Land Suitability Evaluation & Regional Potential Mapping

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

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

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FOREWORD

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

With gratitude to God Almighty, we are proud to welcome the publication of this book entitled *"Land Suitability Evaluation and Mapping of Regional Potential for the Development of Agricultura, Livestock, Fisheries, and Forestry Commodities in Covalima District, Timor-Leste*." This book is a concrete outcome of the 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 region endowed with abundant natural resources, Covalima District faces significant challenges in optimizing land use, particularly under conditions of limited resources and the influence of climate change. This book was prepared to provide structured and relevant solutions to the needs of land resource management in Covalima, with a focus on food security, environmental sustainability, and poverty alleviation.

The data-based approach used in this study successfully mapped the potential of Covalima District for the development of key sectors, including food crops, plantation crops, horticulture, and forestry. Furthermore, the strategies formulated in this book are intended to support sustainable rural economic growth in Covalima, while also creating opportunities for new, relevant employment for local communities.

With coverage of seven main Sub-Districts, namely Fatululic, Fatumean, Fohorem, Maucatar, Suai, Tilomar, and Zumalai, this book offers strategic guidance for the utilization of dryland, which dominates Covalima District. The proposed land suitability zoning approach provides solutions to the challenges of land degradation, erosion hazards, and declining soil fertility. In addition, this book emphasizes the importance of integrating environmental conservation and modern technology to support sustainable land productivity.

We believe that the recommendations presented in this book not only provide direct benefits for food security in Timor-Leste, particularly in Covalima District, but also contribute to the achievement of the Sustainable Development Goals (SDGs), especially those related to zero hunger (SDG 2), climate action (SDG 13), and life on land (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 the development of the agricultural sector in Timor-Leste proceeds in harmony with the conservation of natural resources, ecosystem sustainability, and the improvement of community welfare.

Finally, I would like to express my gratitude to all parties who have contributed to the realization of this book. I hope that this work will 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,
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EXECUTIVE SUMMARY

A. GENERAL OVERVIEW OF THE STUDY AREA

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

1. Demography: Foundation of Human Resource Potential

Covalima District is dominated by dryland and has a substantial farmer population in several Sub-Districts such as Suai and Zumalai, which shows considerable potential for developing the agricultural sector as a backbone of national food security. This demographic structure makes the area a strategic candidate for strengthening national food security through the application of innovative agricultural technologies. The significant involvement of farming communities in this region is a key supporting factor in maximizing the existing agricultural potential.

2. Soil Type: Basis for Land Suitability Evaluation

Covalima District exhibits a diversity of soil types, including Inceptisols, Vertisols, Mollisols, Alfisols, Ultisols, and River soils, which are known to be fertile and have high productivity potential if managed appropriately. This diversity reflects substantial opportunities for developing agriculture based on land suitability. However, soils with characteristics that are prone to erosion, such as Vertisols, require particular attention. The implementation of intensive and well-directed soil conservation strategies is crucial to ensuring the sustainability of land productivity and to supporting sustainable agricultural development in this region.

3. Land Use: Dynamics of Ecosystem and Human Activities

Covalima District has various forms of land use, including forest land, agricultural land, residential and industrial land, and dryland. This distribution is dominated by forest and agricultural land, which are key elements for both ecosystem conservation and increased food production. Areas with intensification potential, such as rice fields in Zumalai, offer major opportunities for optimization through the development of improved irrigation infrastructure and the application of conservation-based land management. This approach is essential to support agricultural sustainability while increasing production. Overall, the land use pattern in this region reflects both complex challenges and significant opportunities. The dominance of forest land creates scope for the development of sustainable forestry-based commodities, while the distribution of agricultural land calls for intensification strategies that prioritize sustainability principles in order to realize the full agrarian potential.

4. Field Conditions: Constraints and Potential

Covalima District faces various challenges in land management, including land degradation caused by erosion, landslides, and critical land conditions. In addition, the lack of adequate irrigation infrastructure and suboptimal land management are major constraints to improving agricultural productivity in the area. On the other hand, the region also holds substantial potential that should be further developed. The development of food crops in Tilomar and horticulture in Zumalai represents strategic opportunities that can make a significant contribution to food security and the local economy. Optimizing this potential requires a soil conservation-based approach to address degradation, as well as community empowerment to achieve sustainable land management.

5. Utilization of *Chromolaena odorata* : From Challange to Opportunity

The invasive plant *Chromolaena odorata* in Covalima District, although it poses significant ecological challenges, also has considerable potential. This plant is utilized as a raw material for organic fertilizer, traditional medicine, and environmentally friendly bioenergy. The utilization of this plant requires strategies that involve various stakeholders, including local communities and the private sector. Such a collaborative approach also contributes to community economic development through the innovation of products based on *Chromolaena odorata*. In this way, holistic management can transform ecological challenges into opportunities that support ecosystem sustainability and community well-being.

B. RESEARCH METHOD

This study used a survey approach, including field observations, interviews, and laboratory analyses, to evaluate land suitability comprehensively. The analysis was based on Homogeneous Land Units as the basis for delineating the area, using thematic maps such as land use, soil type, geology, and slope gradient.

Data analysis was supported by Geographic Information Systems (GIS) to produce accurate and informative map visualizations.

Research Procedures

1. **Soil Sampling**
   a) Composite soil samples were collected at the following depths:
      - **0–30 cm** for annual crops.
      - **0–60 cm** for perennial crops.
2. **Laboratory Analyses**
   The physical and chemical soil parameters analyzed included:
   a) C-organic *(%)*: Walkley dan Black Method.
   b) N-total *(%)*: Kjeldahl Method.
   c) Soil Texture: pipet Method.
   d) Soil pH: potensiometer Method *(H_2O 1:2.5)*.
   e) Available-P & Available-K (ppm):
      - Bray-1 Method for pH < 7 (with conversion ke mg/100 g).
      - Olsen Method for pH > 7 (with conversion ke mg/100 g).
   f) Salinity: *dS/m* using a potensiometer *(H_2O 1:2.5)*.
   g) Cation Exchange Capacity (*cmol/(mg/100g)*) and Base Saturation (%) *dengan NH_4OAc 1N pH 7*.
   h) Total Phosphorus (mg/100 g) and Total Potassium (mg/100 g) determined using the 25 % HCl method.
   i) Soil Fertility status determined: according to the PPT (1995) Method.
   j) Erosion Hazard: assessed through field observations and the Universal Soil Loss Equation (USLE).

Stages of Land Suitability Classification

1. Actual Land Suitability:
   Initial classification was carried out to assess land suitability under existing conditions without improvement.
2. Land Improvement Reccommendations:
   Improvement measures were identified to address limiting factors, including input management such as fertilization and soil and water conservation techniques.
3. Potential Land Suitability:
   Suitability was re-evaluated after considering improvements, in order to maximize land potential.

4. Zoning of Commodity Development Potential:
   Zoning was determined by integrating the agroecological zones of Covalima District, based on land suitability and specific agroecosystem conditions.

C. CHARACTERISTICS OF AGRICULTURE AND FOREST LAND

1. Temperature

Air temperature is a key indicator in land suitability evaluation and was analyzed through a combination of field data and a digital elevation model (SRTM DEM) using the Braak approach. Areas with cool temperatures (18 to 21 °C) have limited production potential and a high erosion risk. The optimal zone (21 to 24 °C) represents moderate conditions that dominate productive areas. This zone is highly suitable for soil and water conservation, which can support sustainable crop growth. Meanwhile, lowland areas with warm temperatures (24 to 26 °C) and high temperatures (> 26 °C) have substantial potential for tropical crops such as rice, corn, and soybean. However, these temperature ranges also increase the risk of high evapotranspiration, requiring adaptive water resource management and the use of heat-tolerant crop varieties.

2. Rainfall

Field data combined with CHIRPS satellite imagery show that rainfall distribution varies across Covalima District. Fatululic Sub-District and part of Fohorem Sub-District receive more than 2,000 mm year$^{-1,}$ which supports high humidity but also increases erosion risk. Fatumean and Tilomar Sub-Districts are dominated by rainfall in the range of 1,500 to 2,000 mm year^{-1}, while Suai and Zumalai Sub-Districts show mixed patterns, with some areas in the range of 1,000 to 1,500 mm year^{-1} and others above 2,000 mm year^{-1}. This variation in water availability requires tailored management strategies to support optimal agricultural productivity.

3. Dry Months

The distribution of dry months in Covalima District reflects variability in water resource stability. Most of the area experiences a dry period of 5 to 6 months, indicating substantial agrarian potential with a relatively low drought risk. This condition provides opportunities for sustainable agricultural development. However, areas with a longer dry period (more than 6 months), such as Suai, Tilomar, and Zumalai Sub-Districts, face greater challenges related to land productivity. To address these challenges, the implementation of innovative water conservation technologies and the development of adaptive infrastructure are required. This approach is important to maintain agricultural productivity while ensuring sustainable water resource management in these areas.

4. Drainage

Most of Covalima District has well drained soils, particularly in Fatululic, Fatumean, Fohorem, and Zumalai Sub-Districts. Maucatar and Tilomar Sub-Districts show more variation, with some areas having poorly drained soils. Well drained conditions support efficient water distribution and land productivity, whereas areas with poorly drained soils require intensive water management to prevent waterlogging. This combination reflects both agrarian potential and challenges in water management.

