number of households keeping poultry in Bobonaro District shows significant differences between Sub-Districts, with chickens being the most commonly kept poultry species (**Figure 9.6**). Bobonaro Sub-District has the highest number of chicken-keeping households, with 2,478 households (22%) and 17,040 chickens. In contrast, Maliana Sub-District has the lowest number of chicken-keeping households, with 2,034 households (18%) and 17,692 chickens.

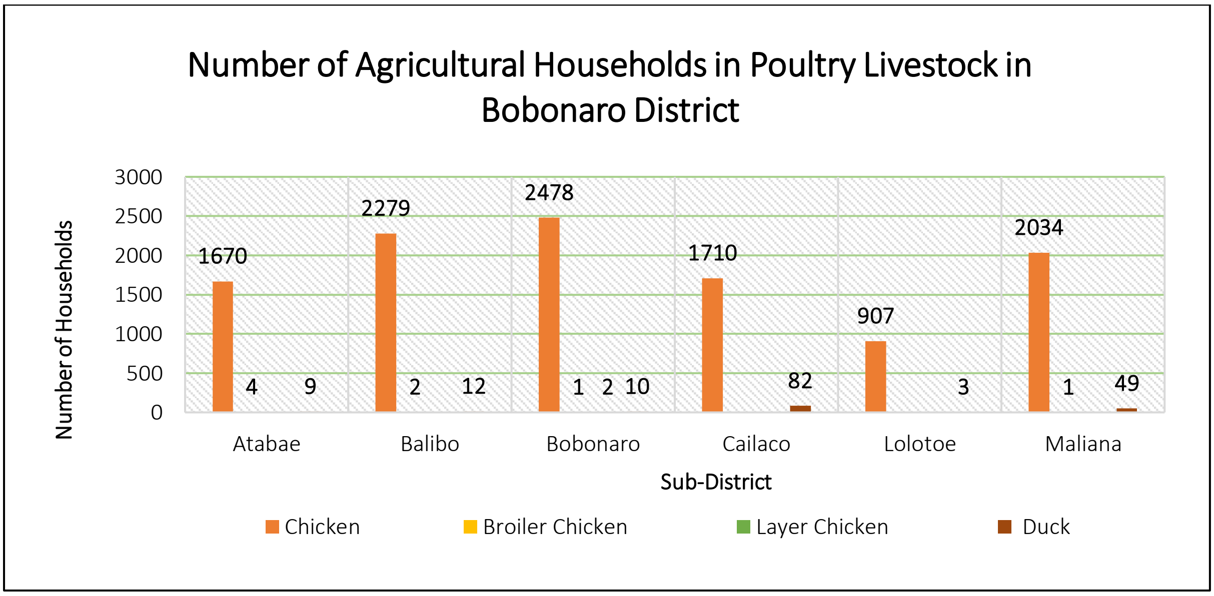


Figure 9.6 Number of Households Keeping Poultry
(Source: Timor-Leste Agriculture Census, 2019)

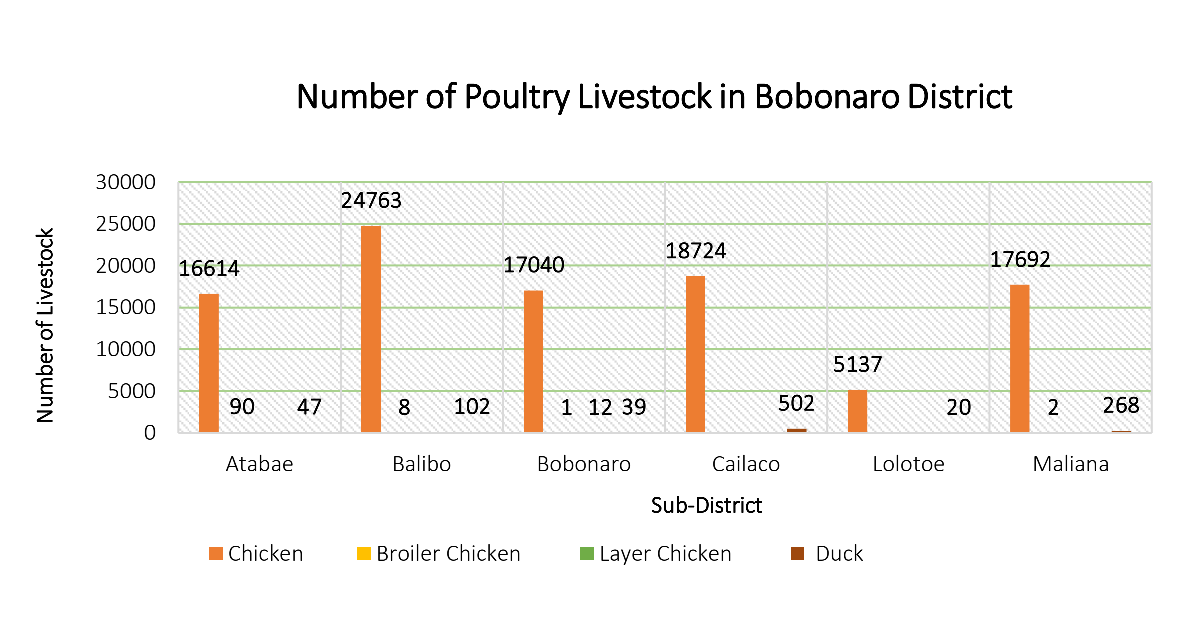


Figure 9.7 Total Number of Poultry
(Source: Timor-Leste Agriculture Census, 2019)

The potential of grazing land is an important asset for the livestock sector, especially for species like cattle, goats, and sheep, which require high-quality grasses to support their growth and production in sustainable livestock systems. Bobonaro District has two types of grazing lands: temporary and permanent grazing lands.

Balibo Sub-District has the largest grazing land area, with 55.19 ha (38.19%) of temporary land and 162.63 ha (61.73%) of permanent land, making it a strategic area for large-scale livestock farming. Lolotoe Sub-District, with a significant area of 32.96 ha (22.81%) of temporary land and 86.67 ha (32.90%) of permanent land, demonstrates potential for developing sustainable grazing systems. On the other hand, Cailaco Sub-District has the smallest grazing land area, with only 0.10 ha (0.07%) of temporary land and 1.53 ha (0.58%) of permanent land, indicating the need for land-use intensification strategies. Other Sub-Districts such as Atabae, Maliana, and Bobonaro have moderate land areas with potential to support small to medium-scale livestock farming. With proper management, these grazing lands can enhance livestock productivity while maintaining the region's ecosystem balance. The grazing land area is shown in **Figure 9.8.**

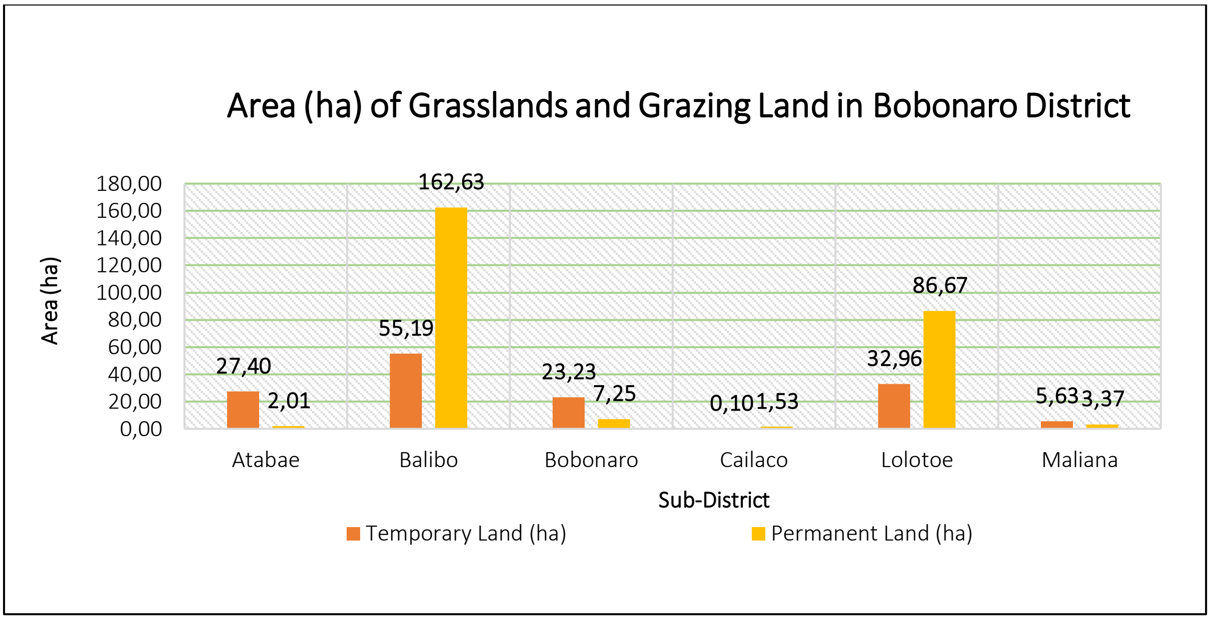


Figure 9.8 Area of Grazing Land
(Source: Timor-Leste Agriculture Census, 2019)

B. Existing Survey Conditions

The Karau Timor Susubeen (KTS) center in Corluli, located in Maliana, Bobonaro District, covers an area of 38 ha and is still under development. Some basic infrastructure is available, including feed storage, breeding pens, and an initial livestock population of 11 Timor buffaloes and 3 Bali cattle. This land was previously used for rice farming and is now being converted and planted with various forage crops (HPT) such as *Gamal*, *Lamtoro*, and other grasses. Given that the livestock facility development is not yet complete, temporary livestock care is being carried out on land owned by the Department of Horticulture. Intensive efforts to plant forage crops continue to support sustainable feed availability once the center is fully operational.


Figure 9.9 Existing Survey Conditions

9.4 DISCUSSION

A. Forage Land Suitability Evaluation

The land suitability analysis for forage crops in Bobonaro District is a method used to assess the suitability of land for the growth of various types of forage plants and grasses in grazing lands within a specific area. This analysis aims to facilitate the development of livestock feed resources while ensuring their optimal availability. According to Djaenudin *et al*. (2003), land suitability is defined as the degree to which land is suitable for a specific use. Land suitability can be assessed based on its current condition (actual land suitability) or after improvements have been made (potential land suitability). Land suitability evaluation in Timor-Leste is conducted using a matching method, which aligns data on land characteristics and quality with land suitability criteria based on the growth requirements of the evaluated crops. Several forage crops that are mapped in accordance with the potential of land resources include elephant grass (*Pennisetum purpureum*), legumes, and field grasses.

The results of the land suitability evaluation in Bobonaro District, including Atabae, Balibo, Bobonaro, Cailaco, Lolotoe, and Maliana Sub-Districts, show potential for developing forage crops such as elephant grass, Setaria, legumes, and grazing lands, as presented in Table 7.3 in this book. The table indicates that, in terms of actual land suitability, grazing land varies significantly from S2 (moderately suitable) to N (not suitable), with limiting factors including total nitrogen (N-total), available potassium (K-available), rainfall, effective soil depth, pH, erosion, and slope. Additionally, there are limitations due to dry months for grazing. These factors can be technically improved, such as by adding NPK fertilizer, creating water ponds and drainage channels, digging planting holes, adding organic matter, planting ground cover crops, adding lime/dolomite, and establishing terracing with strengthening plants. For the dry month limitation, planting can be adjusted to the planting season or aligned with the rainy season.

The KTS (Karau Timor Susubeen) Center in Korluli, Maliana Sub-District, as a survey and observation area, has potential land for forage crops such as elephant grass, Setaria, and grazing lands, with a land suitability class of S2. The limiting factors include organic carbon (SOC), pH, and total nitrogen (N-total). Technical improvements could include adding lime and organic materials to increase the land suitability class to S1. Based on observations, the KTS Center in Korluli has been planted with elephant grass as forage for Timor buffaloes.

To enhance livestock development, particularly forage production in Bobonaro District, several essential steps need to be taken to improve both the quantity and quality of forage, including:

1. **Planting leguminous forage**

Planting leguminous forage is a priority, as legumes generally have higher nutritional content than grasses. However, since legumes have certain limitations in their use, attention should be given to the proportion of their composition with grasses. As a reference, Susetyo (1980) recommends an ideal grazing land composition of 60% grasses and 40% legumes. Furthermore, according to Skerman (1977), legumes also play a role in controlling erosion, even more effectively than forests, due to their strong and deep root systems.

2. **Increasing forage species diversity**

Increasing the diversity of forage species, both legumes and grasses, is crucial for livestock development. The greater the diversity of forage species consumed by livestock, especially ruminants, the more likely it is to meet their complete nutritional needs. Some high-nutrient legume species with potential for development include indigofera, calliandra, tamarind, and stylosanthes. A commonly found local legume is lamtoro taramba. However, it should be noted that caution is needed when feeding lamtoro to pregnant livestock. Although it has high nutritional content, the leaves of lamtoro contain anti-nutritional substances such as mimosine and cyanide acid, which can be toxic if consumed excessively. This can be mitigated by feeding lamtoro in moderate amounts, mixing it with other feed, and ensuring it is wilted (air-dried) to reduce the anti-nutrient levels.

B. Livestock Ecological Potential and Suitability

Bobonaro District has a total area of 137,509.98 ha, with 88,275.03 ha allocated for livestock sector development. Optimizing the use of this potential requires efficient human resource empowerment and land use. One of the important factors in determining the potential of an area for livestock development is its ecological suitability or environmental conditions. Areas that do not meet ecological suitability indicators are categorized as less suitable for livestock development. Therefore, livestock enterprises in Bobonaro District must take ecological suitability into account.

After measuring each parameter in the field, data were analyzed using Geographic Information System (GIS) applications to determine the ecological suitability of five livestock species sheep, cattle, dairy cattle, pigs, and buffalo based on two critical parameters: environmental temperature and rainfall. The ecological land suitability map for livestock in Bobonaro District is presented in **Figure 9.10**.

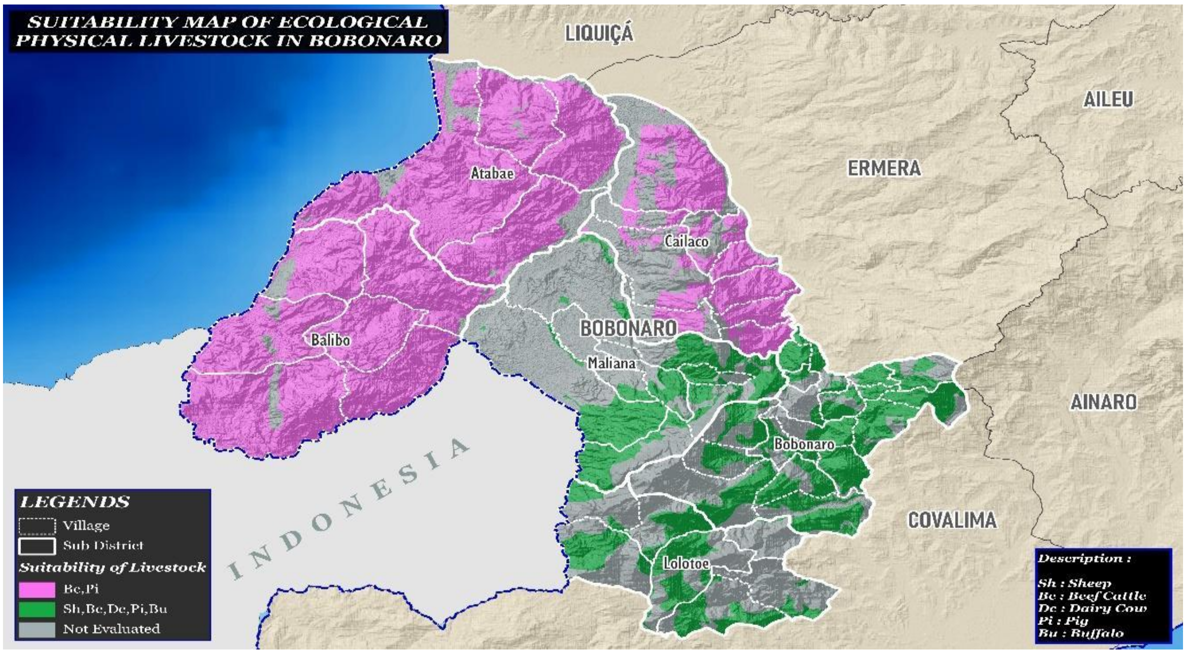


Figure 9.10 Ecological Land Suitability Map for Livestock in Bobonaro District

The available land for livestock development in Bobonaro District consists of mixed garden and grazing land areas. These lands are considered available because they are assumed to produce sufficient forage for livestock, including grasses, legumes, and crop residues. Land areas categorized as unavailable for livestock development include forests and rice paddies. Technically, this factor can be addressed by using livestock housing systems with proper airflow and ventilation. However, for dairy cattle, temperature is a critical factor that must be met for successful farming.