5. Soil Texture

Most areas in Covalima District have fine and moderately fine soil textures, as seen in Fatululic Sub-District, which is entirely fine textured, and in Fatumean Sub-District, where most of the area has similar textures. Zumalai Sub-District shows greater variation, with 41 % of the area having moderately fine texture, 24 % fine, 18 % medium, 12 % moderately coarse, and 6 % coarse texture. Areas with coarse or medium textures require conservation strategies to maintain productivity. The relationship between soil texture, lithology, and soil type provides a basis for sustainable land management that supports site-specific productivity and reduces the risk of soil degradation.

6. Coarse Fragments

Most of Covalima District has low coarse fragment content (< 5 %), covering 60 % of the area, which indicates fine soil textures with high fertility potential. Areas with coarse fragment contents of 5 to 10 % and 10 to 15 % account for 9 % and 2 % of the area, respectively, whereas medium contents (15 to 35 %) occur in only 15 % of the area. Areas with high coarse fragment content (> 35 %) cover 14 % of the area, including 5 % with more than 50 %, indicating potentially rapid drainage that can increase drought risk. These areas require irrigation and soil conservation strategies to maintain productivity.

7. Surface Rock

Most of Covalima District is characterized by low surface rock cover (<5 %), accounting for 49 %, which supports intensive agriculture. Approximately 32 % of the area has moderate surface rock cover (5 to 20 %), 12 % falls within the range of 20 to 50 %, and only 7 % has very high surface rock cover (>50 %), which is more suitable for conservation or forestry. This distribution highlights the need for land management strategies tailored to local conditions to maximize agricultural productivity.

8. Rock Outcrops

Most of Covalima District has low surface rock content (< 5%) over 49% of the area, which supports intensive agriculture. About 32 % of the area has medium rock content (5 to 20%), 12% lies in the range of 20 to 50 %, and only 7% has very high surface rock content (> 50%), which is more suitable for conservation or forestry. This distribution highlights the need for tailored land management strategies to maximize agrarian productivity.

D. SOIL FERTILITY STATUS

The analysis results showed that most soils in Covalima District have low fertility status (55.81 %), followed by medium (32.56 %) and high (11.63%). These categories were determined based on soil chemical parameters such as cation exchange capacity (CEC), base saturation, soil organic carbon (SOC), Phosphorus (P), and Potassium (K). The low soil fertility status is mainly caused by low SOC and potassium contents, as well as soil properties that favor nutrient leaching in areas with high rainfall.

1. Spatial Distribution of Soil Fertility

- Zumalai Sub-District has the highest number of low-fertility land units, with 10 land units.
- Suai Sub-District has 7 land units with low fertility status.
- Fohorem Sub-District has 2 land units with low fertility status and no land with medium status.
- Fatululic Sub-District is dominated by low-fertility land, with only 1 land unit identified in the analysis.
- Fatumean and Tilomar Sub-Districts show a more balanced distribution, each with 2 and 3 land units, respectively, in the medium fertility category.
- Maucatar Sub-District has medium to low soil fertility status, with 4 observation units.

2. Limiting Factors

- **Slope Gradient:** Steep slopes can accelerate erosion, removing the topsoil layer that is rich in organic matter and nutrients.
- **Soil Type:** The dominance of Vertisols, which are generally characterized by 2:1 clay minerals, leads to soil colloids dominated by Ca and K that are highly susceptible to leaching.

E. EROSION AND AGROFORESTRY-BASED CONSERVATION

1. Soil Erosion

Soil erosion plays an important role in land suitability evaluation and the sustainability of land use. In Covalima District, factors such as steep slopes, low vegetation cover, granular soil structure, and minimal conservation measures accelerate erosion rates. The analysis showed that more than 70 % of the area in Covalima District experiences severe to very severe erosion, which results in the loss of fertile topsoil and reduced soil productivity.

The main factors causing erosion in this region include:

a) Topography: Dominant steep slopes, particularly in Suai Sub-District.
b) Soil type: Vertisols that are highly erosion-prone, especially at slopes greater than 15%.
c) Rainfall: High rainfall intensity that causes severe to very severe erosion.
d) Limited vegetation cover: Contributing to the loss of topsoil due to surface runoff.
e) Anthropogenic factors: Land management that does not follow conservation principles accelerates erosion.

2. Agroforestry-Based Conservation

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

a) **Increasing vegetation cover:** to reduce surface runoff and maintain soil moisture.
b) **Improving soil fertility:** through organic matter inputs from litter and roots.
c) **Managing water sustainably:** by retaining water within the soil profile through deep root systems.

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

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

3. Implementation of Agroforestry in Covalima District

Agroforestry systems implemented in Covalima District vary according to the agroecological zones. Examples of effective agroforestry-based conservation systems include:

a) **Alley cropping:** Planting crops between tree rows on steep slopes to control erosion.
b) **Live hedgerows:** Using erosion-tolerant plants such as vetiver to stabilize slopes.
c) **Live stakes:** Using perennial plants such as Leucaena to control erosion, combined with pepper and other climbing crops.
d) **Multistrata planting:** Combining trees, shrubs, and ground cover crops to hold soil and reduce runoff.
e) **Silvopastoral systems:** Integrating forest vegetation with livestock to manage erosion in grazing areas.

4. Conservation Recommendations

a) **Scaling up agroforestry** practices in erosion-prone zones.
b) **Spatial data-based management** to identify priority locations for conservation interventions.
c) **Capacity building for farmers** through training and adoption of modern agroforestry techniques.
d) **Strengthening soil conservation policies** by integrating agroecological approaches into spatial planning.

F. LAND SUITABILITY FOR AGRICULTURE

1. Land Suitability Evaluation

a) Fatululic Sub-District

- Potential food crops include corn, cassava, mung beans, cowpea, and chickpea.
- Horticultural commodities that can be developed include mango, rambutan, and guava.
- Forestry species such as teak and mahogany are the focus in the forestry sector.

b) Fatumean Sub-District

- Food crops that can be developed include corn, mung beans, and cowpea.
- Industrial crops that can be developed include coconut, cacao, clove, and tobacco.
- Horticultural crops with development potential include lettuce, petsai, caisim, amaranth, grape, avocado, and banana.
- Spice crops that can be developed include pepper, candlenut, and lemongrass.

c) Forohem Sub-District

- Forestry species that can be developed include Agathis, Leucaena, and Eucalyptus.
- Food crops with development potential include corn, cassava, and sweet potato.
- Horticultural crops with development potential include lettuce, petsai, caisim, amaranth, grape, avocado, and banana.
- Fruit horticulture that can be integrated into agroforestry systems includes durian, jackfruit, avocado, and candlenut.

d) Suai Sub-District

- Food crops that can be developed include irrigated rice, upland rice, corn, and sorghum.
- Horticultural and industrial crops with development potential include petsai, amaranth, caisim, papaya, banana, mango, jackfruit, coconut, Robusta coffee, and tobacco.
- Spice crops that can be developed include turmeric, aromatic ginger, and galangal.

e) Tilomar Sub-District

- Food crops that can be developed include irrigated rice, upland rice, corn, peanut, cassava, and sweet potato.
- Industrial crops with development potential include coconut, Robusta coffee, cacao, and tobacco.
- Horticultural crops with potential include caisim, eggplant, tomato vegetable, chili, cucumber, bitter melon, mangosteen, mango, jackfruit, and banana.
- Spice crops that can be developed include turmeric and galangal.

f) Zumalai Sub-District

- Food crops that can be developed include irrigated rice, upland rice, corn, tobacco, tomato, eggplant, bitter melon, papaya, banana, and jackfruit.
- Horticultural crops with potential include amaranth, long beans, cucumber, and bitter melon.
- Spice crops that can be developed include turmeric, aromatic ginger, and galangal.

g) Maucatar Sub-District

- Forestry species that can be developed include teak and mahogany.
- Agroforestry crops with potential include avocado, candlenut, Arabica coffee, ginger, turmeric, and aromatic ginger.

2. Agricultural Commodity Development Zones in Covalima District

Covalima District has substantial land resources to support the development of the agriculture, forestry, and livestock sectors. Based on land suitability evaluation, zoning was systematically designed through field observations, laboratory analyses, and agroclimatic mapping. This zoning aims to maximize land management efficiency, support food security, and improve community welfare.

a) Irrigated Rice Fields (23,75% of total area)

- **Area**: 285.64 km^2 at low elevations (< 100 m asl) with slopes of 0 to 8 %.
- **Main zones:** Suai Sub-District and Zumalai Sub-District.
- **Strategy**: Development of supplemental irrigation such as piping systems and pumping in areas with low rainfall.

b) Dryland Agriculture (43,06% of total area)
- **Area:** 517.87 km² at elevations of 100 to 500 m asl with slopes of 8 to 25 %.
- **Main zones:** Suai, Tilomar, and Zumalai Sub-Districts.
- **Main commodities:** corn, cassava, coffee, cacao, and horticultural crops.
- **Strategy:** Soil conservation measures such as strip cropping and crop rotation.

c) Grazing Areas (0,48% of total area)
- **Area:** 5.74 km².
- **Main zone:** Zumalai Sub-District.
- **Strategy:** Rotational grazing systems and integration of agroforestry.

d) Agroforestry (26,49% of total area)
- **Area:** 318.55 km² at elevations above 500 m asl with slopes of 8 to 25 %.
- **Main zones:** Fatumean and Fohorem Sub-Districts.
- **Strategy:** Integration of small-scale livestock to diversify income.

e) Protected Forest Areas (4,69% of total area)
- **Area:** 56.45 km² at elevations of 100 to 500 m asl with slopes of 8 to 25 %.
- **Purpose:** Soil and water conservation and biodiversity conservation.
- **Strategy:** Reforestation and ecosystem restoration to reduce land degradation.