Table 9.1 Land Area for Livestock Development in Bobonaro District

Sub-District	Livestock Development Suitability Results for Large Livestock					Area (ha)
	Sheep	Beef Cattle	Dairy Cattle	Pig	Buffalo	
Atabae	N	S	N	S	N	22.168,28
Balibo	N	S	N	S	N	28.151,67
Bobonaro	S	S	S	S	S	13.020,34
Cailaco	N	S	N	S	N	10.969,57
Lolotoe	S	S	S	S	S	6.052,41
Maliana	S	S	S	S	S	7.912,76

Based on the data analysis presented in **Table 9.1**, the ecological suitability of land for large livestock development, including sheep, beef cattle, dairy cattle, pigs, and buffalo, shows a varied spatial distribution across the study area. Balibo Sub-District is the most dominant region for large livestock development in Bobonaro District, followed by Atabae, Bobonaro, Cailaco, and Maliana. Lolotoe Sub-District occupies the smallest area for livestock development. Bobonaro, Lolotoe, and Maliana Sub-Districts are suitable for developing sheep, beef cattle, dairy cattle, pigs, and buffalo. Livestock development in Atabae, Balibo, and Cailaco Sub-Districts is suitable for beef cattle and pigs but not suitable for sheep, dairy cattle, and buffalo due to limiting factors such as temperature and rainfall.

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

In supporting the livestock sector development program, it is essential to identify and map areas that serve as primary locations for livestock farming and forage cultivation. Bobonaro District, with an average environmental temperature of 23.60°C and annual rainfall of 2,010.89 mm, has ecological potential that is conducive to supporting sustainable livestock enterprises. This climate also supports the continuous availability of forage throughout the year. Environmental temperature plays a central role in determining the thermal comfort and productivity of livestock. If temperatures are too low, livestock may experience cold stress, which increases body heat production and basal metabolic rate. If such conditions persist without adequate feed, livestock's metabolic energy will be depleted, reducing their resilience to extreme temperatures. This can disrupt growth, reduce productivity, and significantly increase the risk of disease. On the other hand, excessively high temperatures lead to reduced feed intake, with livestock opting to drink more water. This reduction in nutrient intake directly impacts livestock production performance. Therefore, optimal environmental management, particularly the regulation of temperature and humidity, is crucial in sustainable livestock farming systems. Such efforts aim to create conditions that support the physiological balance of livestock, ensuring maximum productivity.

C. Socio-Economic Aspects of Livestock Farming

For the people of Bobonaro District, livestock plays a vital and multifunctional role, far beyond being a food source. Livestock is an integral part of the subsistence farming system and evolving civilization. It is common for communities to use livestock, such as cattle, buffalo, and horses, as draft power for plowing fields, enabling farmers to cultivate larger areas and significantly increase agricultural productivity. Furthermore, in some cultures, livestock holds social, economic, or ritual significance. For example, livestock is used as a dowry or offering in traditional ceremonies. Additionally, the number of livestock owned by an individual often serves as a measure of wealth and social status in the community.

One endemic species in Timor-Leste is the Timor buffalo (*Karaw Timor*). The Timor buffalo holds a significant role in the social life of Timor-Leste, especially as an offering in ceremonies related to death, birth, and marriage. Timor buffaloes are also used in traditional transactions such as land sales, their dung is used as fertilizer, and traditionally, the people have consumed buffalo milk to fulfill their animal protein needs, making the Timor buffalo quite valuable.

Buffalo milk has been consumed by the local community for generations and is a popular alternative to cow and goat milk. Buffalo milk is thicker and has a distinct odor compared to cow milk. Historically, the local population consumed buffalo milk directly, without further processing, making it an important part of cultural identity.

Livestock farming in Timor-Leste is generally still carried out using the traditional free-range grazing system, known as the extensive system. According to Williamson and Payne (1993), in the extensive management system, livestock are kept freely and graze on available vegetation. In this system, livestock are released in groups, typically with a few males and several females. The primary characteristic of this system is the absence of shelters and supplementary feeding (Jamili, M. A., 2022). The advantages of the extensive system include minimal labor, short working hours, and the ability of livestock to forage in grazing lands and former agricultural lands. However, the drawbacks include difficulties in controlling feed consumption and livestock being prone to diseases and mortality. Livestock that is not closely monitored often leads to social issues such as livestock theft and damage to farmers' gardens.

The livestock farming pattern still relies on traditional local knowledge passed down through generations. The lack of large-scale livestock industries results in suboptimal livestock production, with many areas needing improvement. The distribution of livestock is relatively low due to limited capital and the lack of breeding practices. Expanding livestock numbers requires significant costs and time, which is why livestock is not seen as a primary income source, leading to low livestock production in the region (Serey *et al*., 2014).

Interviews revealed that the community received assistance in the form of cattle and buffalo from MAPPF in 2014. However, over time, due to low supervision and lack of education, the assistance has not developed as initially intended. The community used the assistance to meet household needs or as dowries. As a result, attention to the sustainability of livestock breeding has been neglected, potentially hindering sustainable development.

Other challenges in livestock farming are complex, spanning from upstream to downstream, and include the need for better infrastructure. In terms of breeding, the community still applies natural mating systems without the use of artificial insemination (AI), making livestock breeding for sustainability difficult. The community also lacks knowledge of proper livestock management practices. Education on good feed management is also insufficient. Additionally, in marketing, farmers can only sell live animals, which limits the ability to raise product prices. Although access to Dili, the urban center, has improved, inadequate road infrastructure remains a barrier to reaching broader markets.

Given the numerous challenges from pre-production to post-production, attention is needed to address these issues, providing a foundation for designing a master plan for livestock development. Recommended improvements include educating the community on breeding techniques and introducing artificial insemination technology. Additionally, educating the community about proper livestock management is crucial to encourage a more economically oriented approach to livestock farming, rather than treating it as just family savings. The government should not only focus on education but also provide financial support in the form of credit loans to help streamline livestock farming efforts. Increasing the marketability of livestock products can also be achieved by educating farmers and opening new marketing channels beyond the sale of live animals.

X. FRESHWATER FISHERIES POTENTIAL

10.1 INTRODUCTION

Timor-Leste, as an island nation, possesses substantial natural resource potential, particularly in the marine and fisheries sector. This study specifically focused on freshwater aquaculture practiced by communities in the lowland and coastal areas of Bobonaro District, given that these regions have biophysical characteristics relatively more favorable for aquaculture development compared to mountainous areas. Lowland and coastal zones generally have more stable access to water from rivers and springs, as well as land conditions that are more suitable for the construction of fish ponds with lower erosion risk. Aquaculture not only contributes to local food security but also creates sustainable economic opportunities for surrounding communities.

However, the development of aquaculture enterprises requires a thorough study of land suitability. The selection of the right location is crucial to the success of this venture because different fish species have varying tolerances to environmental factors such as topography and hydrology, soil conditions, water quality, and climate. Therefore, land suitability analysis becomes an essential initial step in aquaculture planning.

This study aims to evaluate the land suitability in Bobonaro District based on a number of bio-physical parameters identified in the assessment matrix. The matrix includes four main groups of factors: topography and hydrology, soil conditions, water quality, and climate. Each factor is assigned a specific weight reflecting its importance in determining land suitability for aquaculture.

The use of the assessment matrix is key in determining whether the land in Bobonaro District can support a sustainable and efficient aquaculture production system. This evaluation not only emphasizes technical analysis but also incorporates local policies, community participation, and customary practices in water resource management, ensuring that the findings can be optimally applied in Bobonaro District.

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**.

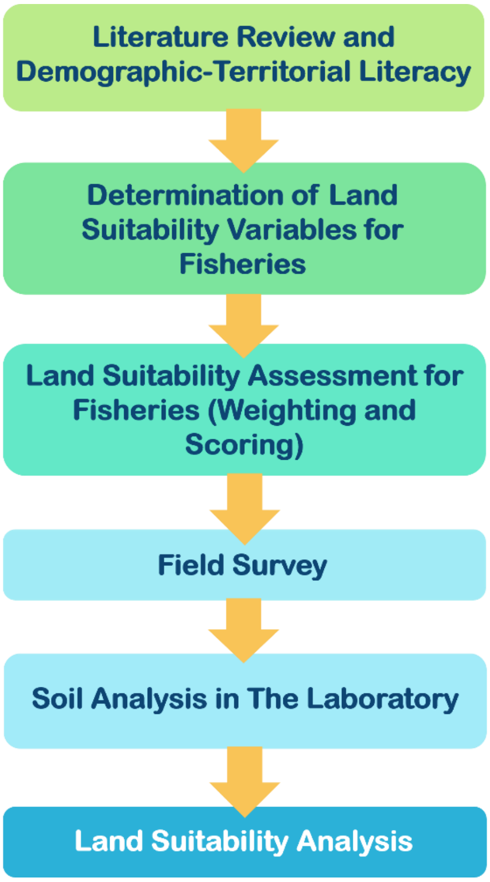


Figure 10. 1 Flowchart of the research process for land suitability in the aquaculture sector

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	%	Gravimetric tools	Laboratory
	- pH_F-pH_{FOX}	-	Spectrophotometer	Laboratory
	- Organic Carbon	mg/L	Spectrophotometer	Laboratory
3.	Water Quality			
	- Temperature	°C	Multimeter EZ-9901	In Situ
	- Salinity	ppt	Refractometer	In Situ
	- pH	-	Multimeter EZ-9901 / pH-meter	In Situ
	- Total Dissolved Solid (TDS)	mg/L	Multimeter EZ-9901	In Situ
	- Ammonia	mg/L	Tetra-Kit (TAN conversion)	In Situ
	- Dissolved Oxygen (DO)	mg/L	DO-meter	In Situ
4.	Climate			
	- Annual rainfall	mm/year	Remote Sensing/ Climatology	Ex Situ / Digital
	- Dry months	-	Remote Sensing/ Climatology	Ex Situ / Digital

a. Topography

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

b. Soil Conditions

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

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

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

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

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

c. Water Quality

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

Water clarity in ponds is determined by the degree of turbidity, which results from the suspension of organic particles, colloidal soil, or plankton density. In newly established ponds on peat or acid sulfate soils, water clarity may decrease due to suspended particles or iron hydroxide ($Fe(OH)_3$) compounds or organic acids and tannins leached from plant root residues, resulting in brownish-black colored water (Poernomo, 1988). The optimal temperature for vannamei shrimp growth is 28°C to 30°C (Ponce-Palatox *et al.*, 1997). The ideal water temperature for milkfish culture is 27°C to 31°C (Ismail *et al.*, 1993). The optimal water temperature for tilapia culture is 25°C to 30°C (Stickney, 2000; Hossain *et al.*, 2007), with tolerance for temperatures between 15°C and 37°C (Wiryanta *et al.*, 2010).

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

The tolerance limits of aquatic organisms to pH vary and are influenced by factors such as dissolved oxygen, alkalinity, the presence of ions, and the organism's stage of development. Milkfish grow optimally at a pH range of 7.0 to

8.5 (Ismail *et al*., 1993). According to Swingle (1968), the ideal pH for aquatic organisms is between 6.5 and 9.0, while values between 9.5 and 11.0 or 4.0 and 6.0 result in low production. pH values below 4.0 or above 11.0 are toxic to fish.

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

d. Climate

Kondisi rata-rata cuaca pada periode yang panjang dikenal dengan iklim. Unsur-unsur iklim yang penting untuk budidaya tambak adalah rainfall. Rainfall antara 2.000-3.000 mm/tahun dengan dry months 2-3 bulan cukup baik untuk tambak (Mustafa *et al*., 2011). Dry months menurut klasifikasi iklim dari Schmidt dan Ferguson (1951) adalah bulan dengan rainfall < 60mm. Persiapan tambak adalah salah satu kegiatan yang harus dilakukan sebelum dilakukan penebaran. Pada saat persiapan tambak dilakukan pengeringan tambak dengan tujuan untuk memperbaiki sifat fisik tanah, meningkatkan mineralisasi bahan organik dan menghilangkan bahan-bahan beracun berupa hidrogen sulfida, amonia, dan metan. Karena itu, diperlukan adanya bulan-dry months tertentu pada setiap tahun.

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 Bobonaro District

No.	Schedule	Sub-District	Village	Purpose (Ownership)
1	21 May 2025	Balibo	Leohito	Business (Individual)
2	21 May 2025	Maliana	Raifun	Non-Business (Government)

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

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

F. Soil Analysis in the Laboratory

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

Table 10. 6 Soil Analysis Parameters and Their Relationship and Significance to Aquatic Commodity Habitats

Soil Parameter	Purpose & Significance	Relationship with Water Quality	Impact on Aquatic Commodity Habitat
Clay Content	Clay fraction plays a key role in soil physical properties such as water retention, permeability, and nutrient retention. High clay content enhances the soil's ability to store nutrients but can hinder aeration.	Affects water infiltration and retention as well as sediment transport.	High clay → ideal habitat for mollusks, but poor for demersal fish that need coarse substrates.
pH_F-pH_{FOX}	The difference between pH_F and pH_{FOX} indicates latent acidity potential. A significantly lower pH_{FOX} indicates potential acid sulfate soils, which is important for wetland restoration or land use planning.	Indicator of latent soil acidity → affects water column pH.	Low pH → physiological stress on fish and shrimp; affects metal bioavailability.

Organic Carbon	Organic carbon is a primary indicator of soil fertility and quality. High organic carbon content suggests healthy soil conditions and has potential as a carbon sink (blue carbon), especially relevant in mangrove and wetland ecosystems.	Source of organic nutrients in remineralization processes → influences DO and primary productivity.	Determines soil fertility for aquaculture and the growth substrate for macroalgae and seagrasses.

G. Aquaculture Land Suitability Analysis

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

Table 10. 7 Land Suitability Criteria for Tilapia Farming (*Oreochromis niloticus*)

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

Source: Mustafa (2012)

Table 10. 8 Land `Suitability Criteria for Carp Farming (Cyprinus carpio)

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

Source : Mustafa (2012)

10.3 EXISTING CONDITIONS AND OBSERVATION RESULTS

A. Capture Fisheries

1. Number of Fishing Households

Bobonaro District exhibits a varied distribution of fishing households across its sub-districts, reflecting the different roles that the fisheries sector plays in each area. According to the data, Atabae Sub-District recorded the highest number of fishing households, with 222 households (62.71%), followed by Balibo Sub-District with 115 households (32.49%). These two sub-districts show higher concentrations of fisheries activities, supported by better access to aquatic resources. Meanwhile, Bobonaro Sub-District has only 9 fishing households (2.54%), while Cailaco, Lolotoe, and Maliana recorded much smaller numbers, with 3, 4, and 1 household, respectively. This distribution indicates that not all areas in Bobonaro are highly involved in the fisheries sector.