G. LAND SUITABILITY FOR AGRICULTURE

a) Agroforestry (26,49% of total area)
- **Area:** 318.55 km² at elevations above 500 m asl with slopes of 8 to 25 %.
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H. LIVESTOCK POTENTIAL IN COVALIMA DISTRICT

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

a) **Land Suitability for Forage Feed.**
   Fatululic, Fatumean, Fohorem, Maucatar, Suai, Tilomar, and Zumalai Sub-Districts have potential for the development of forage crops such as elephantgrass, *Setaria*, legumes, and grazing lands. Land suitability levels range from moderately suitable (S2) to not suitable (N). Limiting factors include rainfall, slope gradient, erosion, soil pH, nutrient status (Total Nitrogen, Available Potassium), effective soil depth, and dry months. Improvements can be made through irrigation, terracing, organic and inorganic fertilization, and the planting of terrace-stabilizing species.

b) **Ecological Suitability for Livestock.**
   Based on geospatial analysis, Suai Sub-District is the most dominant area for the development of large livestock (sheep, beef cattle, dairy cattle, pigs, and buffaloes), followed by Zumalai, Fatumean, Tilomar, Maucatar, and Fohorem Sub-Districts, while Fatululic Sub-District has the smallest area. Climatic conditions with a mean temperature of 24.9 °C and annual rainfall of 1,848 mm year^{-1} support forage production throughout the year, although temperature becomes a limiting factor particularly for dairy cattle. For poultry, land in all areas is considered highly suitable due to their high adaptive capacity. Lactos, Calobor, and Fohorem are recommended as centers for sustainable beef cattle development.

c) **Socioeconomics Aspects of Community Livestock Production.**
   Extensive systems (free grazing) remain dominant in Covalima District. Their advantages include low labor requirements, but the disadvantages include difficulties in controlling livestock nutrition, disease risks, theft, and conflicts with farmers. Government livestock assistance provided since 2014 has not yet been optimal due to limited education, capital

constraints, prevailing natural mating practices (with artificial insemination not yet widely adopted), minimal feed management, and restricted market access (mostly live animal sales only). Suggested solutions include education on breeding and livestock management, implementation of artificial insemination, provision of credit or loans to increase livestock populations, and development of marketing channels for processed products to increase added value.

I. FRESHWATER FISHERIES POTENTIAL IN COVALIMA

This study aimed to evaluate land suitability for aquaculture development in Covalima District, Timor-Leste, as an effort to support food security, improve nutrition, and strengthen the local economy. The methodology used included Geographic Information System (GIS) analysis, field observations, and water quality measurements to map actual and potential land suitability. There are two main locations that serve as centers of aquaculture activities, each representing different ecosystem characteristics:

a) **The first location is in Suai Loro Village (Suai Sub-District),** focusing on tilapia and milkfish culture in ponds or lagoons. The main partners at this site are pond owners with an educational background in animal husbandry. The reasons for selecting this location include active partners, an interest in expanding businesses, a suitability score greater than three, and the availability of local feed resources.
b) **The second location is in Beco Village (Maucatar Sub-District),** with silvofishery activities for mangrove crab. Partners at this site include the government and local fisher groups. Location selection was based on the availability of 300 ha of mangrove forest and the need for a sustainable coastal use model.

The analysis showed that Covalima District has significant potential for aquaculture, especially freshwater fish in Maucatar and brackish-water commodities in Suai. Technical improvements, including enhanced aeration, use of local feed, water quality testing, and integration of silvofishery systems in mangrove areas, are important steps.

J. RESEARCH RECOMMENDATIONS

1. **Optimization of Food Zone Production**
   - **Improvement of irrigation infrastructure** Expansion of irrigation networks is important in Fatumean and Fohorem Sub-Districts. These areas have the potential to become significant rice production centers in Covalima District. To support intensified cropping patterns, priority measures include the development of micro-irrigation systems and the construction of small reservoirs to ensure stable water supply.
   - **Diversification of food commodities** Beyond the main focus on rice production, these food zones offer opportunities for the cultivation of other food crops such as corn, soybean, and cassava. Commodity diversification not only broadens food sources but also enhances food security through more varied agricultural outputs.
2. **Utilization of Agroforestry and Protected Forest Potential**
   a) **Development of Agroforestry system:**
   - **Industrial crops:** Focus on high-value crops such as Robusta coffee, Arabica coffee, cacao, and coconut in Fatululic, Fatumean, Fohorem, Maucatar, Suai, Tilomar, and Zumalai Sub-Districts.
   - **Horticulture:** Integration of fruit crops (avocado, mango, banana) and vegetables (tomato, chili) with forest trees on sloping land to support soil conservation.

   b) **Protected Forest Management:**
   - Prioritize protected forests for biodiversity conservation, climate change mitigation, and land resource management.
   - **Production forests:** Plant teak, mahogany, and Albizia to generate economic value while involving local communities in sustainable management.
3. **Utilization of Weed Biomass:** Utilizing *Chromolaena odorata* biomass for organic fertilizer or bioenergy can reduce pressure on forest ecosystems.
4. **Infrastructure and Technology Development**
   a) **Construction of supporting infrastructure:**
   - **Small reservoirs and rainwater:** storage structures: Built in dryland zones to increase water availability during the dry season.
   - **Drainage channels:** Help control runoff on sloping areas, particularly in agroforestry zones.

b) **Use of GIS and remote sensing technologies:** Utilization of GIS and remote sensing for mapping land potential and monitoring land cover.

5. Community Capacity Building

a) **Training and education**: On soil conservation, water management, and commodity diversification for farmers in different zones.

b) **Empowerment of women and communities**: Training in agroforestry and biomass management to promote social inclusion and increase household income.

6. Policies and Incentives

a) **Economic incentives:** Subsidies, microcredit, and bonuses for businesses based on agroforestry and conservation.

b) **Zoning regulations:** Spatial planning aligned with the zoning results.

7. Monitoring dan Evaluation

a) **GIS technology:** Use GIS to monitor the effectiveness of land management strategies, changes in land cover, and land capability in Covalima District.

b) **Local participation:** Involvement of communities, stakeholders, and government to maintain the relevance of strategies.

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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.

This strategic step positions Timor-Leste on the regional stage, where food self-sufficiency and food security are among the main benchmarks of national progress. As a country that gained independence in 2002, Timor-Leste faces major challenges in optimizing its natural resources to meet the food needs of a growing population.

In this global and regional context, 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 achieve these goals, Timor-Leste needs to identify and develop areas with strategic potential, one of which is Covalima District.

Focus Area: Potential of Flat Land in Covalima

Covalima District is one of the areas with substantial potential to support national food security. With a population of 73,933 inhabitants (end of 2022) and an average population density of 61 persons km^2, this district requires optimization of agricultural land to increase productivity.

The main geographic asset of Covalima lies in its topography. The district has land with flat to gently sloping terrain (0 to 8 %) covering 22.09 % of its total area. These extensive flat lands, concentrated in the southern coastal area such as Zumalai, Suai, and Tilomar Sub-Districts, have considerable potential for the intensive development of irrigated agriculture.

Technical Basis: Soil Potential and Water Availability

The topographic potential is supported by two key technical factors: soil (edaphic) conditions and water (hydrological) availability.

1. **Soil characteristics:** Soil conditions in Covalima are highly diverse. Although the area is dominated by Entisols (32.11 %), which generally have relatively low fertility, these soils can be effectively optimized through the application of irrigation technologies and organic fertilization.

Greater potential lies in other, more fertile soil types:

a) **Inceptisols (25.76 %)** and **Mollisols (16.52 %)** offer significant opportunities for intensive agriculture, particularly strategic food crops such as rice.
b) **Vertisols (16.99 %)**, with their high water retention capacity, are also highly suitable for the development of irrigated rice fields, especially when combined with sound water management systems.

2. **Hidrological potential:** A major supporting factor in Covalima is water availability. The district is traversed by an extensive river network covering 4,185.16 ha (3.49 % of the total area). This represents a major asset for the development of modern irrigation infrastructure. The implementation of technologies such as piping systems, pumping, and drip irrigation can increase water use efficiency and support more stable agricultural production throughout the year.

Opportunities for Integrated Sector Development

With its flat land assets and abundant water resources, Covalima has strong potential for the development of integrated systems that encompass not only agriculture but also forestry, livestock, and fisheries.

a) **Agriculture and agroforestry:** In addition to irrigated rice fields on flat land, the application of agroforestry on sloping land can function as a conservation system that maintains ecosystem balance, reduces erosion, and ensures long-term production sustainability (Nair, 2011).
b) **Livestock**: Extensive flat land in the coastal area is also ideal for optimizing grazing areas for cattle and goats, which are important commodities in Timor-Leste.
c) **Fisheries (freshwater and brackish-water):** The extensive river network creates opportunities for freshwater fisheries. At the same time, the southern coastal zone has strong prospects for the development of brackish-water fisheries through intensive ponds and modern aquaculture systems such as biofloc-based culture.

Integration between agriculture, livestock, and fisheries in an integrated farming system can create a production system that is far more efficient and sustainable in Covalima.

Purpose of the Evaluation in This Book

The research underlying this book therefore aims to evaluate land suitability and map the potential for regional development in Covalima District. The main focus is on the agricultural sector, with additional exploration of livestock and fisheries (freshwater and brackish-water) as integrated supporting sectors.

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

The name Covalima derives from the Tetun Terik term Coba lima, which symbolizes the five traditional rulers in Camnasa, Fohoren, Suai, Maucatar, and Taromana. Before Portuguese colonialism, the area had customary governance, and beginning in 1698 it started to be integrated into the colonial administration. In 1859 Covalima was included in Dotik District; after World War II it briefly became a Circunscrição Civil, then was merged with Bobonaro due to economic constraints. During the Indonesian occupation it held district status, and after Timor-Leste's independence it was designated as a District.

II. GENERAL OVERVIEW OF THE AREA

2.1 DEMOGRAPHY

Covalima District is one of the districts in Timor-Leste located in the southwestern part of the country. It borders the Timor Sea to the south, Bobonaro District to the north, Ainaro District to the east, and Indonesia's East Nusa Tenggara Province to the west. Geographically, Covalima District is located 9°05′ – 9°30′ S-125°40′ – 125° E. The administrative map of Covalima District is presented in the figure below **(Figure 2.1).**

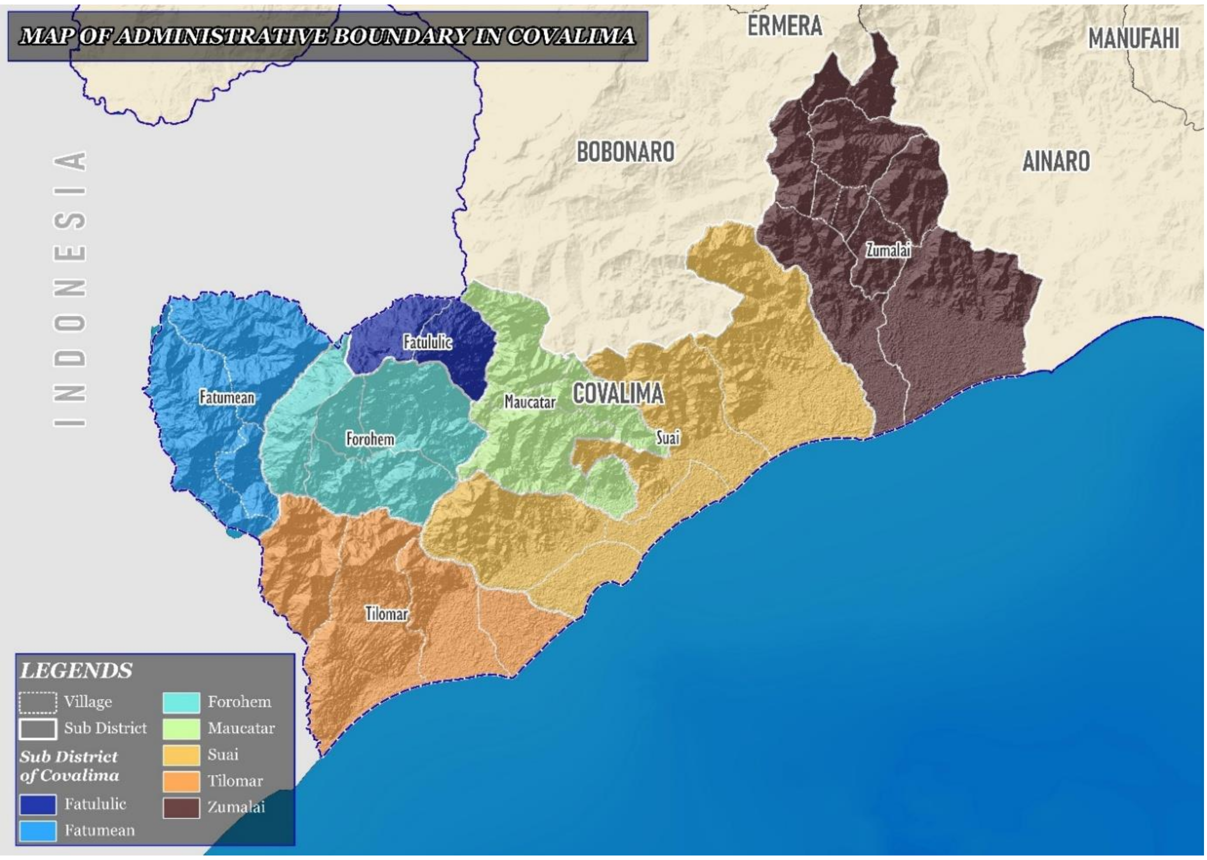


Figure 2.1 Administrative Area of Covalima District

The name *Covalima* derives from the *Tetun Terik* term *Coba lima*, which symbolizes the five traditional rulers in Camnasa, Fohoren, Suai, Maucatar, and Taromana. Before Portuguese colonialism, the area had customary governance, and beginning in 1698 it started to be integrated into the colonial administration. In 1859 Covalima was included in Dotik District; after World War II it briefly became a *Circunscrição Civil*, then was merged with Bobonaro due to economic constraints. During the Indonesian occupation it held district status, and after

Timor-Leste's independence it was designated as a District. The population of Covalima District at 87,766, and a total area of 1,198.9 km^2 (Autoridade Munisipal Covalima, 2025). These data are presented in the table below **(Table 2.1).**

Table 2.1 Demographic Data of Covalima District

Sub-District	Area (ha)
Fatululic	4.555,57
Fatumean	13.210,88
Tilomar	19.395,15
Zumalai	28.284,3
Maucatar	11.417,04
Suai	30.159,21
Forohem	13.232,32

2.2 SOIL TYPES

Information on soil types in Covalima District was classified using Soil Taxonomy (1992 Keys). Classification was carried out only to the great group level. There were 7 soil orders, 16 suborders, and 22 great groups.

Covalima District was dominated by Entisols, covering 38,629 ha (32.11 %) **(Figure 2.2)**, distributed across the entire study area except Fatumean Sub-District **(Figure 2.3).** This was followed by Inceptisols at 30,966 ha (25.76 %), Vertisols at 20,444 ha (16.99 %), Mollisols at 19,859 ha (16.52 %), Alfisols and Ultisols at 6,171 ha (5.13 %), and the River order at 4,185 ha (3.49 %).