The variation in the number of fishing households suggests different potential for fisheries management in each sub-district. Atabae and Balibo Sub-Districts have opportunities to expand their fisheries activities through investments in infrastructure, such as fishponds or more efficient fishing equipment. Meanwhile, sub-districts with fewer fishing households, such as Maliana and Lolotoe, could focus on small-scale or pilot projects suited to their local capacity. With a well-planned approach, the fisheries sector in Bobonaro District could be optimized to support the local economy and meet the food needs of the population. Graphs illustrating the number of fishing households are shown in **Figure 10.2** and **Figure 10.3.**

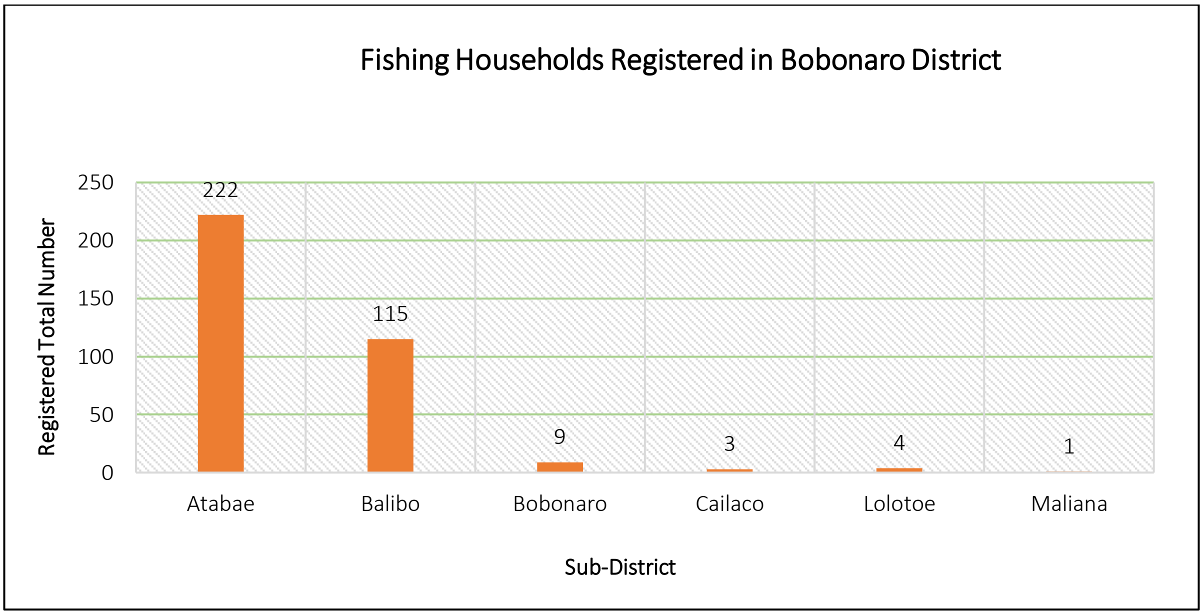


Figure 10. 2 Fishing Households in Bobonaro District
(Source: Timor-Leste Agriculture Census, 2019)

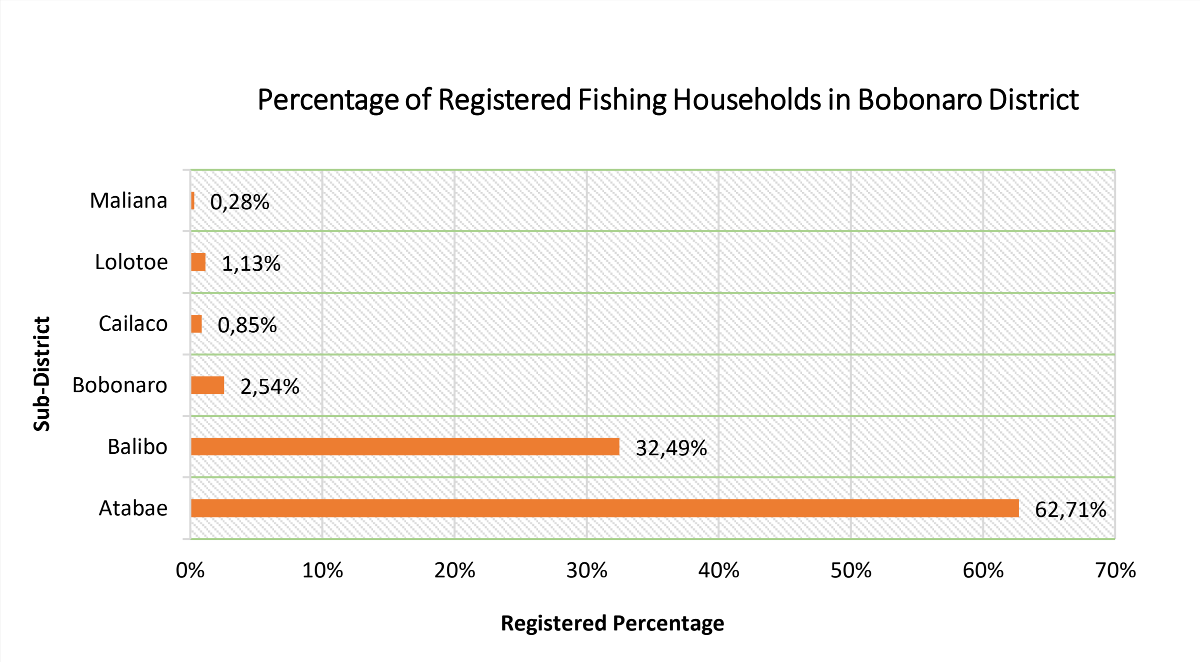


Figure 10. 3 Percentage of Fishing Households in Bobonaro District
(Source: Timor-Leste Agriculture Census, 2019)

2. Households Involved in Fishing Activities

Households involved in fish capture are categorized into three activity types: for consumption and social obligations, for consumption and occasional sales, and for direct sales.

Bobonaro District shows a diverse distribution based on the purpose and scale of activities. Atabae Sub-District, with the highest number of households in the capture category for consumption and social obligations, recorded 6 households (23.08%), for consumption and occasional sales, 94 households (59.87%), and for direct sales, 130 households (72.63%). This reflects the important role of fish capture both as a food source and income. Balibo Sub-District also recorded significant participation, with 12 households (46.15%) for consumption and social obligations, 56 households (35.67%) for consumption and occasional sales, and 46 households (25.70%) focused on direct sales. Bobonaro, Cailaco, Lolotoe, and Maliana Sub-Districts recorded much smaller numbers across all categories, indicating more limited involvement in this activity.

The differences in participation reflect varying potential for development in each sub-district. Atabae and Balibo Sub-Districts could become centers for fisheries development by strengthening infrastructure and supporting households in improving capture efficiency and marketing. Meanwhile, sub-districts with lower involvement, such as Bobonaro and Maliana, could focus on small-scale development that suits local capacities and needs. Through planned management, fish capture activities in Bobonaro District could be optimized to provide broader economic, social, and ecological benefits. The number of households involved in fish capture activities is shown in **Figure 10.4** and **Figure 10.5**.

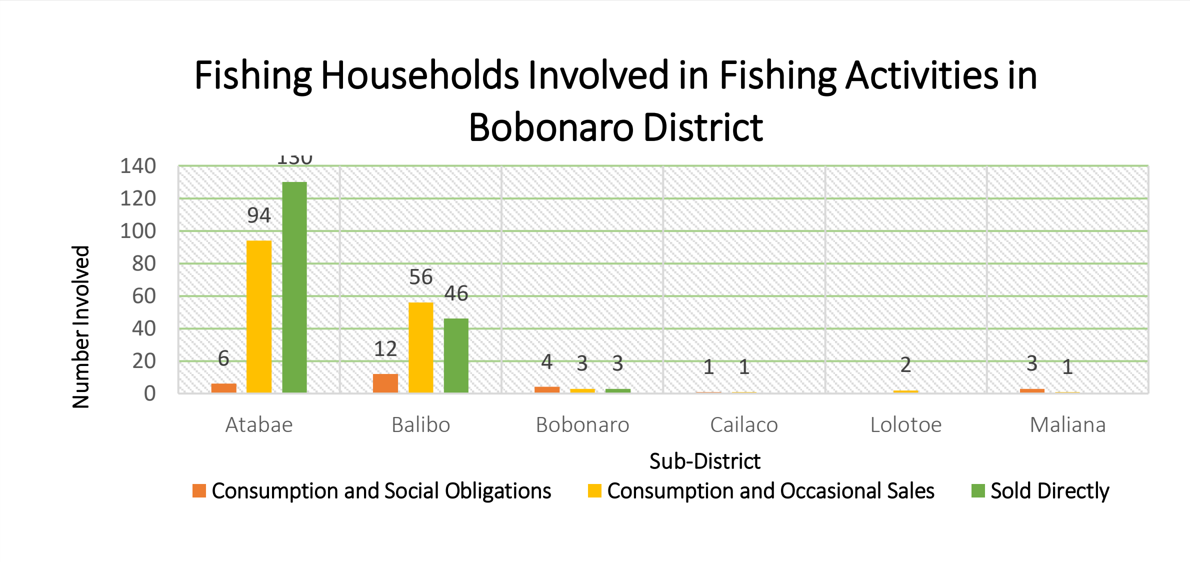


Figure 10. 4 Number of Households Involved in Fishing Activities
(Source: Timor-Leste Agriculture Census, 2019)

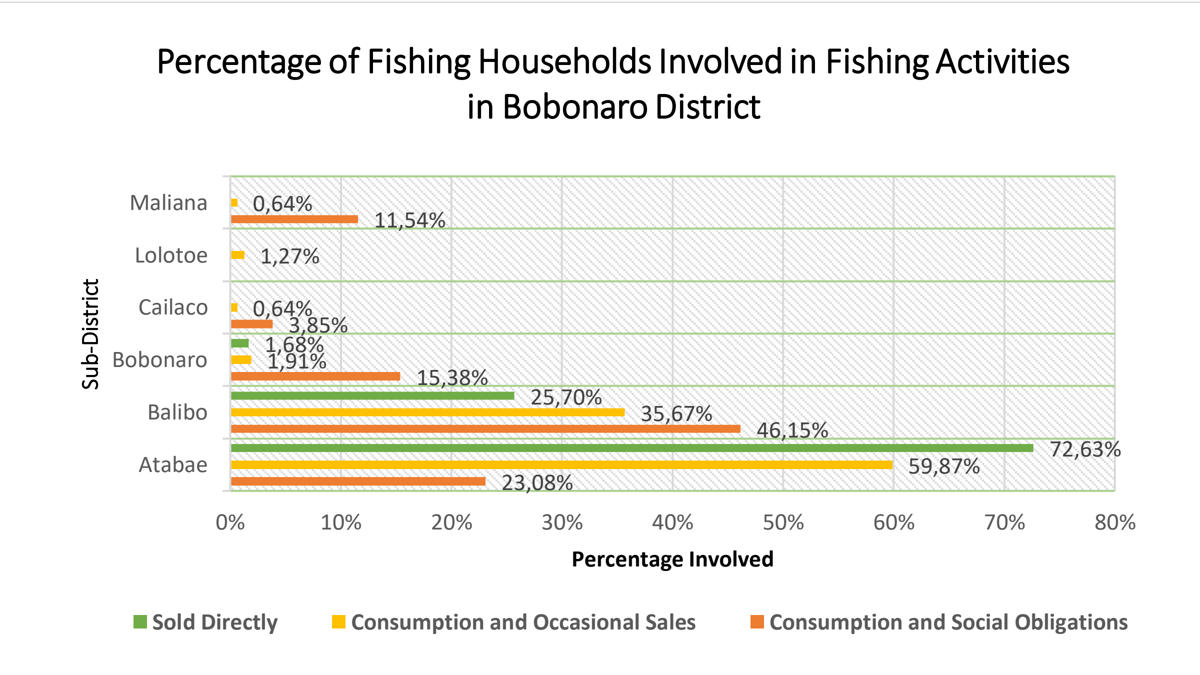


Figure 10. 5 Percentage Number of Households Involved in Fishing Activities
(Source: Timor-Leste Agriculture Census, 2019)

B. Aquaculture

Aquaculture in Bobonaro District has the potential to support local livelihoods, especially through the sustainable management of both marine and terrestrial resources. This region is known for its marine biodiversity, which can be utilized for fish farming and other aquaculture development.

According to data from the 2022 Timor-Leste Census, the consumption of fish from aquaculture at the household level has increased year by year. In 2019, aquaculture fish consumption reached 0.10 kg per person per year, increasing to 0.15 kg per person per year in 2020. This figure remained stable until 2023, reflecting consistent management and distribution of aquaculture products in the region.

This increase highlights the potential of Bobonaro District to continue developing its aquaculture sector to further increase fish consumption at the local level. By strengthening fisheries infrastructure and applying modern aquaculture technologies, the region can make a greater contribution to food security and improve the fish consumption patterns of its population. This also opens up opportunities to create economic value by expanding aquaculture products to a broader local market.

1. Proportion of Land for Aquaculture

The area of aquaculture land in Bobonaro District shows variation in proportions across sub-districts, reflecting different potentials and levels of utilization of aquatic resources. Cailaco Sub-District has the largest area of aquaculture land, at 53.24 ha, accounting for approximately 29.03% of the total aquaculture land in the district. It is followed by Atabae Sub-District with 46.92 ha (25.59%) and Balibo Sub-District with 44.65 ha (24.35%), both contributing significantly to aquaculture activities. Maliana Sub-District has an aquaculture area of 26.10 ha (14.23%), while Lolotoe Sub-District recorded 10.21 ha (5.57%). In contrast, Bobonaro Sub-District has the smallest proportion, with only 2.25 ha, or about 1.22% of the total.