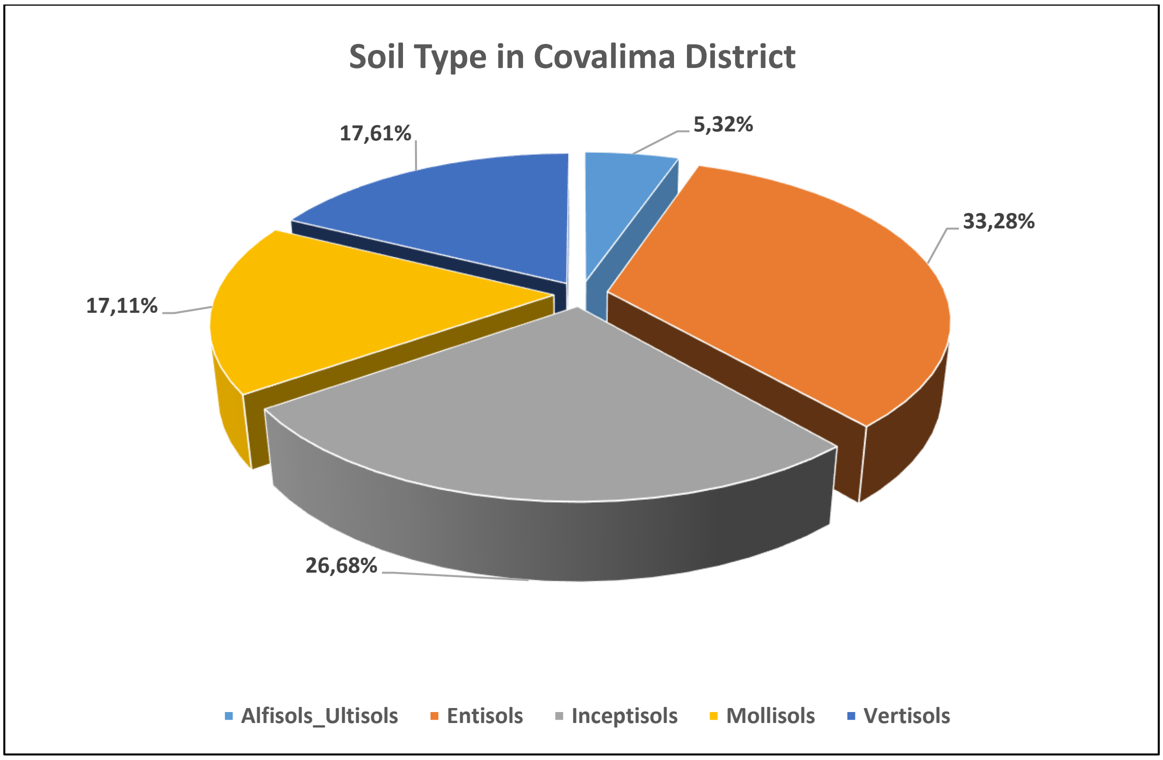


Figure 2.2 Area by Soil Type

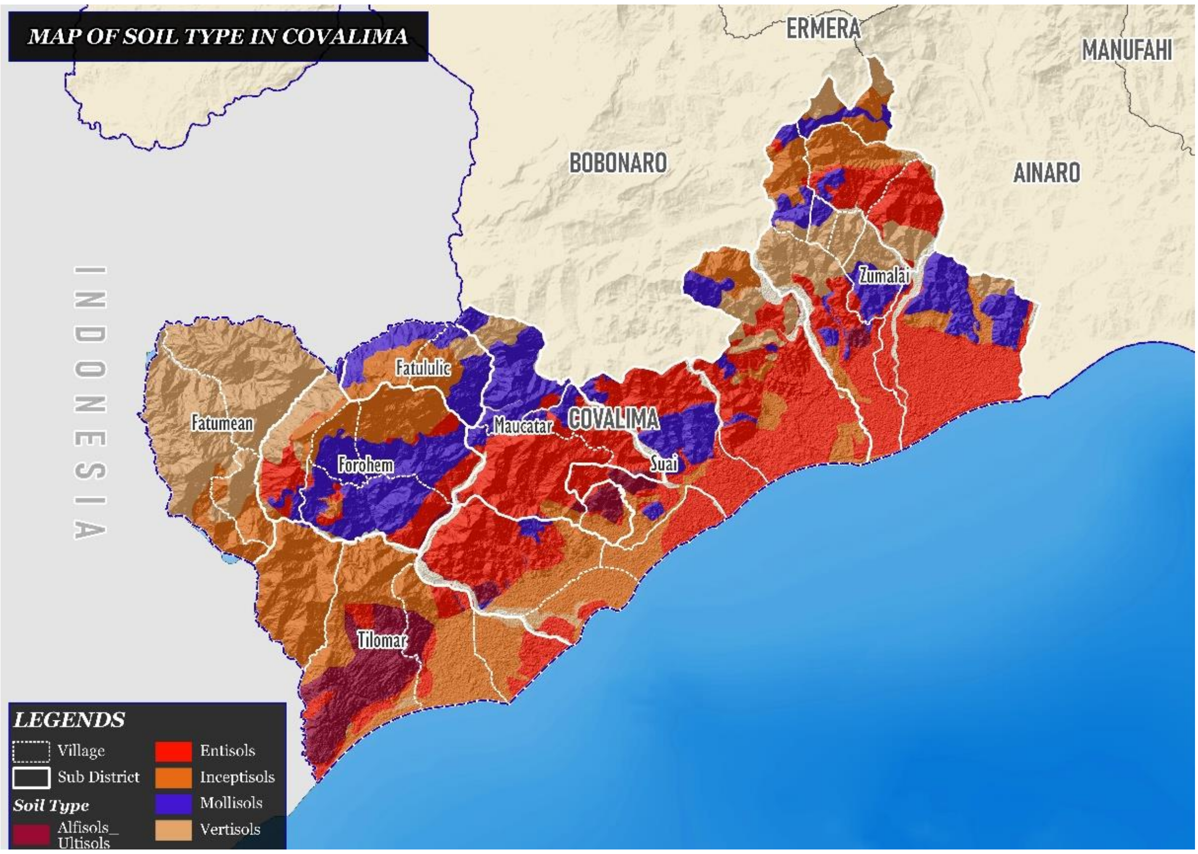


Figure 2.3 Soil Type Map of Covalima District

2.3 LAND USE

Covalima District, Timor-Leste, has diverse land-use types that provide an important basis for the development of agricultural and forest commodities. Land use in Covalima District is dominated by forest land covering 101,934 ha (84.76 %) and agricultural land covering 12,289 ha (10.22 %). This is followed by settlement and industrial land use covering 4,951 ha (4.12 %), and uncultivated dryland covering 1,080 ha (0.90 %). The area by land-use type is presented in **Figure 2.4.**

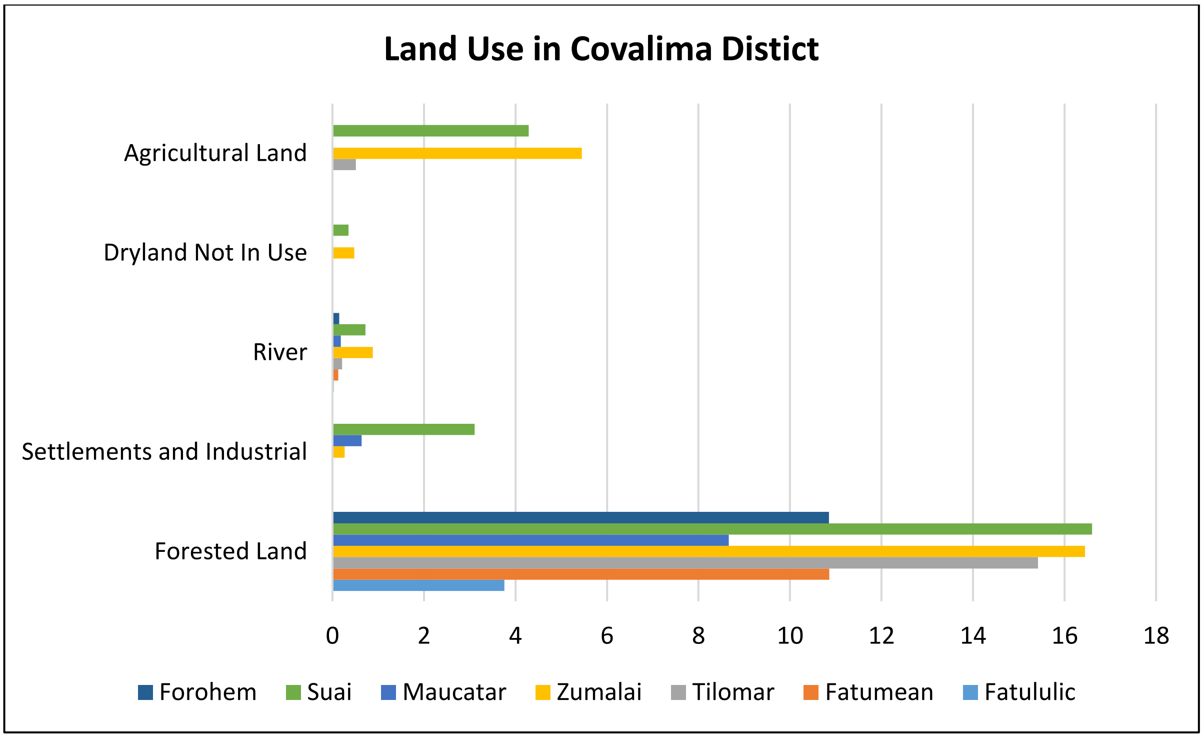


Figure 2.4 Area of Each Land-Use Type (%) in Covalima District

Fatululic Sub-District had forest area accounting for only 3.76 % of its territory and river area of only 0.03 %. In Fatumean Sub-District, forest land accounted for 10.86 % of its territory and river area for 0.13 %. Tilomar Sub-District had forest covering 15.42 % of its total area, agricultural land in Tilomar Sub-District accounted for only 0.51 %, with total river area of 0.21 %. Meanwhile, commercial agricultural land in this sub-district covered 14.38 %.

Zumalai Sub-District had forest covering 16.45 % and constituted the second-largest forest area in Covalima District after Suai Sub-District. Agricultural land in Zumalai Sub-District accounted for only 5.45 %, with river area of 0.88 %. Settlement and industrial land covered only 0.27 %, and uncultivated dryland covered 0.48 %. Maucatar Sub-District had forest covering 8.66 % of its territory, river area of only 0.18 %, and settlement and industrial land of 0.64 %.

Suai Sub-District has forest land covering only 16.6 % of its total area, making it the largest forest area in Covalima District. Agricultural land in Suai Sub-District covers only 4.29 %, with a total river area of 0.72 %. The uncultivated dryland in this sub-district covers 0.35 %, while settlement and industrial land cover 3.11 %. Forohem Sub-District has forest land covering 10.85 % of its total area, with the river area accounting for only 0.15 % **(Figure 2.4).**

Overall, land use in Covalima District presents both challenges and significant opportunities. The dominance of forest land offers the potential to develop sustainable forest commodities, while the scattered agricultural lands require strategies for sustainable intensification. With support from the Ministry of Agriculture, Fisheries, Livestock, and Forestry of Timor-Leste, integrated and data-driven planning is essential to ensure the optimal use of land, enhance agricultural productivity, and support national food security sustainably.

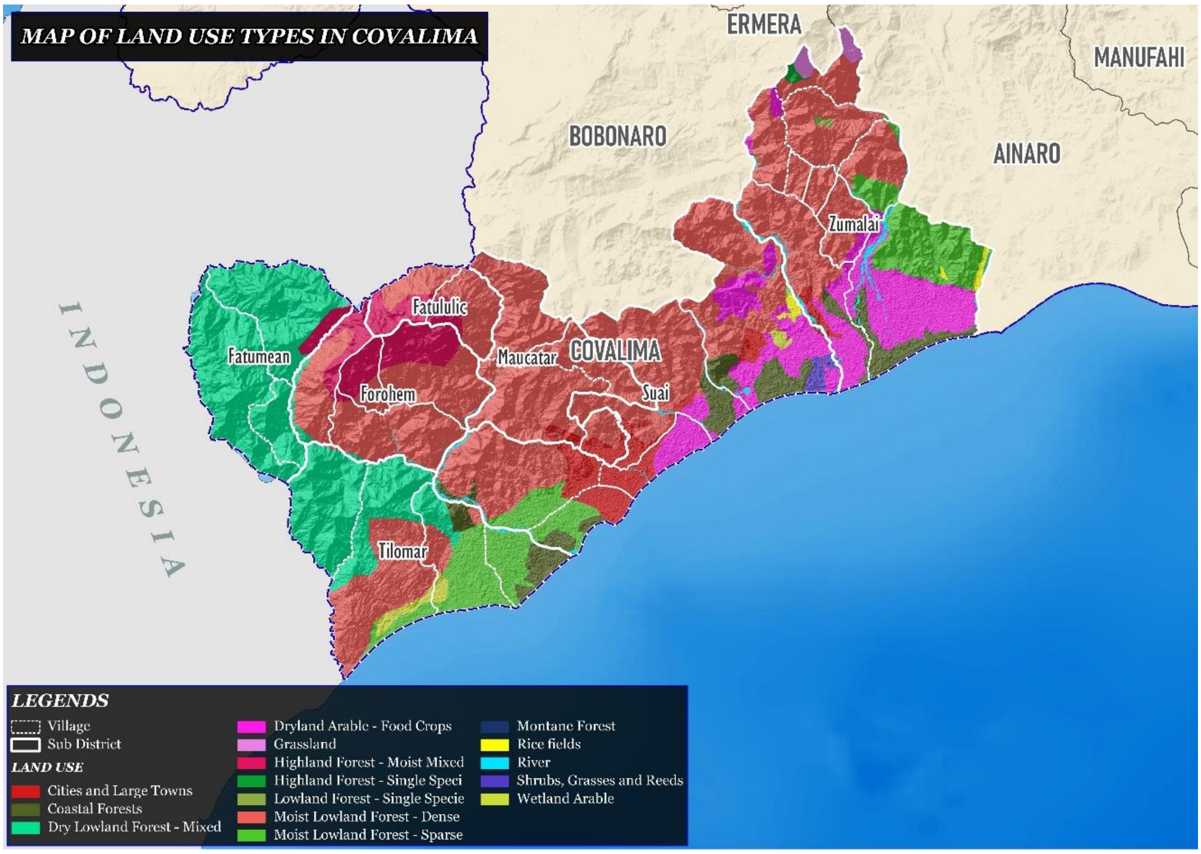


Figure 2.5 Land Use Map of Covalima District

2.4 EXISTING CONDITION

In Covalima District, the main issues were the difficulty of access to agricultural land and the lack of extension services for farmers or landowners regarding optimal land management practices to maximize agricultural yields **(Figure 2.6).** In areas with steep slope gradients, both in agricultural land and forests, the risk of erosion was very high, posing a major challenge for land management.

Figure 2.6 Field Conditions of Mixed Gardens
(Source: Researcher Documentation, 2024)

Tilomar Sub-District had potential land widely planted with sago. In addition to sago, other commodities that needed to be developed included rice, corn, and horticultural crops. In Zumalai Sub-District, particularly in Aldeia Bernia, vegetation comprised breadfruit, sago, mango, candlenut, and jackfruit. Although these commodities had good potential, reorganization and improved maintenance were required so that agricultural production could be optimized and provide greater benefits to local communities.

In areas with steep slope gradients, both in agricultural land and forests, erosion risk was very high. Therefore, land management had to be carried out carefully, including the application of soil and water conservation techniques to prevent erosion and maintain soil fertility. Good spatial arrangement and sustainable management practices were expected not only to increase agricultural yields but also to contribute to environmental conservation, providing long-term benefits for local communities and the sustainability of natural resources.

2.5 *Chromolaena odorata*

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

Figure 2.7 *C. odorata* Plant
(Source: Wiktrop)

In tropical Asia, *C. odorata* is commonly found from lowlands up to 500 m asl, especially in open areas such as coconut and rubber plantations, household yards, and grazing lands (Peniwiratri and Arbiwati, 2021). The plant has a distinctive morphology, with cylindrical pubescent stems, simple leaves with serrated margins, and compound inflorescences that are bluish at a young stage and turn brown with age **(Figure 2.8)**. In terms of chemical constituents, *C. odorata* contains active compounds such as flavonoids, tannins, alkaloids, saponins, and essential oils (Jamatia *et al*., 2024). The presence of these compounds provides substantial potential for this plant as raw material for traditional medicines to treat various ailments, such as diabetes, burns, hypertension, and skin infections (Jamatia *et al*., 2024).

In Timor-Leste, *C. odorata* was first recorded in the 1980s and spread rapidly due to slash-and-burn practices and the tropical dry climate that supports its growth (Day *et al*., 2013). The species is able to grow on various soil types, including marginal infertile land, with an optimal elevation between 500 and 2,000 m asl (Westaway *et al*., 2018). This rapid invasive growth reflects a remarkable adaptive capacity to new environments, but it also poses a serious threat to the sustainability of productive land.

Figure 2.8 Leaf and Flower Structure of *Chromolaena odorata*
(Source: Ashasathees)

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

In the agricultural sector, *C. odorata* is known to form dense thickets that inhibit the growth of cultivated crops such as maize, coffee, and various horticultural crops. This weed aggressively invades land newly opened for subsistence farming, which is the primary livelihood of rural communities. Its ability to absorb soil nutrients more rapidly than cultivated plants, due to a deep root system with extensive branching, creates detrimental competition for nutrients. As a result, agricultural productivity decreases markedly, with implications for local food security.

Negative impacts are also evident in the livestock sector. The leaves of *C. odorata* contain pyrrolizidine alkaloids that are hepatotoxic and can cause liver damage in livestock such as cattle and goats when consumed in large quantities. In addition, the spread of this weed in pastures reduces the availability of forage grasses, decreases grazing capacity, and negatively affects the livelihoods of herders, particularly in regions such as Timor-Leste.

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

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

As an indicator of soil fertility, it can play a role in increasing nutrient content, especially phosphorus, in sandy soils when its biomass is mixed with manure. Studies have shown that this combination can support the growth of cultivated crops such as shallot. In addition, the high organic matter content of *C. odorata* makes it a potential material for producing environmentally friendly organic fertilizer.

In traditional medicine, this plant has long been used for treating burns, diabetes, hypertension, and skin infections. Its flavonoid and phenolic constituents confer strong antioxidant, antiinflammatory, and antibacterial properties. Its uses vary among countries; in Vietnam, the leaves of *C. odorata* are used to treat soft-tissue wounds and manage leech bites, while in Africa the plant is used as a natural antiseptic.

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

III. RESEARCH METHOD

This study was conducted in Covalima District, Timor-Leste, with the primary objective of evaluating land suitability for agricultural development. Data were collected through field surveys, laboratory analyses, and the use of geographic information systems (GIS). The study was carried out from July to August 2024 and comprised direct field observations, soil sampling, interviews with local farmers, and GIS-based mapping. All stages of the research were organized systematically to generate accurate information that could serve as a basis for planning sustainable land management.

3.1 RESEACRH DESIGN

A. Methodological Approach

This study applied quantitative and qualitative approaches. The quantitative approach aimed to obtain numerical data for statistical analysis, while the qualitative approach was used to explore farmers experiences and perceptions related to agricultural practices in the study area (Trigunasih, 2016). The methods included field observations and laboratory analyses, as well as the collection of soil samples and interviews with local communities.

B. Determination of Sampling Point

Sampling points in this study were determined using the Land Unit Homogeneity (SLH) approach, which was derived by overlaying various thematic maps, such as the Land Use Map, Soil Type Map, Geology Map, and Slope Map. The analysis and delineation of land units were conducted using QGIS 3.10 software (Trigunasih *et al.*, 2023). Soil samples were collected randomly and compositely through soil boring. Each land unit was represented by one composite soil sample, collected at a depth of 0-30 cm for annual crops and 30-60 cm for perennial crops. Each soil sample weighed 1 kg for further laboratory analysis.

C. Soil Morphological Observation

During the soil sampling process, environmental conditions were observed and recorded using a soil observation form. Parameters observed included soil color, texture, structure, consistency, and drainage conditions. For more detailed analysis, ring samples were used for collecting intact soil samples to measure bulk density (BD) and soil porosity, which play a role in determining soil fertility and water retention capacity (Sukarman *et al*., 2017).

D. Interviews and Questionnaires

Along with the field survey, systematic interviews and questionnaires were conducted with local farmers using purposive sampling or judgmental sampling methods, which considered the experience and expertise of the respondents in the agricultural sector (Sekaran & Bougie, 2013). The collected data covered planting patterns, agricultural constraints, and land use systems in the study area.

E. Land Suitability Evaluation

The results from field surveys, climate data, and laboratory analyses were tabulated and evaluated using an agroecosystem land suitability assessment system based on the criteria outlined by Ritung *et al*. (2011). The classification method used follows the FAO (1976) system with a matching approach, which matches land characteristics with the growth requirements of the studied crops. Agricultural commodities evaluated in this study included food crops, horticultural crops, and industrial crops.

3.2 RESEARCH PROCEDURES

A. Literature Review

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

B. Land Unit Analysis

Land unit analysis aimed to determine land units as the basis for planning field observations. The homogeneous land units obtained were used as references for soil sampling and for preparing the land suitability map. The land unit analysis process comprised:

a. Interpretation of Digital Elevation Model (DEM) maps to analyze landform and slope gradient.
b. Satellite image analysis to verify actual land-use patterns, particularly in areas that had undergone land conversion such as paddy fields, settlements, and other infrastructure.
c. Use of supporting data in the form of slope maps, geology maps, and soil type maps to strengthen land-unit delineation.
d. Overlay of various thematic maps to produce homogeneous land units that served as the basis for soil sampling.

C. Field Survey

The field survey was conducted to verify the conformity of the homogeneous land units with actual field conditions. If discrepancies were found between the map analysis and field reality, adjustments were made through redelineation. Sampling points were determined based on the results of the land unit analysis and current field conditions.

In addition, interviews with local farmers were conducted to obtain supplementary information on agricultural practices and challenges in land management. Observations focused on environmental factors affecting agricultural productivity, such as soil drainage, effective depth, erosion risk, flood risk, and the presence of surface rock outcrops (Ritung *et al*., 2011).