This data indicates that sub-districts such as Cailaco, Atabae, and Balibo could become the main centers for aquaculture development in the region, given the available land area. Conversely, sub-districts with smaller areas, such as Bobonaro, could adopt intensification strategies and technological innovations to maximize their aquaculture potential. Optimizing land management in these areas could support productivity increases and contribute to the sustainable development of the fisheries sector in Bobonaro District. The proportion of land used for aquaculture is shown in **Figure 10.6** and **Figure 10.7.**

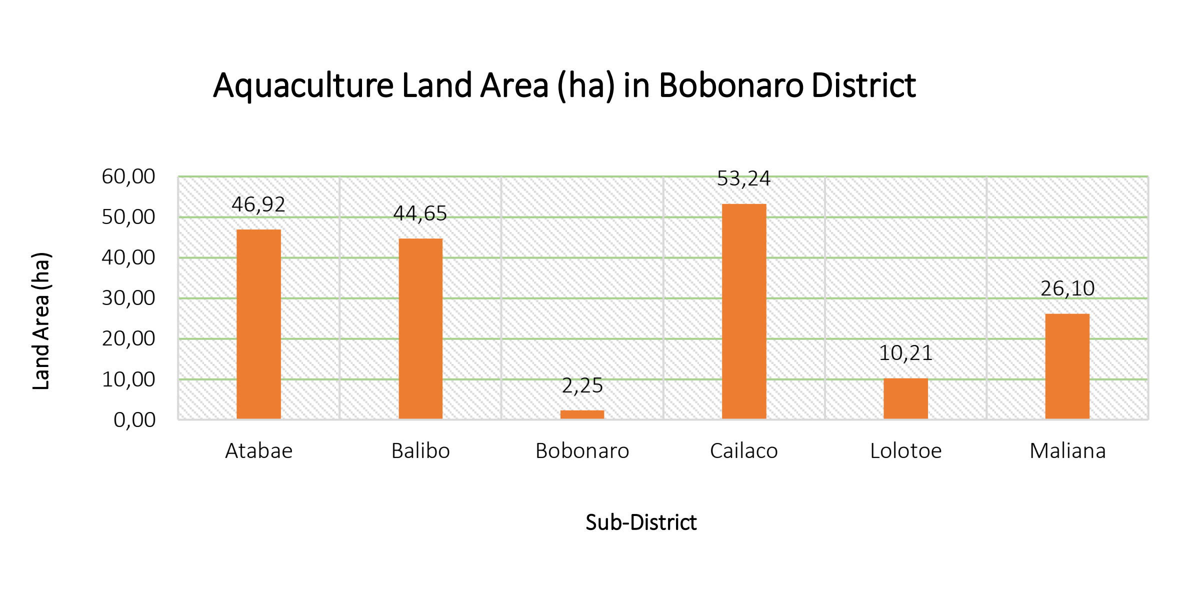


Figure 10. 6 Aquaculture Land Area in Bobonaro District
(Source: Timor-Leste Agriculture Census, 2019)

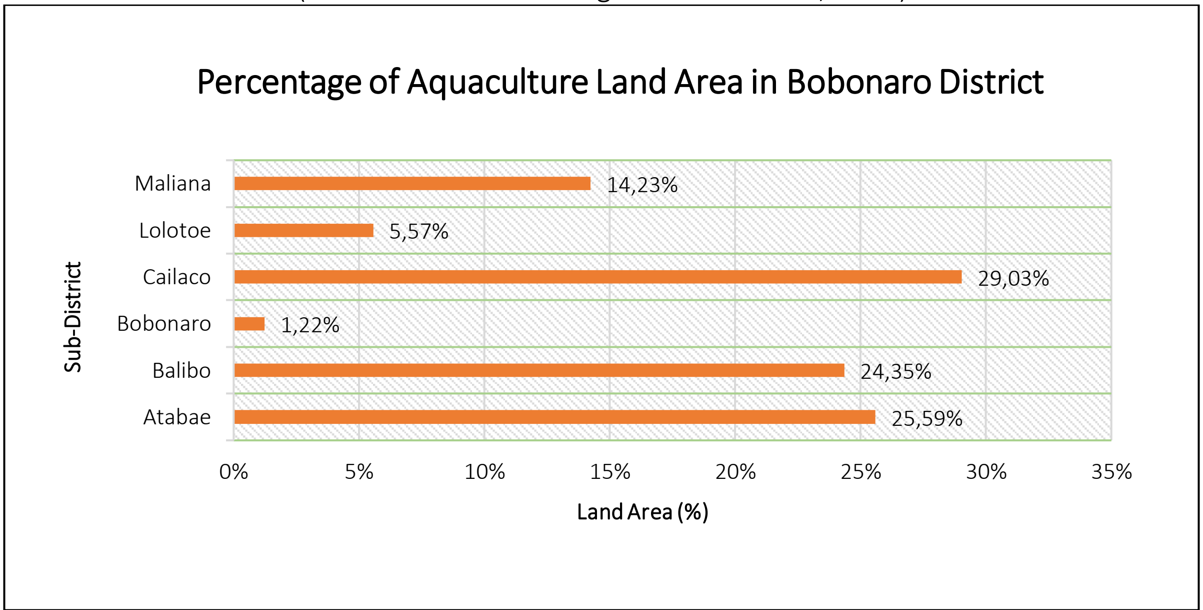


Figure 10. 7 Percentage of Aquaculture Land in Bobonaro District
(Source: Timor-Leste Agriculture Census, 2019)

2. Aquaculture Households

Households play a crucial role in driving the development of the aquaculture sector, particularly in Bobonaro District. Through their active involvement, households can increase fish production, efficiently utilize aquatic resources, and strengthen the local economy. Households are also the main units of management that support sustainable fish farming, either through innovative farming techniques or maintaining aquatic ecosystems.

According to the data, Maliana Sub-District has the highest number of households involved in aquaculture, with 93 households (34.32%), emphasizing its potential as a key center for sector development. This is followed by Balibo Sub-District with 66 households (24.35%) and Bobonaro Sub-District with 34 households (12.55%), both showing significant contributions to aquaculture production in the area. Meanwhile, Atabae Sub-District has 33 households (12.18%), Cailaco Sub-District 27 households (9.96%), and Lolotoe Sub-District recorded the smallest number, with 18 households (6.64%). This variation suggests different levels of involvement, which may be influenced by factors such as access to water resources or infrastructure support.

With this diverse level of involvement, Bobonaro District has great potential to enhance its aquaculture sector through training, infrastructure investment, and household empowerment, particularly in areas with lower participation. This approach could promote more integrated management and provide broader economic impacts for the community. The number of households involved in aquaculture in Bobonaro District is shown in **Figure 10.8** and **Figure 10.9**.

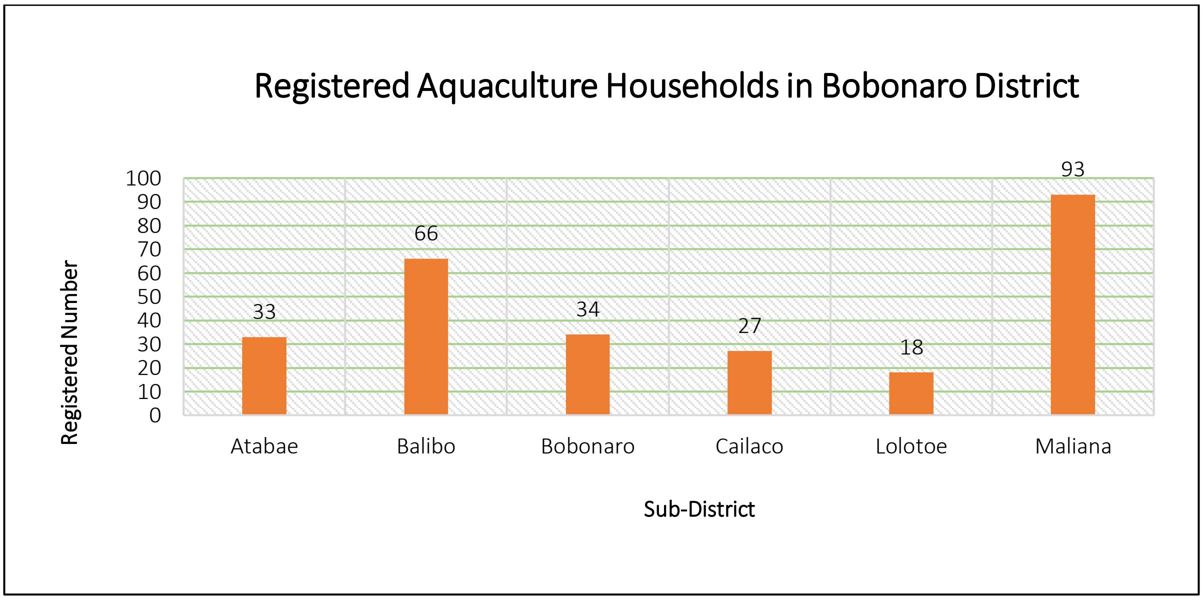


Figure 10. 8 Aquaculture Households in Bobonaro District
(Source: Timor-Leste Agriculture Census, 2019)

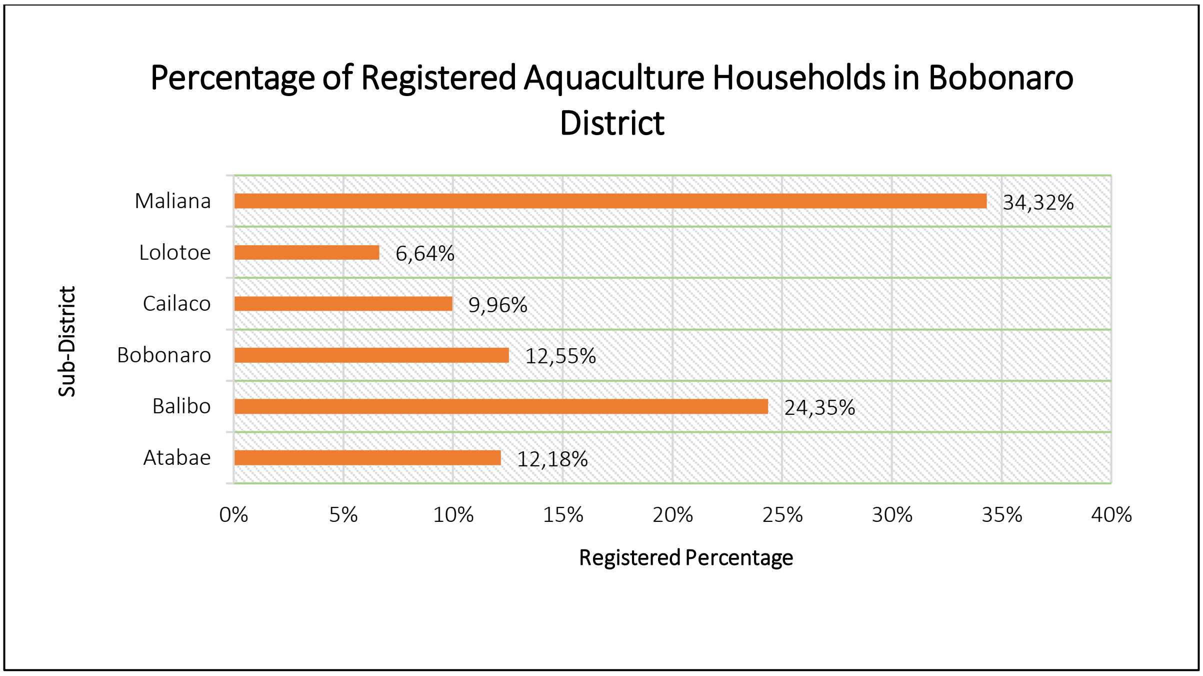


Figure 10. 9 Percentage of Aquaculture Households in Bobonaro District
(Source: Timor-Leste Agriculture Census, 2019)

3. Aquaculture Systems

Aquaculture farming systems play an important role in improving fish production sustainably. With various methods such as fishponds, shrimp ponds, cages, rice-fish systems, and hatcheries, aquaculture can be adapted to local geographic conditions and community needs. Each system has unique advantages, such as quality control in fishponds, land efficiency through rice-fish systems, and high-quality fish production with cages. These farming systems support food availability, increase income, and preserve local aquatic ecosystems.

In Bobonaro District, fishponds are the dominant aquaculture system, particularly in Maliana Sub-District, with 129 ponds (35.73%), making it the primary fish production center. Balibo Sub-District follows with 118 ponds (32.69%), while Lolotoe Sub-District has 17 ponds (4.71%), showing less involvement in aquaculture compared to other areas. Shrimp ponds are used in Atabae Sub-District (2 ponds) and Maliana Sub-District (1 pond), indicating potential for coastal area management. Fish cages, although only found in Atabae with 5 cages, play an important role in producing high-quality fish. Rice-fish systems, integrating fish farming with rice cultivation, are found in Balibo and Cailaco with 5 and 2 systems, respectively, reflecting land use efficiency. Meanwhile, fish hatcheries are only found in Balibo with 1 unit, playing an important role in providing quality seeds to support the sustainability of the aquaculture sector.

The diversity of farming systems reflects the potential of Bobonaro District to optimize local resources. With more integrated management and the application of modern technologies, the aquaculture sector in this region has great opportunities for continued growth and making significant contributions to community welfare. The use of facilities for aquaculture farming in Bobonaro District is shown in **Figure 10.10** and **Figure 10.11.**

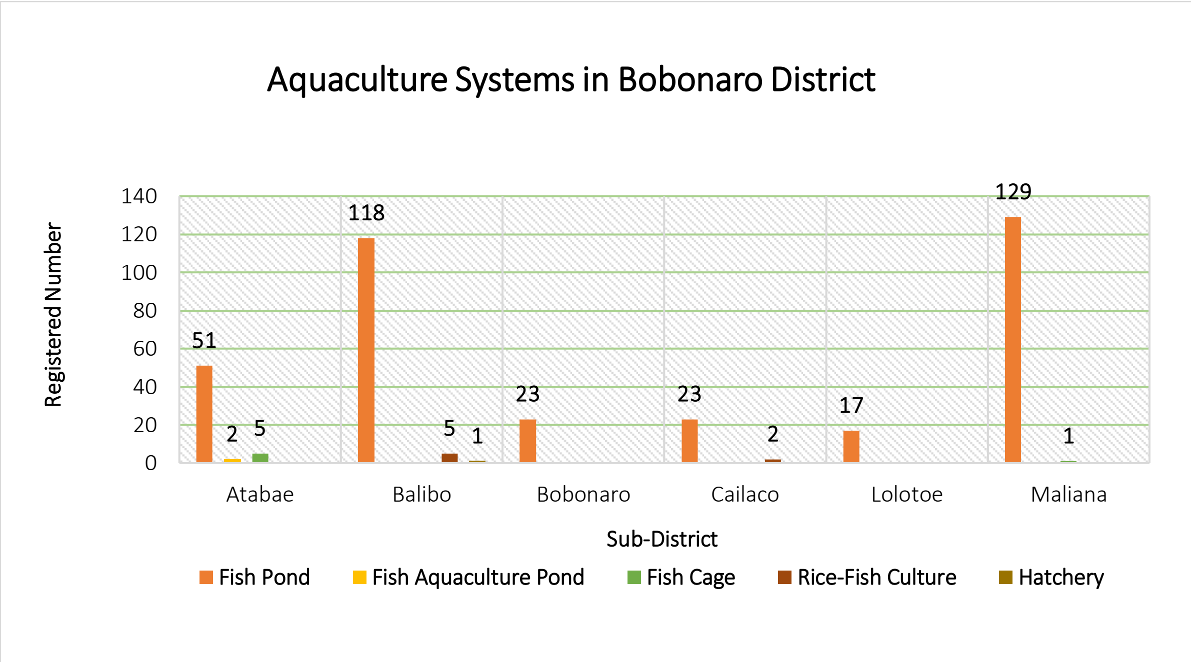


Figure 10. 10 Aquaculture Systems in Bobonaro District
(Source: Timor-Leste Agriculture Census, 2019)

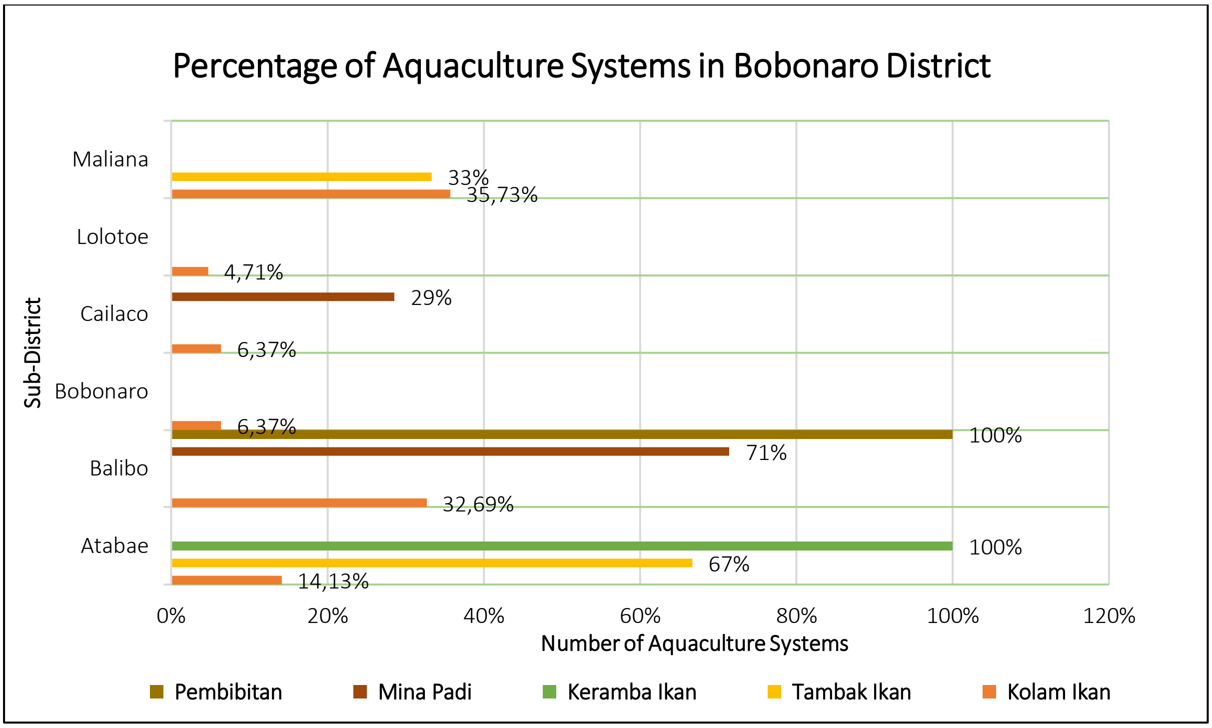


Figure 10. 11 Percentage of Aquaculture Systems in Bobonaro District
(Source: Timor-Leste Agriculture Census, 2019)

C. Field Observation Results

Bobonaro District demonstrates the development of fish farming activities involving various ownership schemes, from public-private partnerships to household groups. Although some activities have adopted semi-intensive approaches with better feed and pond management, structural challenges such as limited local feed availability and water quality risks still hinder sustainable productivity improvements.

In Leohito Village, Balibo Sub-District, there is an aquaculture unit managed by two different entities. The hatchery ponds are managed through a public-private partnership (PPP), while the grow-out ponds are owned and managed by community groups. The total number of ponds available at this location is quite large, with 8 PPP-owned ponds and 210 community-owned ponds. Of these, 110 ponds are 6×5 meters, and 100 are 30×20 meters. There are also earthen ponds measuring 12×16 meters specifically used for tilapia farming, with a stocking density of 7 fish per m^2.

Before the ponds are filled with water, preparation steps include liming and pond bottom fertilization. During the growing phase, fish are fed pellet feed, approximately 4 sacks per pond, with each sack weighing 30 kg and valued at around 40 USD. Although feed costs are high due to reliance on imports from neighboring countries, farmers report relatively high survival rates of 95%.

However, this location also experienced a mass fish death incident, which occurred in January 2023 and resulted in significant economic losses. Despite these challenges, there are plans for an expansion of 4 ha of fish farming, indicating further development potential.

Figure 10. 12 Farming Facilities in Leohito Village
(Source: Research Documentation, 2025)

Meanwhile, in Raifun Village, Maliana Sub-District, there is a government-run freshwater farming facility managed by technical staff with a high school-level education. This facility utilizes concrete ponds without aeration systems. The cultivated commodities include tilapia and carp, with water sourced from springs channeled through small ditches. The limited water flow is a major constraint, compounded by pollution risks from nearby settlements that use the same water channels for household activities.

Another critical issue is feed availability. During a field visit, it was found that the facility was experiencing a feed stock shortage, which directly impacted the fish, causing stress and signs of nutritional deficiency. Dependence on imported feed makes the facility vulnerable, highlighting the need for efforts to develop independent feed production to support the sustainability of activities at this site.

Figure 10. 13 Farming Facility in Raifun Village
(Source: Research Documentation, 2025)

Overall, Bobonaro District has a well-established aquaculture structure and capacity, particularly in terms of the area and number of available ponds. However, to optimize this potential, strategic interventions are needed to improve the quality and quantity of local feed, apply simple aeration and irrigation systems, and strengthen biosecurity measures to prevent mass fish deaths due to diseases or water pollution. Technical training programs, policy support for production input provision, and strengthening local institutional capacity are key factors in developing the aquaculture sector in this region.

10.4 COMPREHENSIVE LAND SUITABILITY ANALYSIS FOR AQUACULTURE

A. Aquaculture Land Suitability in Bobonaro District

Land suitability refers to the degree to which a piece of land is appropriate for a specific use, in this case, for aquaculture industry development. The purpose of this evaluation is to determine whether the physical, chemical, and climatic characteristics of the land can optimally and sustainably support the production of aquatic commodities. Land suitability assessment can be evaluated by considering two main conditions: current conditions (as they are) and potential conditions (after improvements have been made).

The current condition reflects the land's capability in its natural state, as indicated by field survey data. This assessment does not yet include management aspects that could be applied to address existing limiting factors. In the evaluation process, each land quality is analyzed based on limiting factors, and scoring is performed to obtain a final value. The results provide an actual overview of the obstacles encountered in the direct utilization of the land.

In contrast, potential land suitability refers to the degree to which land could be suitable after efforts have been made to improve the limiting factors. For example, land that was initially classified as marginally suitable (S3) could be improved to moderately suitable (S2) or highly suitable (S1) through interventions such as topography improvement or water quality enhancement. The assessment of potential conditions involves identifying and correcting land characteristics that impede land suitability, with the goal of improving suitability class.

The application of technology plays an important role in improving land suitability from current to potential suitability. However, not all land characteristics can be improved with current technology, and some improvements may require complex management practices. Therefore, in land use planning for aquaculture, the primary focus is on potential land suitability. This evaluation provides an overview of the maximum potential of the land for various uses after improvements and serves as a basis for designing efficient and sustainable land use strategies. Through this approach, the necessary technical steps for achieving optimal production outcomes can be formulated more effectively.

B. Results of Aquaculture Land Suitability Evaluation

Land suitability analysis is a critical step in developing a sustainable land management strategy for aquaculture. This evaluation is conducted using an integrated approach, which involves the use of geospatial data, field observations, and laboratory analysis of the physical and chemical properties of water and soil. Through this approach, the bio-physical potential and constraints of the land can be identified to support the development of various aquaculture commodities.

The data collected are analyzed based on the growing requirements for each type of aquatic commodity in its current state, as well as the potential suitability after various land improvement efforts such as topographic modification, water quality management, or the implementation of adaptive aquaculture techniques. This process provides comprehensive information for determining development priorities, identifying limiting factors, and designing appropriate technical solutions. This scientific approach forms the basis for the land suitability evaluation in Bobonaro District.

The results of this analysis provide strategic guidance to maximize land productivity while maintaining the sustainability of water resources in each area. The field and laboratory data used as the basis for land suitability assessment are presented in the relevant supporting documents. The aquaculture land distribution map in Bobonaro District is shown in **Figure 10.14.**

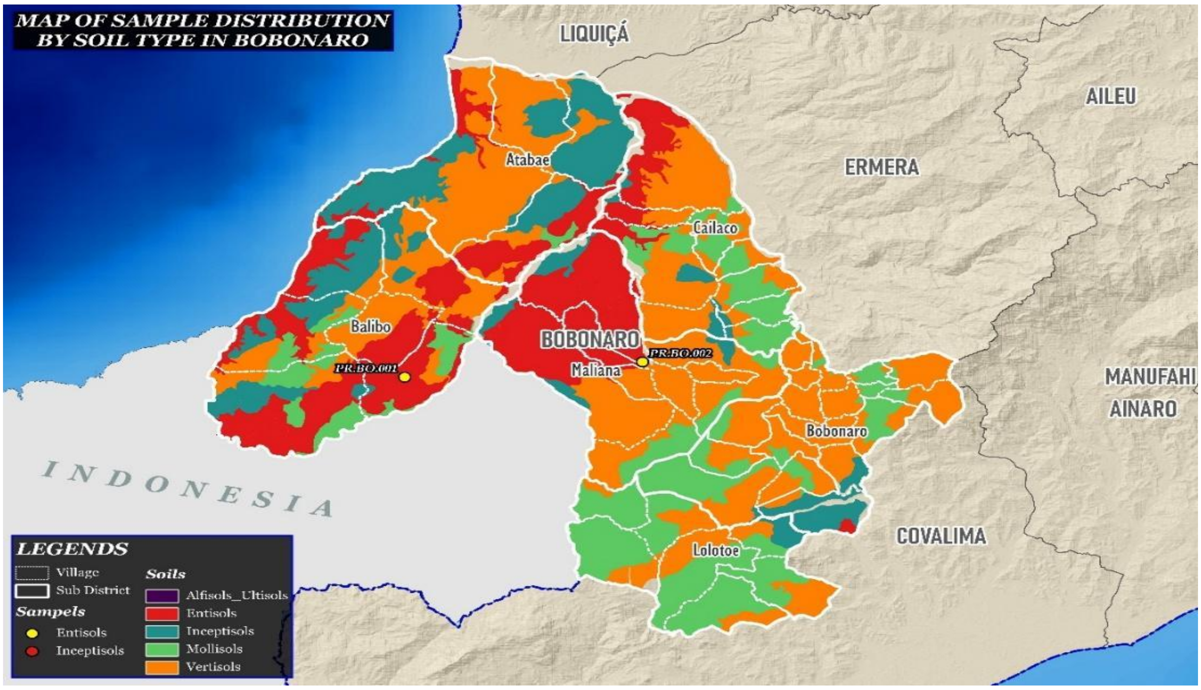


Figure 10. 14 Map of Soil Distribution on Aquaculture Land in Bobonaro District

a. Land Suitability Evaluation in Balibo Sub-District

Balibo Sub-District is one of the areas in Bobonaro District that has the potential to be developed as an aquaculture center. However, based on the land suitability evaluation, it was found that most aquaculture commodities, both freshwater (guorami, catfish, carp, tilapia) and brackish water (milkfish, mangrove crab, vannamei shrimp), face significant constraints in both the current and potential conditions (**Table 10.9**). Two main limiting factors that consistently emerge are slope gradient and the length of the dry season (dry months), both of which are rated as "Not Suitable" (N) for almost all commodities.

Slope gradient poses a major physical challenge because it affects the feasibility of pond construction. Steep slopes increase the risk of landslides and complicate water management, making aquaculture activities technically and economically unfeasible without intervention. Interventions or corrective measures on this parameter can improve land suitability. **Table 10.11** presents several technical solutions, such as the implementation of stepped pond systems that follow land contours. While this system requires higher construction costs, it can significantly increase the suitability score from N to S3 (marginally suitable).

The dry season is a climatic limiting factor that cannot be corrected technically because it depends on annual rainfall patterns. Therefore, the suitability value for this parameter remains in the N category, even if improvements are made to other factors. An alternative management approach could include the use of closed-system aquaculture, water use efficiency, or the use of water retention ponds and rainwater harvesting systems, although these measures do not automatically change the land suitability rating.

In addition to these two main limiting factors, several other parameters such as low temperature, suboptimal pH, low dissolved oxygen (DO), rainfall, and low salinity (for brackish water commodities) also emerged as additional constraints. Low temperatures may inhibit fish metabolism and slow growth rates. This can be addressed by using shallow ponds or ponds with dark-colored bottoms to increase heat absorption. For suboptimal pH, corrective measures include periodic water exchanges or the use of zeolite to stabilize water chemistry. Meanwhile, low dissolved oxygen (DO) can be improved by using simple aeration systems or modern aeration equipment.

Brackish water commodities such as bandeng and vannamei shrimp face challenges related to low salinity. This issue can be mitigated by mixing seawater, either conventionally or using pumps. While this requires additional costs and is highly dependent on proximity to seawater sources, corrective measures have shown improvements in land suitability across most parameters, making this area more viable for aquaculture development.

With the technical interventions described, Balibo Sub-District remains promising for aquaculture development, particularly for freshwater commodities. Fish such as mas are relatively adaptable to fluctuations in water quality, including low temperatures, and have a fast growth cycle. With the right land improvement strategies, Balibo Sub-District has the potential to be developed into a productive and sustainable aquaculture zone.

Table 10. 9 Land Suitability Analysis for Aquaculture Commodities in Balibo Sub-District

Commodity	Current Land Suitability Limiting Factors	Current Final Evaluation	Potential Land Suitability Limiting Factors	Potential Final Evaluation
Gourami (*Ospronemus gouramy*)	N: Slope gradient, Dry months S3: Rainfall S2: Low temperature	3.17	N: Dry months S3: Rainfall, slope gradient	3.34
Catfish (*Clarias batrachus*)	N: Slope gradient, Dry months S3: Rainfall S2: Low temperature	3.02	N: Dry months S3: Rainfall, slope gradient	3.34
Carp (*Cyprinus carpio*)	N: Slope gradient, Dry months S3: Rainfall S2: DO	3.07	N: Dry months S3: Rainfall, slope gradient	3.34
Tilapia (*Oreochromis niloticus*)	N: Slope gradient, Dry months S3: Rainfall S2: pH, DO, Low temperature	2.95	N: Dry months S3: Rainfall, slope gradient	3.34
Milkfish (*Chanos chanos*)	N: Slope gradient, Dry months S3: Low salinity S2: Low temperature, pH, rainfall	2.96	N: Dry months S2: Rainfall, slope gradient	3.52
Mangrove crab (*Scylla serrata*)	N: Low salinity, slope gradient, dry months S2: Low temperature, DO, rainfall	2.78	N: Dry months S2: Rainfall, slope gradient	3.52
Vannamei (*Litopenaeus vannamei*)	N: Slope gradient, dry months S3: Low salinity S2: Low temperature, pH, DO	3.17	N: Dry months, slope gradient S3: Rainfall	3.56

b. Land Suitability Evaluation in Maliana Sub-District

Maliana Sub-District shows land characteristics quite similar to those of Balibo Sub-District, but with some important differences in limiting factors. Based on the land suitability analysis, almost all aquaculture commodities studied, both freshwater (gourami, catfish, carp, tilapia) and brackish water (milkfish, mangrove crab, vannamei shrimp), face significant constraints. The most common limiting factors are slope gradient and the dry season, both rated as "Not Suitable" (N) in the current condition.

Slope gradient is the most fundamental technical factor in pond construction. Land with steep slopes complicates conventional pond construction due to the high risk of erosion and the need for complex water management systems. To address this, the recommended solution is the implementation of stepped pond systems as outlined in **Table 10.11**. This approach allows ponds to be constructed following the natural land contours, improving water flow efficiency. As a result, land suitability could increase from N to S3 (marginally suitable) for most commodities.

The dry season factor, which reflects water limitations during the dry months, remains a major obstacle as it cannot be directly corrected. Management alternatives such as building retention ponds, rainwater harvesting ponds, and improving water use efficiency can be implemented. However, these efforts do not automatically alter the suitability status for this parameter. In addition to these main factors, several additional constraints were found, including low temperature, suboptimal pH, high total dissolved solids (TDS), low rainfall, and low salinity.

Low temperatures are a challenge for commodities such as gurami and nila, but this can be mitigated with simple techniques like using shallow ponds or ponds with dark-colored bottoms to increase water temperature. pH problems can be controlled through regular water exchange and the use of zeolite, which stabilizes water chemistry while absorbing harmful substances. High TDS, which affects fish osmoregulation, can be reduced with simple filtration systems, or on a larger scale through reverse osmosis (RO) technology. Although this requires additional costs, it has proven effective in improving water quality.

For brackish water commodities such as bandeng, vannamei, and mangrove crab, the main challenge is low salinity. Improvement efforts can include mixing seawater, either manually or with pumps, depending on proximity to seawater sources. However, it is important to note that Maliana Sub-District does not have coastal areas and is located quite far from the sea. This significant limitation in accessing seawater makes brackish water aquaculture unfeasible in this area, both technically and economically. Therefore, aquaculture development in Maliana Sub-District should focus on freshwater commodities that are more suited to the local environmental conditions.