Soil sampling was carried out using a boring method to a depth of 0-30 cm for annual crops and 30-60 cm for perennial crops. The collected soil samples were then analyzed further in the laboratory to identify soil physical and chemical properties that influence land fertility. Climate data, such as temperature, rainfall, and air humidity, were obtained from local climate observation stations and presented in tabulated form. The results of the land suitability evaluation and the characteristics of each land unit are presented in **Table 3.1.**

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

No	Parameter	Data Acquisition		Data Source
		Primary	Secondary	
1	Temperature		√	Remote Sensing/ Climatology of Timor-Leste
2	Rainfall		√	Remote Sensing/ Climatology of Timor-Leste
3	Dry Months		√	Remote Sensing/ Climatology of Timor-Leste
4	Humidity		√	Remote Sensing/ Climatology of Timor-Leste
5	Drainage	√		Field Survey
6	Soil Texture	√		Laboratory Results
7	Coarse fragments	√		Field Survey
8	Effective Soil Depth	√		Field Survey
9	Cation exchange capacity (CEC)	√		Laboratory Results
10	Base saturation (BS)	√		Laboratory Results
11	Soil pH	√		Laboratory Results
12	Soil organic Carbon (SOC)	√		Laboratory Results
13	Total Nitrogen	√		Laboratory Results
14	P_2O_5	√		Laboratory Results
15	K_2O	√		Laboratory Results
16	Salinity	√		Laboratory Results
17	Alkalinity	√		Laboratory Results
18	Slope gradient	√		Field Survey
19	Erosion hazard	√		Field Survey
20	Flood hazard	√		Field Survey
21	Surface rock cover	√		Field Survey
22	Rock outcrops	√		Field Survey

D. Soil Laboratory Analysis

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

a. Organic carbon (C-organic) using the Walkley and Black method (%).
b. Total nitrogen (N-total) using the Kjeldahl method (%).
c. Soil texture using the pipette method.
d. Soil pH using a potentiometer (H2O 1:2.5).
e. Available phosphorus (P-available, ppm) and potassium (K-available, ppm) using the Bray-1 method if soil pH is below 7, and the Olsen method if pH is above 7, with unit conversion (mg/100 g).

f. Total phosphorus (P-total) and potassium (K-total) using 25% HCl method.
g. Soil salinity (dS/m) using a potentiometer (H_2O 1:2.5).
h. Cation exchange capacity (CEC, cmol) and base saturation (KB, %) using NH4OAc 1N (pH 7).
i. Determination of soil fertility status based on the method from PPT (1995).
j. Erosion risk using the Universal Soil Loss Equation (USLE).

E. Land Suitability Analysis

The results of the field observations and laboratory analyses were tabulated as data on the characteristics/quality of the agroecosystem land. Land suitability analysis was carried out by matching the characteristics/quality data of the land with the growth requirements of bamboo, teak, mahogany, pine, coffee, cocoa, and coconut. This allowed the determination of land suitability classes based on the criteria outlined by Ritung *et al*. (2011). Land suitability classification was analyzed at the land unit level.

The land suitability class was divided into actual and potential suitability. Actual land suitability for each homogeneous land unit was determined by matching the land characteristics/quality with the growth requirements of crops without improvements to limiting factors. Potential land suitability was determined by considering inputs and management actions for each homogeneous land unit, assuming improvements are made to address limiting factors.

F. Agricultural Commodity Development Planning

Commodity planning was based on the evaluation of potential land suitability for the development of agricultural commodities. This was done by determining the highest land suitability class for each crop as the main parameter. Other parameters included the primary land use of each homogeneous land unit and the feasibility of agricultural enterprises.

G. Land Use Guidelines

Land use guidelines were developed at the land unit level, based on the results of the highest land suitability assessment followed by lower suitability classes, addressing limiting factors, and management improvement actions for each homogeneous land unit across the 7 Sub-Districts of Covalima District. The creation of digital maps using GIS greatly facilitated the interpretation of information. The information provided included agroecosystem land suitability, land use guidelines, and zoning for agricultural commodities.

Land suitability classification results were mapped for each group of evaluated crops. Land suitability for the crops was presented in a map of agricultural commodity zoning, while land use planning was presented in a map of land use guidelines. A systematic flowchart of the research process is 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). The integration of these two components results in a comprehensive information system using the QGIS 3.10 application. The information provided includes land suitability classes for food crops, horticultural crops, industrial crops, spices and medicinal plants, livestock feed, and grazing based on their suitability. The land suitability maps, along with the database and land resource information, are based on suitability criteria aligned with its development, such as varieties, cultivation technologies, and land management practices.

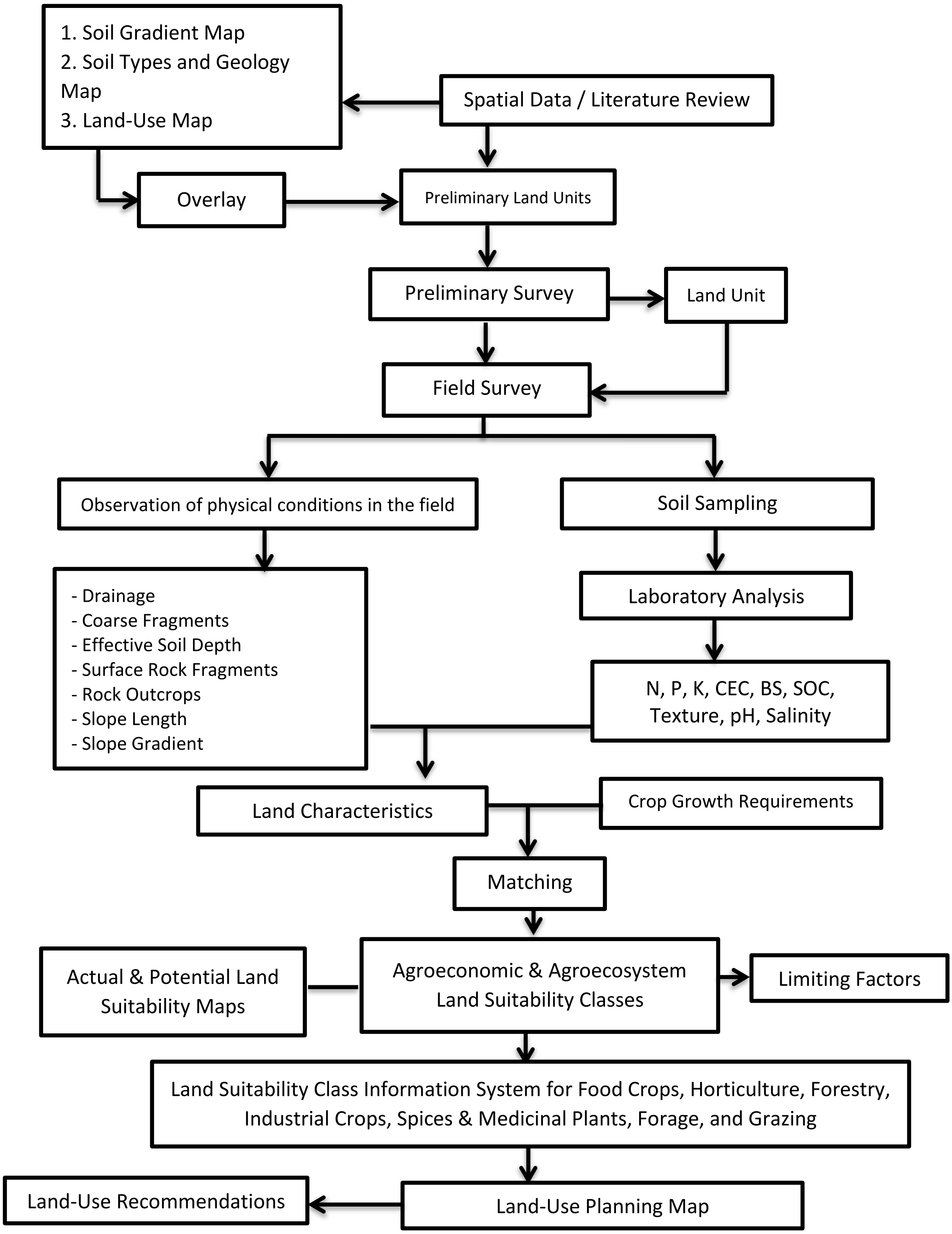


Figure 3.1 Research Process Flow Chart

The land use planning map is derived from land suitability classification and commodity zoning. The land use planning map is a thematic digital map that provides guidance for land use across various crop commodities, including food crops, horticultural crops, industrial crops, spices and medicinal plants, livestock feed, and grazing. The digital map is the result of converting primary and secondary data and information from raster and analog forms into digital data. The advantage of digital maps includes the ease of editing errors, easy duplication, long-term storage, and the ability to measure distances and areas on the screen, without requiring field measurements that would otherwise be time-consuming and costly (Nugroho and Yarianto SBS, 2010). The resulting maps are available in both digital and analog forms, or hard copies in *.jpeg format, which can be printed, and digital maps in *.dbf or *.shp formats, which are integrated, easily copied, and informative. The map's edge information includes the map's name, followed by the map creator’s name, scale, and legend (including homogeneous land unit, study area, soil type, slope, and land use), source, coordinate positions (latitude and longitude), and the datum system used.

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 is a system that can:

1. Collect, store, and retrieve information based on spatial location.
2. Identify locations within a specific area that meet established criteria.
3. Explore relationships between different data sets in a specific area.
4. Facilitate the selection and distribution of data for specific analytical models that can predict the impacts of alternatives on the conditions of a given area.
5. Present a specific area graphically and numerically both before and after analysis (Murai, 2006).

From various definitions of GIS, several key terms emerge, such as: geographically referenced data, spatial and attribute data analysis to generate 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 geographic perspective. This is particularly relevant in development planning, as planning occurs within a specific regional (spatial) context.