Table 10. 10 Land Suitability Analysis for Aquaculture Commodities in Maliana 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 S2: Low temperature, pH, rainfall	3.16	N: Dry months S3: Slope gradient S2: Rainfall	3.4
Catfish (*Clarias batrachus*)	N: Slope gradient, dry months S2: Low temperature, rainfall	3.23	N: Dry months S3: Slope gradient S2: Rainfall	3.4
Carp (*Cyprinus carpio*)	N: Slope gradient, dry months S2: Rainfall	3.28	N: Dry months S3: Slope gradient S2: Rainfall	3.4
Tilapia (*Oreochromis niloticus*)	N: Slope gradient, dry months S2: Low temperature rendah, rainfall	3.23	N: Dry months S3: Slope gradient S2: Rainfall	3.4
Milkfish (*Chanos chanos*)	N: Slope gradient, Dry months S2: Low temperature, Low salinity, rainfall	3.13	N: Dry months S3: Slope gradient S2: Rainfall	3.4
Mangrove crab (*Scylla serrata*)	N: Low salinity, dry months S3: Slope gradient S2: Low temperature	3.11	N: Dry months S2: Slope gradient	3.58
Vannamei (*Litopenaeus vannamei*)	N: Slope gradient, dry months S2: Low temperature, Low salinity, rainfall	3.13	N: Dry months S3: Slope gradient S2: Rainfall	3.4

C. Aquaculture Land Improvement Efforts

The results of the current land suitability evaluation in Bobonaro District indicate various limiting factors that render most areas unsuitable or only marginally suitable for aquaculture. To improve land suitability, corrective measures or improvements to limiting factors are needed where feasible. Land improvement efforts in the context of aquaculture include technical interventions aimed at improving the bio-physical condition of the land and the environmental quality of water to meet the optimal needs of cultivated commodities. These improvements may involve habitat modifications (e.g., improving pond conditions), water quality manipulation, or the provision of supporting infrastructure..

Table 10.11 outlines the types of improvement efforts with varying management difficulty levels. The difficulty levels are categorized into low, medium, and high. Each level has assumptions for assessing the improvement of actual land quality to potential quality, as shown in **Table 10.12**.

Table 10. 11 Recommended Improvement Measures for Limiting Parameters

No	Parameter	Improvement Measures	Management Difficulty Level
1	Low Temperature	- Use of shallow ponds - Use of dark-colored ponds - Use of water heaters	- Low - Low - High
2	Low Salinity	- Conventional seawater mixing - Seawater mixing with pump systems	- Medium - High
3	Water pH	- Regular water changes - Use of zeolite	- Medium - High
4	Slope	- Use of terraced pond systems	- High
5	Rainfall	- Cannot be improved	

Description :

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

Table 10. 12 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)*

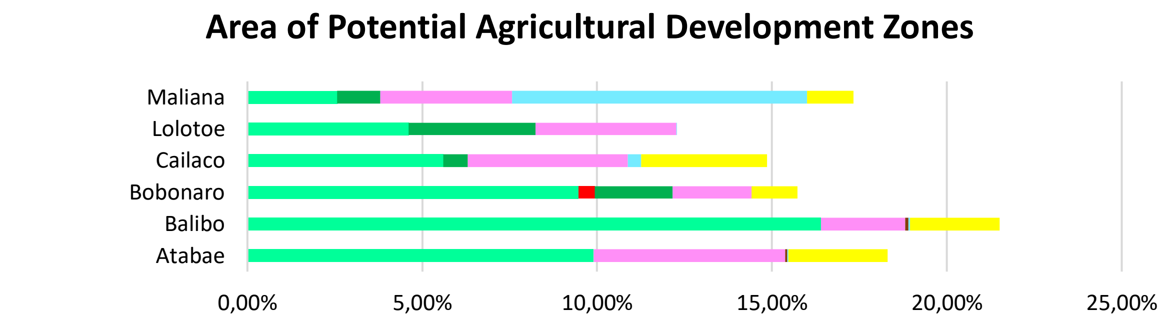
+++ *Improvement will increase the suitability class by three levels (N to S1)*

XI. DEVELOPMENT ZONING OF AGRICULTURAL COMMODITIES

11.1 ZONING FOR AGRICULTURAL COMMODITIES DEVELOPMENT

Timor-Leste has significant land resource potential to support the development of the agriculture, forestry, and livestock sectors. To maximize this potential, land suitability evaluation is conducted using a comprehensive scientific approach, including field observations, laboratory testing of soil samples, and matching crop growth requirements with agro-climatic maps of the region. The results of this evaluation lead to scientifically-based zoning to systematically identify the potential for developing various strategic commodities, such as rice, maize, horticultural crops, industrial crops, and forest areas. This zoning is expected to support efficient and sustainable land resource management, contributing to national food security while improving the well-being of the local population.

Bobonaro District has land potential divided into several main categories, including irrigated rice fields covering 122.27 km² (8.89%), rainfed rice fields 160.33 km² (11.65%), mangroves 2.13 km² (0.16%), grazing areas 6.35 km² (0.46%), dryland farming or mixed gardens 309.88 km² (22.52%), agroforestry 667.78 km² (48.53%), and protected and conservation forests covering 107.18 km² (7.79%). Data on potential agricultural commodity development by Sub-District are presented in **Figure 11.1**, with spatial distribution shown in **Figure 11.2**. This zoning reflects the diverse potential land uses to support agriculture, forestry, and livestock sectors sustainably, contributing to food security, environmental protection, and improved community welfare.



	Atabae	Balibo	Bobonaro	Cailaco	Lolotoe	Maliana
Agroforestry	9,90%	16,40%	9,47%	5,60%	4,61%	2,56%
Grazing Area	0,00%	0,00%	0,46%	0,00%	0,00%	0,00%
Protected Forest	0,00%	0,00%	2,23%	0,71%	3,62%	1,24%
Mixed Garden	5,48%	2,41%	2,26%	4,57%	4,03%	3,77%
Mangrove Forest	0,06%	0,10%	0,00%	0,00%	0,00%	0,00%
Irrigated Rice Fields	0,03%	0,04%	0,00%	0,38%	0,00%	8,43%
Rainfed Rice Fields	2,84%	2,57%	1,31%	3,60%	0,00%	1,33%

Figure 11.1 Area of Agricultural and Forestry Commodity Development in Bobonaro District

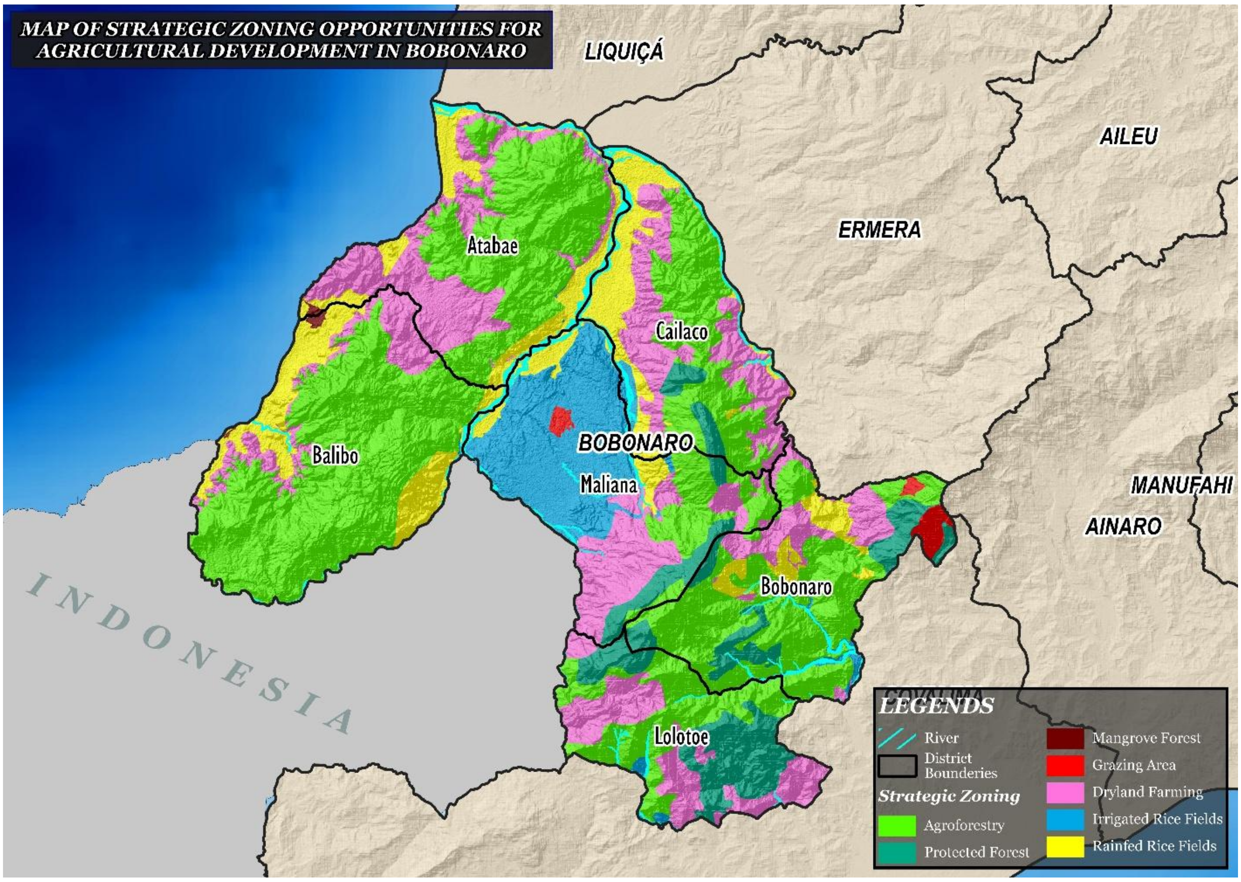


Figure 11.2 Potential Agricultural and Forestry Commodity Development Map in Bobonaro District

A. Irrigated Rice Fields

The irrigated rice field zone covers an area of 122.27 km², or 8.89% of the total area of Bobonaro District, located in regions with elevations ranging from below 100 m to above 500 m above sea level, with a slope gradient of 0 to 8%. This area falls within agro-climatic Zone B, characterized by a wet season lasting between 5 and 6 months each year, suitable for sustainable cropping systems. The primary irrigated rice fields are located in Maliana Sub-District, covering 8.43%, making it a center for rice production in Bobonaro District, supported by relatively good irrigation access and agro-climatic conditions that support year-round agriculture.

B. Rainfed Rice Fields

Rainfed rice fields cover an area of 160.33 km², or 11.65% of the total area, dominated by agro-climatic Zones A, C, and E. These zones are characterized by a wet season lasting 4 to 8 months, situated at elevations ranging from below 100 m to above 500 m above sea level, with slope gradients of 8 to 15%. The primary areas of rainfed rice fields are found in Cailaco Sub-District (4%), Atabae Sub-District (3%), and Balibo Sub-District (3%). Recommended strategies include the construction of water ponds, the use of drought-tolerant rice varieties, and water management practices to improve yields.

C. Dryland Farming (Mixed Gardens and Upland Crops)

Dryland farming covers an area of 309.88 km², or approximately 22.52% of the total area. This land is distributed across areas with elevations ranging from below 100 m to above 500 m above sea level. Dominated by agro-climatic Zones A, B, C, D, and E, this area has a wet season lasting between 4 and 9 months per year. Slope gradients vary from 8% to 25%. The most significant areas of dryland farming include Atabae Sub-District (5%), Cailaco Sub-District (5%), Lolotoe Sub-District (4%), and Maliana Sub-District (4%). With these characteristics, dryland farming has significant potential but requires specific approaches to optimize productivity. The varied agro-climatic and topographical zones provide opportunities for crop management tailored to each region's needs. This can help improve yields and enhance the livelihoods of local farmers.

D. Grazing Areas

Grazing areas cover 6.35 km², or about 0.46% of the total area. Although small, this area plays an essential role in supporting livestock activities, particularly for goats and cattle. With suitable conditions, this area allows farmers and livestock keepers to utilize the land effectively for grazing, with the primary distribution in Bobonaro Sub-District.

Table 11.1 Recommendations for Agricultural Commodities Development for Food Crops, Industry, Horticulture, Spices, Medicinal Plants, and Forestry in Bobonaro District

NO	DISTRICT	SUB-DISTRICT	DRYLAND AGRICULTURE (PLANTATIONS & HORTICULTURE)	FORESTRY	LIVESTOCK FEED & GRAZING AREAS
1	Atabae	WETLAND FOOD CROPS S3: Irrigated Rice DRYLAND FOOD CROPS S2 : Upland Rice, Corn, Mung bean, Cowpea, Soghum, Cassava, Soybean, Peanut, Taro S3 : Sweet potato	INDUSTRY S2 : Tobacco, S3 : Rubber, Coconut, Oil palm, Arabica Coffee, Robusta Coffee, Cacao, Clove, Tea, Tobacco, Melinjo, Kapok, Cotton, Quinine FRUITS S2 : Guava, Soursop, Breadfruit, Longan, Watermelon, melon, Papaya, Mango, Durian, Rambutan, Custard Apple, Snakfriut, Jackfruit, Strawberry, Pineapple, S3 : Banana, Orange, Avocado, Grape, Passion Friut VEGETABLES S2 : Shallot, Chili, Bell Pepper, Green Bean, Broccoli, Caisim, Cucumber, Eggplant, Bitter melon, Tomato Vegetable, Cabbage, Long bean S3 : Snow pea FLOWERS S2 : Rose, Aster, Sunflower SPICES & MEDICINAL PLANTS S2 : Vetiver root, Lemongrass, Vanilla, Candlenut, Jatropha, Aromatic Ginger, Tumeric, Galangal	**S2 :** Melaleuca, Pine, Sandalwood **S3 :** Teak, Mahogany, Agathis, Altingia, Albizia, *Leucaena*, Acacia, *Eucalyptus*	Livestock Feed **S2 :** Elephantgrass, Setaria, Legumes Grazing S3: Grazing

			S3 : Ginger, Cinnamon, Nutmeg, Pepper, Cardamom, Sesame		
2	Balibo	WETLAND FOOD CROPS S3: Irrigated Rice DRYLAND FOOD CROPS S2 : Upland Rice, Corn, Mung bean, Cowpea, Soghum, Cassava, Soybean, Peanut, Taro S3 : Sweet potato	INDUSTRY S2 : Tobacco, S3 : Rubber, Coconut, Oil palm, Arabica Coffee, Robusta Coffee, Cacao, Clove, Tea, Tobacco, Melinjo, Kapok, Cotton, Quinine FRUITS S2 : Guava, Soursop, Breadfruit, Longan, Watermelon, melon, Papaya, Mango, Durian, Rambutan, Custard Apple, Snakfriut, Jackfruit, Strawberry, Pineapple, S3 : Banana, Orange, Avocado, Grape, Passion Fruit VEGETABLES S2 : Shallot, Chili, Bell Pepper, Green Bean, Broccoli, Caisim, Cucumber, Eggplant, Bitter melon, Tomato Vegetable, Cabbage, Long bean S3 : Snow pea FLOWERS S2 : Rose, Aster, Sunflower SPICES & MEDICINAL PLANTS S2 : Vetiver root, Lemongrass, Vanilla, Candlenut, Jatropha, Aromatic Ginger, Tumeric, Galangal **S3 :** Ginger, Cinnamon, Nutmeg, Pepper, Cardamom, Sesame	**S2 :** Melaleuca, Pine, Sandalwood **S3 :** Teak, Mahogany, Agathis, Altingia, Albizia, *Leucaena*, Acacia, *Eucalyptus*	Livestock Feed **S2 :** Elephantgrass, Setaria, Legumes **Grazing** S3: Grazing

3	Bobonaro	**WETLAND FOOD CROPS** **S3**: Irrigated Rice **DRYLAND FOOD CROPS** **S2** : Upland Rice, Corn, Mung bean, Cowpea, Soghum, Cassava, Soybean, Peanut, Taro **S3** : Sweet potato	**INDUSTRY** **S2** : Tobacco, **S3** : Rubber, Coconut, Oil palm, Arabica Coffee, Robusta Coffee, Cacao, Clove, Tea, Tobacco, Melinjo, Kapok, Cotton, Quinine **FRUITS** **S2** : Guava, Soursop, Breadfruit, Longan, Watermelon, melon, Papaya, Mango, Durian, Rambutan, Custard Apple, Snakfriut, Jackfruit, Strawberry, Pineapple, **S3** : Banana, Orange, Avocado, Grape, Passion Friut **VEGETABLES** **S2** : Shallot, Chili, Bell Pepper, Green Bean, Broccoli, Caisim, Cucumber, Eggplant, Bitter melon, Tomato Vegetable, Cabbage, Long bean **S3** : Snow pea **FLOWERS** **S2** : Rose, Aster, Sunflower **SPICES & MEDICINAL PLANTS** **S2** : Vetiver root, Lemongrass, Vanilla, Candlenut, Jatropha, Aromatic Ginger, Tumeric, Galangal **S3 :** Ginger, Cinnamon, Nutmeg, Pepper, Cardamom, Sesame	**S2 :** Melaleuca, Pine, Sandalwood **S3 :** Teak, Mahogany, Agathis, Altingia, Albizia, *Leucaena*, Acacia, *Eucalyptus*	**Livestock Feed** **S2 :** Elephantgrass, Setaria, Legumes **Grazing** **S3**: Grazing
4	Cailaco	**WETLAND FOOD CROPS** **S3**: Irrigated Rice	**INDUSTRY** **S2** : Tobacco,	**S2 :** Melaleuca, Pine, Sandalwood	**Livestock Feed** **S2 :** Elephantgrass, Setaria, Legumes

		DRYLAND FOOD CROPS **S2** : Upland Rice, Corn, Mung bean, Cowpea, Soghum, Cassava, Soybean, Peanut, Taro **S3** : Sweet potato	**S3** : Rubber, Coconut, Oil palm, Arabica Coffee, Robusta Coffee, Cacao, Clove, Tea, Tobacco, Melinjo, Kapok, Cotton, Quinine **FRUITS** **S2** : Guava, Soursop, Breadfruit, Longan, Watermelon, melon, Papaya, Mango, Durian, Rambutan, Custard Apple, Snakfriut, Jackfruit, Strawberry, Pineapple, **S3** : Banana, Orange, Avocado, Grape, Passion Friut **VEGETABLES** **S2** : Shallot, Chili, Bell Pepper, Green Bean, Broccoli, Caisim, Cucumber, Eggplant, Bitter melon, Tomato Vegetable, Cabbage, Long bean **S3** : Snow pea **FLOWERS** **S2** : Rose, Aster, Sunflower **SPICES & MEDICINAL PLANTS** **S2** : Vetiver root, Lemongrass, Vanilla, Candlenut, Jatropha, Aromatic Ginger, Tumeric, Galangal **S3 :** Ginger, Cinnamon, Nutmeg, Pepper, Cardamom, Sesame	**S3 :** Teak, Mahogany, Agathis, Altingia, Albizia, *Leucaena*, Acacia, *Eucalyptus*	**Grazing** **S3**: Grazing
5	Lolotoe	**WETLAND FOOD CROPS** **S3**: Irrigated Rice	**INDUSTRY** **S2** : Tobacco, **S3** : Rubber, Coconut, Oil palm, Arabica Coffee, Robusta Coffee, Cacao, Clove, Tea, Tobacco, Melinjo, Kapok, Cotton, Quinine	**S2 :** Melaleuca, Pine, Sandalwood **S3 :** Teak, Mahogany, Agathis, Altingia, Albizia, *Leucaena*, Acacia, *Eucalyptus*	**Livestock Feed** **S2 :** Elephantgrass, Setaria, Legumes **Grazing**

		DRYLAND FOOD CROPS **S2** : Upland Rice, Corn, Mung bean, Cowpea, Soghum, Cassava, Soybean, Peanut, Taro **S3** : Sweet potato	**FRUITS** **S2** : Guava, Soursop, Breadfruit, Longan, Watermelon, melon, Papaya, Mango, Durian, Rambutan, Custard Apple, Snakfriut, Jackfruit, Strawberry, Pineapple, **S3** : Banana, Orange, Avocado, Grape, Passion Friut **VEGETABLES** **S2** : Shallot, Chili, Bell Pepper, Green Bean, Broccoli, Caisim, Cucumber, Eggplant, Bitter melon, Tomato Vegetable, Cabbage, Long bean **S3** : Snow pea **FLOWERS** **S2** : Rose, Aster, Sunflower **SPICES & MEDICINAL PLANTS** **S2** : Vetiver root, Lemongrass, Vanilla, Candlenut, Jatropha, Aromatic Ginger, Tumeric, Galangal **S3 :** Ginger, Cinnamon, Nutmeg, Pepper, Cardamom, Sesame		**S3**: Grazing
6	Maliana	**WETLAND FOOD CROPS** **S3**: Irrigated Rice **DRYLAND FOOD CROPS** **S2** : Upland Rice, Corn, Mung bean, Cowpea,	**INDUSTRY** **S2** : Tobacco, **S3** : Rubber, Coconut, Oil palm, Arabica Coffee, Robusta Coffee, Cacao, Clove, Tea, Tobacco, Melinjo, Kapok, Cotton, Quinine **FRUITS**	**S2 :** Melaleuca, Pine, Sandalwood **S3 :** Teak, Mahogany, Agathis, Altingia, Albizia, *Leucaena*, Acacia, *Eucalyptus*	**Livestock Feed** **S2 :** Elephantgrass, Setaria, Legumes **Grazing** **S3**: Grazing

		Soghum, Cassava, Soybean, Peanut, Taro **S3** : Sweet potato	**S2** : Guava, Soursop, Breadfruit, Longan, Watermelon, melon, Papaya, Mango, Durian, Rambutan, Custard Apple, Snakfriut, Jackfruit, Strawberry, Pineapple, **S3** : Banana, Orange, Avocado, Grape, Passion Friut VEGETABLES **S2** : Shallot, Chili, Bell Pepper, Green Bean, Broccoli, Caisim, Cucumber, Eggplant, Bitter melon, Tomato Vegetable, Cabbage, Long bean **S3** : Snow pea FLOWERS **S2** : Rose, Aster, Sunflower SPICES & MEDICINAL PLANTS **S2** : Vetiver root, Lemongrass, Vanilla, Candlenut, Jatropha, Aromatic Ginger, Tumeric, Galangal **S3 :** Ginger, Cinnamon, Nutmeg, Pepper, Cardamom, Sesame		

Note: S1: Highly Suitable, S2: Moderately Suitable, S3: Marginally Suitable, N: Not Suitable

11.2 POTENTIAL FOOD CROPS DEVELOPMENT ZONE

According to the **Crop and Food Security Assessment Mission** (CFSAM) report, agricultural production in Bobonaro District significantly contributes to food security in 2021. Corn production during the planting season covered an area of 4,500 ha, with a productivity rate of 2.9 tons per ha. The total corn production for the planting season reached 13,050 tons, with an additional 550 tons from the second harvest, bringing the total to 13,600 tons per ha. Rice production covered an area of 3,200 ha, producing 3.3 tons per ha, yielding 2 tons per ha of rice. Therefore, the total rice production in Bobonaro District reached 6,300 tons, with an additional 600 tons from the second harvest, bringing the total rice production to 6,900 tons. Tuber crops contributed 5,500 tons to the food production. Overall, the total food production in this region, when converted to cereal equivalents, amounted to 22,260 tons. The conversion to cereal equivalents standardizes the production results of various agricultural commodities into a single unit based on calorie or energy content (for example, rice or wheat).

The research conducted in Bobonaro District identifies potential zones for food crop development. Bobonaro District has significant potential for food crop development, which can support national food security and reduce dependence on imports. Agro-climatic zoning shows that Maliana Sub-District has large areas suitable for developing irrigated rice as well as other food crops such as upland rice, maize, sorghum, cassava, and taro. Each Sub-District has unique characteristics and potential, allowing for specific management approaches to maximize productivity and sustainability.

Food crops are a priority in the effort to achieve food security in Bobonaro District, particularly in Maliana Sub-District. With its vast land potential, the development of irrigated rice fields is a key component of this strategy. The irrigated rice field area, covering a total of 122.27 km² in Bobonaro District, has agro-climatic characteristics that support agricultural intensification, although improvements in supporting infrastructure, such as water ponds and pipeline drainage, are needed to maximize water usage.

In addition to irrigated rice fields, rainfed rice also plays an important role, covering 160.33 km² or about 11.65% of the total area. Cailaco Sub-District has the largest area of rainfed rice, making it a center for seasonal rice production. The bimodal rainfall in this region allows rainfed rice to grow well, although long-term success requires drought-resistant rice varieties and efficient water management strategies to support national food needs sustainably.

The dominance of drylands in Bobonaro District offers great potential for diversifying food crops, covering 309.88 km². Dryland farming is a backbone of food security, with significant potential for tuber crops such as cassava and sweet potatoes. Areas such as Bobonaro District show potential for developing food crops and horticulture, using agro-climatic approaches and soil conservation techniques such as strip cropping and crop rotation. Dryland areas in Cailaco and Atabae Sub-Districts have significant potential for diversifying food crops, including maize, sorghum, and peanuts, which can support the local economy and strengthen national food security.

With a comprehensive management strategy, Bobonaro District contributes to the goal of achieving food self-sufficiency. The development of irrigated and rainfed rice, supported by dryland agricultural diversification, can serve as a cornerstone for strengthening the country's agricultural sector. Through collaboration between the government and local communities, as well as the adoption of modern technologies, Bobonaro District has significant opportunities to increase domestic food production sustainably.

XII. RECOMMENDATIONS

12.1 LAND MANAGEMENT RECOMMENDATIONS

These recommendations are based on scientific research that comprehensively maps the potential of Bobonaro District for the development of food/horticulture commodities, plantations, forestry, and grazing areas. The zoning of the area, identified through land suitability evaluation, forms the primary basis for designing land management strategies focused on food security, economic sustainability, and environmental protection. Based on the analysis, the total zoning area is divided into six main categories: irrigated rice covers 8.89% of the total area, rainfed rice covers 11.65%, dryland agriculture/mixed cropping covers 22.52%, agroforestry covers 48.53%, grazing areas cover 0.46%, and protected/conservation forests cover 7.79%. This division reflects the diversity of the area's bio-physical potential and the importance of specific approaches for managing each zone.

The food zone plays a strategic role in supporting national food security. Areas identified as food production centers, such as Maliana Sub-District, Cailaco Sub-District, Atabae Sub-District, and Lolotoe Sub-District in Bobonaro District, are key. With the optimization of irrigation networks, land management focused on improving fertility, and the application of sustainable agricultural technologies, this food zone can directly contribute to achieving SDGs related to hunger eradication and improving the quality of life in rural areas.

The agroforestry and protected forest zones, which together account for 56.53% of the total area, are important areas for economic diversification through the development of high-value commodities. Regions such as Atabae Sub-District, Cailaco Sub-District, Lolotoe Sub-District, and Maliana Sub-District have significant potential for industrial crops such as robusta coffee, arabica coffee, and coconut, as well as horticultural fruits and vegetables like avocado, mango, tomato, and chili. Agroforestry systems, integrated with horticultural crops, not only increase land productivity but also play a role in soil and water conservation, reducing erosion risks, and supporting adaptation to climate change.

The forestry zone also includes protected forests, designed for ecosystem conservation, prioritizing biodiversity protection, water resource management, and climate change mitigation. The protected forests are recommended to be developed throughout district to reduce greenhouse gas emissions, increase carbon stocks, and maintain ecosystem stability. Additionally, production forests with species such as teak, mahogany, and albizia are proposed to provide economic value while involving local communities in sustainable forest management.

This strategy directly supports the SDGs, particularly those related to food security, climate change, and water resource conservation. By integrating scientific approaches and zonal-based management, this recommendation aims not only to provide solutions to land issues in Bobonaro District but also to promote balanced sustainable development between economic needs and ecological preservation.

Improvement efforts on each limiting factor are crucial for enhancing productivity and sustainability in agriculture. Various challenges, such as shallow effective soil depth, poor drainage, erosion risks, and surface rocks, require appropriate solutions to maximize the potential of the land. Recommendations for improvements on each limiting factor, as a basis for implementing the enhancement of land suitability for agricultural and forestry commodity development, are presented in Table 12.1.

Table 12.1 Recommendations for Improvements on Each Limiting Factor

No	Land Quality/ Characteristics	Type of Improvement Activity	Management Level
1.	**Temperature (tc)** - Average annual temperature	Replace with suitable commodities/varieties	No improvement possible
2.	**Water Availability (wa)**		
	- Annual rainfall	Irrigation/pond construction/drip irrigation	Medium, High
	- Rainfall during growth period	Planting pattern/calendar adjustment	
3.	**Root Media (rc)**		
	- Drainage	Improvement of drainage systems, such as the construction of drainage channels, bunds/raised beds	Medium, High
	- Texture	No improvement possible, can be mitigated by adding organic matter	High
	- Effective depth	Generally not improvable, except in soft and thin hardpan layers by breaking it during land preparation	Medium, High
	- Coarse material	**Depends on the quantity and distribution in the profile** (if the quantity is <35%, it is called an obstructing layer and can be mitigated by adding organic matter and minimum tillage. If the quantity is >90%, it is called a restricting layer, which limits rooting and is difficult to improve).	High
4	**Nutrient Retention (nr)**		
	- Soil CEC	Addition of organic matter	Medium, High
	- Bs	Liming, addition of organic matter	Medium, High
	- pH	Liming is carried out when soil pH is low, whereas at high pH sulfur or ammonium sulfate fertilizer can be applied	Medium, High
	- C-organic	Addition of organic matter/organic fertilizer, and returning crop residues to the soil	Medium, High
5.	**Nutrient Availability (na)** - N-Total	N fertilization (urea and ammonium sulfate)	Low, Medium, High

	- P-Available - K- Available	P fertilization (SP-36 and TSP) K fertilization (KCl) Compound fertilizer (NPK)	Low, Medium, High Low, Medium, High
6.	**Erosion Hazard (eh)** - Lereng (%) - Bahaya Erosi	Reducing erosion through terracing, contour planting, planting ground cover crops, application of mulch/crop residues, and implementation of agroforestry.	Medium, High
7.	**Flood Hazard (fh)** - Tinggi - Lama	Construction of flood control embankments, construction of drainage channels to accelerate water discharge, and construction of infiltration wells.	High
8.	**Land Preparation (lp)** - Batuan permukaan (%) - Singkapan batuan (%)	If the amount is small, stones are removed; if it is high or very high, no-tillage is applied, planting holes are made, and organic matter is added.	Medium, High
9.	**Technical Culture Improvement**	Establishment of plantations, pruning, and maintenance/care.	Medium, High

Explanation:

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

12.2 GLOBAL RECOMMENDATIONS

This recommendation is designed to provide strategic, data-based guidance to policymakers in Bobonaro District, focusing on conservation management and the sustainable use of weeds. This approach aims to address complex ecological challenges while integrating management strategies that support food security, environmental sustainability, and community welfare. One of the main challenges is the weed *Chromolaena odorata* (*C. odorata*), which has invasive biological characteristics and high regeneration capacity. Conventional approaches like eradication are often ineffective, costly, and potentially exacerbate ecosystem degradation.

As an alternative, a strategy based on sustainable utilization can turn this threat into an opportunity by optimizing the economic, social, and ecological value of *C. odorata*. In the context of marginal lands, which are dominant in Timor-Leste, this approach is relevant to support sustainable development. By integrating soil conservation, agroforestry, and innovative weed management, this strategy offers a comprehensive solution to optimize natural resources and provide long-term positive impacts for both the community and the environment.

A. New Paradigm: Utilization of *Chromolaena odorata*

The eradication approach for *C. odorata* is often ineffective due to its rapid regeneration from remaining roots or stems, abundant seed production, and the negative ecological impact of herbicide use. Destructive practices like slash-and-burn also risk increasing land degradation. As an alternative, a sustainable utilization approach offers a more optimal solution by using *C. odorata* as a biomass source for organic fertilizer, biochar, or plant-based fuel, as well as a raw material for pharmaceutical products due to its antimicrobial and anti-inflammatory properties.

The success of this strategy requires local community support through training focused on processing biomass into value-added products. The government, academia, and the private sector also play a critical role in developing simple research-based technologies and marketing products derived from *C. odorata*. Supporting policies, such as mapping priority areas, providing economic incentives, and conducting awareness programs, are necessary to enhance public awareness and strengthen the implementation of this strategy. With this holistic approach, a weed that has long been a threat can be turned into an opportunity that supports sustainable development across multiple aspects, including the environment and economy.

B. Soil and Water Conservation

This soil and water conservation recommendation considers efficiency and ease of implementation. Agroforestry systems, such as *agrisilviculture* (trees and food crops), *silvopastoral* (trees and pastures), and *agrosilvopastoral* (combining crops, trees, and livestock), provide long-term solutions that integrate conservation with economic productivity. In addition, biopore holes and drainage channels help with water infiltration and increase groundwater reserves in rocky or horticultural lands.

In the steep landscape of Bobonaro District, which is vulnerable to erosion, strategies like terracing can reduce surface water flow and improve water absorption, while groundcover vegetation, such as legumes and deep-rooted grasses, mitigates erosion risks. Check dam technologies, such as brushwood for small channels, loose stones for rocky areas, and gabions for larger flows, are also effective in reducing erosion in water channels. Policy support is needed through conservation regulations on steep slopes and customary laws at the village level. This approach is expected to strengthen sustainable conservation efforts and provide environmental, economic, and social benefits for communities in Bobonaro District.

C. Organic Matter Addition and Fertilization

Most areas in Bobonaro District have low organic matter content, which negatively affects soil fertility, water retention capacity, and microorganism activity. One solution is to utilize local organic waste such as manure, compost, and biochar to improve soil structure, remove toxins, and enhance soil biological activity. This step supports the growth of key commodities such as rainfed rice, sorghum, chili, and tomatoes. Adding crop residues as mulch on the soil surface is also highly effective in maintaining moisture, improving water retention, and preventing erosion. This technique is applicable to both flat and sloping lands that are vulnerable to drought. Furthermore, location-specific fertilization with adjusted doses, such as 200 kg NPK, 175 kg Urea, 40 kg SP-36, and 100 kg KCl per hectare, can increase soil nitrogen, phosphorus, and potassium content. This method is highly supportive for the development of irrigated rice by adjusting to the fertility characteristics of the soil in Bobonaro District. This strategy is expected to significantly improve soil quality and provide long-term positive impacts for the agricultural sector.

D. Drainage Management and Shallow Soil Depth

The rocky and sloping lands in Bobonaro District face poor drainage and shallow effective soil depth. To address this, a range of integrated technical solutions has been proposed to support the sustainability of land use and increase agricultural and forestry productivity. Drainage channels in the form of bunds or raised beds are specifically designed to prevent waterlogging and improve water management efficiency in horticultural land. This system reduces excess water loss, improves soil aeration, and ensures optimal water distribution, making it highly beneficial for horticultural crops in challenging environments.

Biopore hole techniques, or rorak, as well as infiltration wells, are effective approaches to improving water infiltration in rocky soils. These holes can also be used for placing organic materials such as plant residues or organic fertilizers to improve drainage quality. Additionally, these technologies help increase the soil's capacity to store water during dry seasons, thus supporting the sustainability of water resources. Creating deep planting holes is another solution to support the growth of deep-rooted plants. This approach is particularly relevant for industrial crops like coconut and timber trees, which are often planted in shallow soils. This method allows plants to thrive even in less-than-ideal soil conditions. These strategies aim to optimize the management of rocky and sloping lands, creating sustainable solutions for environmental improvement and land productivity in the area.

E. Alternative Crop Development on Rocky Land

Rocky lands require adaptive approaches that support plant growth in challenging environmental conditions. One alternative is planting medicinal and spice crops such as turmeric, ginger, galangal, and aromatic ginger. These crops grow well on rocky lands, particularly if planted under the shade of forestry trees that provide additional protection while enhancing land-use efficiency. Another strategy is to use cover crops, such as legumes and Setaria grass, which effectively reduce erosion, improve soil structure, and increase organic matter content. These plants offer long-term benefits for maintaining soil quality on rocky land. Additionally, deep-rooted industrial crops such as coconut and timber trees are recommended. These crops are highly tolerant of shallow soils and can adapt well to rocky environments, making them an ideal solution to maximize the potential of such lands. This strategy is expected to have a positive impact on the sustainability of rocky land use.

F. Implementation Strategy

The implementation strategy, based on the zoning of the area, aims to improve land management in Bobonaro District. The zoning, which includes irrigated rice (8.89%), rainfed rice (11.65%), dryland agriculture/mixed cropping (22.52%), agroforestry (48.53%), grazing areas (0.46%), and protected forests (7.79%), forms the basis for designing management strategies focused on food security, economic sustainability, and environmental preservation. Based on a zonal approach, the following steps are important:

1. Optimizing Production in Food Zones

   Food zones consisting of irrigated and rainfed rice play a strategic role in supporting national food security:

   - **Irrigation Network Development:** Expansion of the irrigation network in Maliana Sub-District, which has the potential to become the main rice production center in Bobonaro District. Micro-irrigation and ponds should be prioritized to support intensive cropping patterns.
   - **Management of Rainfed Rice:** Use drought-resistant rice varieties in areas with monomodal rainfall patterns. Farmers should also be trained to use simple water management methods, such as rainwater harvesting, to improve agricultural yields.
   - **Diversification of Commodities:** In addition to rice, this zone can be used for food crops such as corn, soybeans, and cassava as part of food diversification efforts.

2. Utilizing Agroforestry and Protected Forest Potential

   The agroforestry and protected forest zones, which cover 56.32% of the total area, offer significant opportunities for economic diversification and ecosystem conservation:

   - **Agroforestry Development:**
     - **Industrial Crops:** Planting high-value commodities such as robusta coffee, arabica coffee, cacao, and coconut in Atabae Sub-District, Balibo Sub-District, Bobonaro Sub-District, and Cailaco Sub-District.

- **Horticulture**: Integrating fruit crops (avocado, mango) and vegetables (tomato, chili) with forestry trees on sloping lands to conserve soil.

- **Protected Forest Management:**
  - Focus **protected forests** on preserving biodiversity, reducing the impacts of climate change, and managing land resources.
  - **Production Forests:** Planting teak, mahogany, and albizia to generate economic value while involving local communities in sustainable management.
- **Utilization of Weed Biomass:**

  Use *Chromolaena odorata* biomass for organic fertilizers or bioenergy to reduce pressure on forest ecosystems.

3. Infrastructure and Technology Development

- **Supporting Infrastructure:**
  - **Ponds and Rainwater Reservoirs:** Built in rainfed rice and dryland areas to improve water supply during the dry season.
  - **Drainage Channels:** Designed to control water runoff in sloping areas, particularly in agroforestry zones.
- **GIS and Remote Sensing Technology:**
  - Mapping land potential to support more accurate spatial planning.
  - Monitoring land cover changes to assess the effectiveness of conservation strategies.

4. Community Capacity Building
   - **Training and Education:**
     - Training in soil conservation and water management for farmers in each zone.
     - Education on commodity diversification in agroforestry zones to increase income.
   - **Community Empowerment:** Form zoning-based farmer groups to support participatory strategy implementation.
   - **Empowerment of Women:** Focus on training in agroforestry management and weed biomass utilization to enhance social inclusion and family income.
5. Weed Management Strategy: Utilization of *Chromolaena odorata*
   - **Biomass Utilization:**
     - Process *C. odorata biomass* into organic fertilizer to improve soil fertility.
     - Produce biochar and briquettes as bioenergy for local community needs.
   - **Herbal Product Development:** Explore the potential of *C. odorata* as a raw material for traditional medicine in collaboration with the pharmaceutical sector.
   - **Multistakeholder Collaboration**: The government, academia, and the private sector should work together in research and technology development related to weed utilization.
6. Integrated Spatial Planning Zoning

   The zoning approach supports more efficient land use:
   - **Protected and Conservation Forests:** Focus on areas with slopes >45% to protect ecosystems.
   - **Agroforestry Zones:** Include areas with slopes of 15–45% for timber and horticultural cultivation.
   - **Intensive Agricultural Zones:** Allocate flat areas and slopes <15% for major food crop production.

7. Policies and Incentives

- Economic Incentives:
  - Subsidies and incentives for farmers adopting conservation technologies.
  - Micro-credit for agroforestry and weed biomass-based enterprises.
- Zoning Regulations: Regulate land use according to the adapted zoning to ensure sustainable management.

8. Monitoring and Evaluation

- Data-Based Monitoring: Use GIS technology to monitor strategy effectiveness and land condition changes.
- Participatory Evaluation: Involve local communities, stakeholders, and government in the evaluation process to ensure strategies align with needs.

This strategy combines scientific approaches, advanced technologies, and community participation. Based on the zonal approach, this strategy not only addresses conservation and food security issues but also encourages sustainable local economic development in Bobonaro District.

12.3 CONCLUSIONS AND RECOMMENDATIONS FOR THE LIVESTOCK SECTOR

The KTS (Karaw Timor Susubeen) Korluli Maliana Center has potential land for forage feed such as elephant grass, Setaria, and grazing areas. Short-term recommendations begin with preparing high-nutrient forage land for milk productivity.

The government can introduce forage varieties such as Setaria grass and legumes like gamal, kaliandra, and indigofera. For feeding, a composition of 60% grass and 40% legume should be used. Additionally, supplementary feeds such as bran, concentrate, or flushing feed should be given in certain buffalo conditions. Long-term recommendations include improving reproductive technologies and training human resources. Reproductive aspects need significant attention as they directly affect milk production through workforce training.

Future challenges may include silent heat in buffalo, which can be addressed with education and skills to detect heat accurately. Training can be further enhanced through certified artificial insemination (AI) training, enabling the KTS (Karaw Timor Susubeen) Korluli Maliana Center to adapt to livestock technologies that enhance milk production efficiency.

12.4 CONCLUSIONS AND RECOMMENDATIONS FOR THE FRESHWATER FISHERIES SECTOR

The land evaluation for aquaculture in Bobonaro District shows promising potential for the development of the aquaculture sector, in terms of land capacity, existing farming systems, and community involvement. There are two main locations for aquaculture activities: Leohito Village (Balibo Sub-District) and Raifun Village (Maliana Sub-District), which have implemented both earthen and concrete pond systems.

The land suitability analysis indicates that freshwater commodities such as carp, gourami, catfish, and tilapia have relatively high actual and potential suitability (actual score range 2.95–3.28; potential score increases to 3.4–3.56). Meanwhile, brackish water commodities such as milkfish, vannamei shrimp, and mud crabs face limitations from salinity and topography, although potential scores indicate further development opportunities with technical interventions and management improvements.

Overall, the main challenges in developing aquaculture in Bobonaro District include: limited supply and high feed costs due to dependence on imports, water quality risks, limited water flow, steep land topography, and long dry seasons, all of which are dominant limiting factors for most commodities. However, community institutional structures, public-private partnerships, and planned land expansion in Balibo confirm the readiness of this region to develop as an aquaculture hub.

1. Specific Location-Based Technical Recommendations

Field studies in several village across Timor-Leste have identified key challenges in managing fisheries and aquaculture, ranging from feed supply limitations, water pollution risks, to access to clean water sources. Each location has distinct issues, and thus, specific technical recommendations based on local conditions are needed to enhance productivity, sustainability, and the resilience of community enterprises. The specific technical recommendations for each location are summarized in **Table 12.2**.

Table 12.2 Specific Location-Based Technical Recommendations

Location	Key Issues	Technical Recommendations
Leohito Village (Balibo)	High dependency on imported feed, mortality risks due to water pollution, and limited aeration technology.	Develop community-scale self-sufficient feed production units. Implement an integrated biosecurity system, including simple aeration systems and water quality monitoring. Provide community-based disease management and biosecurity training.
Raifun Village (Maliana)	Limited water flow and pollution from domestic activities.	Re-map clean water sources and build simple filtration systems for incoming water. Integrate micro-storage reservoirs and improve irrigation water management. Support feed supply chains through partnerships with the private sector and cooperatives.

2. Pilot Project Location Proposal

Based on land suitability scores, infrastructure, and community participation, a freshwater pilot project is recommended for Leohito Village, Balibo Sub-District, with commodities including catfish, gourami, and carp. This location was chosen due to the availability of 210 ponds, active community management, and high fish survival rates.

3. Strategic Recommendations for Local Government (District and Sub-District)

- Promote the development of local feed industries based on local agricultural raw materials to reduce production costs.
- Facilitate training on self-processing of feed for farmer groups in priority areas.
- Improve infrastructure and revitalize irrigation and aeration systems to support water supply and maintain environmental quality for aquaculture.
- Establish a Municipal Aquaculture Forum to coordinate stakeholders, technical trainers, and government bodies in aquaculture development.
- Review institutional approaches at government offices to make them more adaptive and innovative, including strengthening technical human resource capacities.

- Diversify commodities and markets by encouraging pilot trials of brackish water species cultivation, such as mud crab and vannamei shrimp, through a cluster-based approach on the northern coast of Bobonaro District.
- Open access to local and inter-district markets by strengthening distribution networks and trade partnership schemes.
- For sub-districts with limited land (such as Bobonaro Sub-District), the government should develop technology-based intensification strategies (e.g., biofloc, aquaponics).

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Bobonaro Municipality

Bobonaro Municipality is one of the strategic areas for integrated agricultural development in Timor-Leste. With a land composition consisting of irrigated rice fields at 8.89 %, rainfed rice fields at 11.65 %, dryland farming at 22.52 %, grazing areas at 0.46 %, agroforestry at 48.43 %, and protected and conservation forest areas at 7.79 %, the Municipality has ecosystem diversity that supports the diversification of agricultural, forestry, and livestock commodities. Food crops suitable for the agroecological conditions include irrigated rice, upland rice, maize, sorghum, and wheat. For horticulture, the Municipality has potential to develop vegetables such as chili, tomato, and bitter melon, as well as fruits such as pineapple, salak, and durian. Relevant spice and medicinal plants are turmeric and galangal, while industrial crops with economic value include coconut, robusta coffee, and tobacco. In the forestry sector, priority species for development include teak, mahogany, and agathis. Maliana, as the main center of rice production, has long been recognized as a national rice granary. Soil fertility and the support of irrigation networks make this area a priority in food security programs. Through the Maliana II Irrigation Project, the government has expanded the coverage of irrigated rice fields to thousands of hectares with the aim of increasing productivity, strengthening food security, and supporting the welfare of local farmers.

The livestock sector in Bobonaro is dominated by cattle, pigs, goats, and chickens, supported by forage feed such as elephant grass, setaria, and legumes. The KTS Korluli center in Maliana is recommended as a pilot project site focusing on the development of cattle, buffalo, and small livestock. In the fisheries sector, there are two main aquaculture sites, namely Leohito Village (Balibo Administrative Post) and Raifun Village (Maliana Administrative Post), with leading commodities including catfish, gourami, and common carp. Multisector integration is realized through integrated farming systems based on the five farming principles, combining crop cultivation, livestock production, and aquaculture intensification. As a strategic step, three villages Ritabou, Leohito, and Lahomea have been designated as pilot project sites for integrated agricultural development. This pilot project is expected to serve as a model that can be replicated in other areas, while simultaneously strengthening national food security and supporting Timor-Leste's position within ASEAN.