The term "Geographic" is part of the spatial (spatial) domain. These two terms are often used interchangeably, leading to the emergence of the third term, "geospatial." All three terms have the same meaning within the context of GIS. The use of the term "Geographic" refers to issues related to the Earth's surface, either two or three-dimensional (Prahasta, 2005).

The term "geographic information" refers to information about places located on the Earth's surface, knowledge of the position of an object on the Earth's surface, and information about the attributes of objects found on the Earth's surface whose positions are provided 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 is also a type of software that can be used for input, storage, manipulation, display, and output of geographic information along with its attributes (Prahasta, 2005). **Figure 3.2** shows the components that make up GIS.

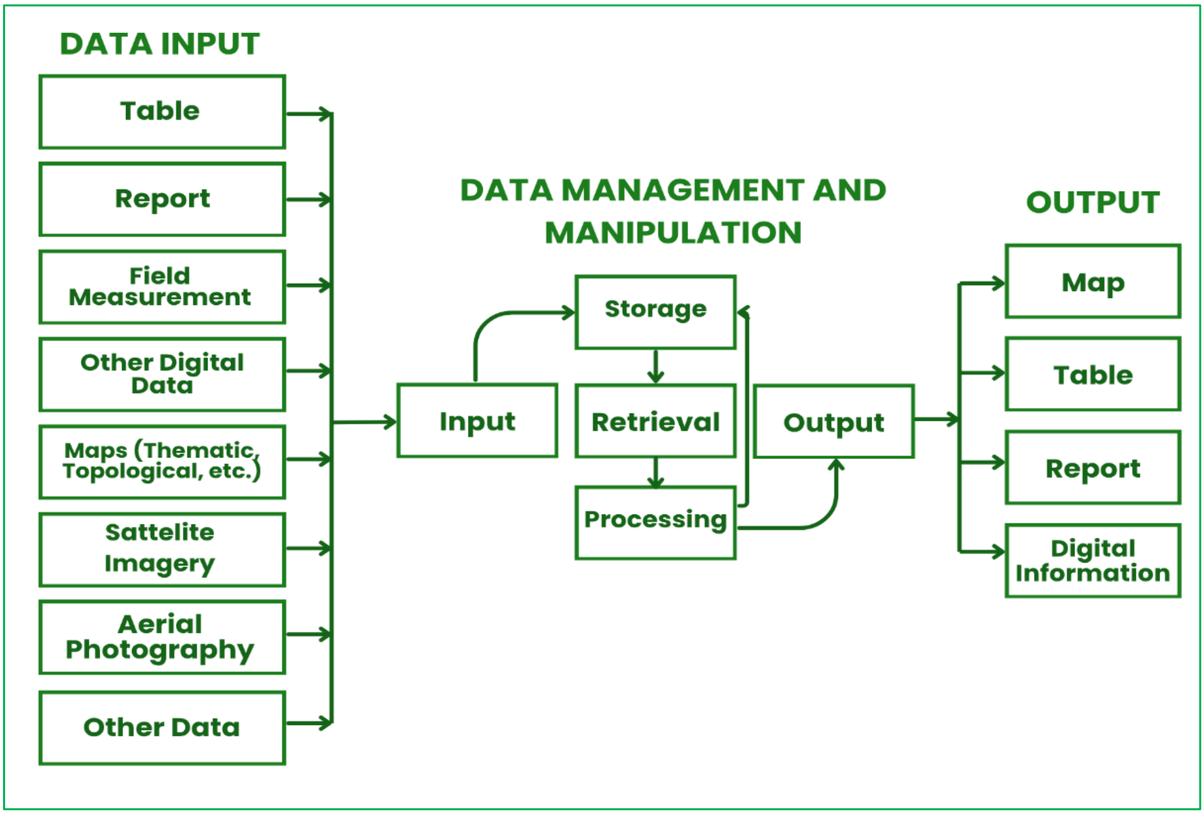


Figure 3.2 Components of SIG
(Source: Prahasta, 2005)

Geographic Information Systems (GIS) can be applied in various fields. Some of the capabilities of this system are as follows (Prahasta, 2005):

1. **Cartographic Capabilities**

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

2. **Data Management Capabilities**

   GIS has the ability to store, process, and manipulate geographically referenced data. This data management capability also includes processing attribute data, which involves storing and displaying specific attribute data associated with certain geographical maps.

3. **Analysis Capabilities**

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

4. **GIS and Multimedia Integration**

   The ability to integrate GIS and multimedia is a result of creativity from the local people of Bali. Through the integration of multimedia systems with GIS, the final output of GIS analysis becomes more attractive and easier to read and understand.

A. GIS Processes and Components

SIG essentially performs six processes (Prahasta, 2005):

1. **Data Input**

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

2. **Data Transformation**

   The data types used in GIS may need to be transformed or manipulated in certain ways to conform to the system. For example, differences in scale may require data to be transformed into the same scale before integration.

This transformation can be temporary for display purposes or permanent for analysis processes.

3. **Editing**

   The editing stage involves correcting digital data. This correction can include adding or removing arcs or features, such as editing excess (overshoot) or missing (undershoot) arcs. Editing is also performed to manually add arcs, such as creating polygons, lines, or points.

4. **Data Management**

   After spatial data is inputted, the next process involves handling descriptive data. This includes annotation (adding text to coverage), labeling (adding information to maps), and attributing, which involves attaching additional attributes to label IDs to provide more information about the polygons or arcs they represent.

5. **Query and Analysis**

   Queries in GIS are essentially analytical processes but conducted through tabular processes. Fundamentally, GIS analysis uses spatial analysis. GIS offers many advantages in spatial analysis, but two critical aspects are:

   a) Proximity Analysis

      This type of analysis is based on the distance between layers. Questions such as how many houses are in a watershed can be analyzed. In proximity analysis, GIS uses a process called buffering (creating a supporting layer around a given layer within a specific distance) to determine how close the relationships are between parts of a layer.

   b) Overlay Analysis

      The process of integrating data from different layers is called overlay. This is essentially a visual operation, but it requires combining more than one layer physically. An example of overlay analysis would be integrating data on soil, slope, and vegetation, or land ownership with land tax assessments.

6. **Visualization**

   For some types of geographic operations, the best final result is presented in maps or graphs. Maps are highly effective for storing and providing geographic information.

B. GIS Components

In general, GIS operates through the integration of five components: hardware, software, data, people, and methods, which are explained as follows (Budianto, 2010):

1. Hardware

The hardware is the computer on which GIS operates. Currently, GIS can work 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 that support queries, analysis, and geographic visualization.
d. A graphical user interface (GUI) for accessing tools.

3. Data

Data is a crucial component of GIS. 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 along with their attributes. The raster data model represents, places, and stores spatial data using a matrix or pixels that form a grid. Each pixel or cell has its own attribute, including its unique coordinates (at the grid corner, center, or elsewhere). The accuracy of these data models depends on the resolution or pixel size on the Earth's surface.

4. Human

GIS technology would not be effective without people who manage the system and build applicable plans in real-world conditions. Similar to other information systems, GIS users range from technical specialists who design and maintain the system to end-users who use GIS to assist with their daily tasks.

5. Methods

A good GIS system is one that aligns a well-designed plan with real-world rules. Methods and implementations will vary for each specific issue.

C. Data Processing in GIS

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

1. **Basic Map Digitization**

   Map digitization is done on the 1:25,000 scale Rupabumi Indonesia map, which will later be used as the basis for the survey and map digitization process, including data updating. This data conversion is done layer by layer and includes topology.

2. **Data Import**

   Data import is done on satellite imagery that has a different format than the software used for processing. Data format conversion is an essential initial step in image processing tasks.

3. **Geometric Correction of Imagery**

   Geometric correction of images is required so that satellite imagery has map reference coordinates. This geometric correction can be done using three methods: image-to-image (previously corrected images), image-to-ground (where map coordinates are measured directly in the field using GPS), and image-to-map.

4. **Digital Image Processing**

   Satellite images are digitally processed to enhance the standard spatial resolution of 25 m on multispectral channels to 15 m color resolution. This process uses image data fusion techniques, such as the Brovey Transform, for visual interpretation of planimetric objects like transportation networks and rivers.

5. **Satellite Image Classification**

   The classification process involves digital classification and a knowledge-based approach to extract spatial information about land use. This classification is done using supervised classification and filtering methods. The digital classification model, with more accurate clustering than human eyes, is supplemented with visual interpretation from the Brovey Transform data.

6. **Spatial Information Updating**

   Spatial information update will be conducted using raster-vector overlay methods complemented with a light table effect to interpret and analyze land use spatial information.

7. **Field Survey**

Field surveys are carried out to correct errors in image interpretation, gather spatial information on questionable objects from the imagery, and plot the positions of significant objects that cannot be directly extracted from the images.

8. **Re-interpretation and Editing**

This process is performed to correct inaccurate image interpretations based on fieldwork findings, and will be carried out digitally in the laboratory for final, updated spatial information.

9. **Edge Matching**

Edge matching ensures the alignment of map sheets, and this process is done digitally for all adjacent layers.

10. **Digital Cartography and Map Production**

Cartography will be fully digital to achieve standardized map layouts based on cartographic principles, referring to thematic maps issued by the Geospatial Information Agency.

11. **Database Development and Modeling**

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

IV. LAND CHARACTERISTIC

4.1 TEMPERATURE

Air temperature is one of the main factors in land suitability evaluation because it strongly influences the sustainability of natural resource management and the potential for regional development. In this study, temperature distribution was analyzed by integrating field measurements with geospatial data from the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) using the Braak formula approach. This analysis provided a comprehensive depiction of temperature variability that reflects the complexity of topography, elevation, and microclimates in Timor-Leste.

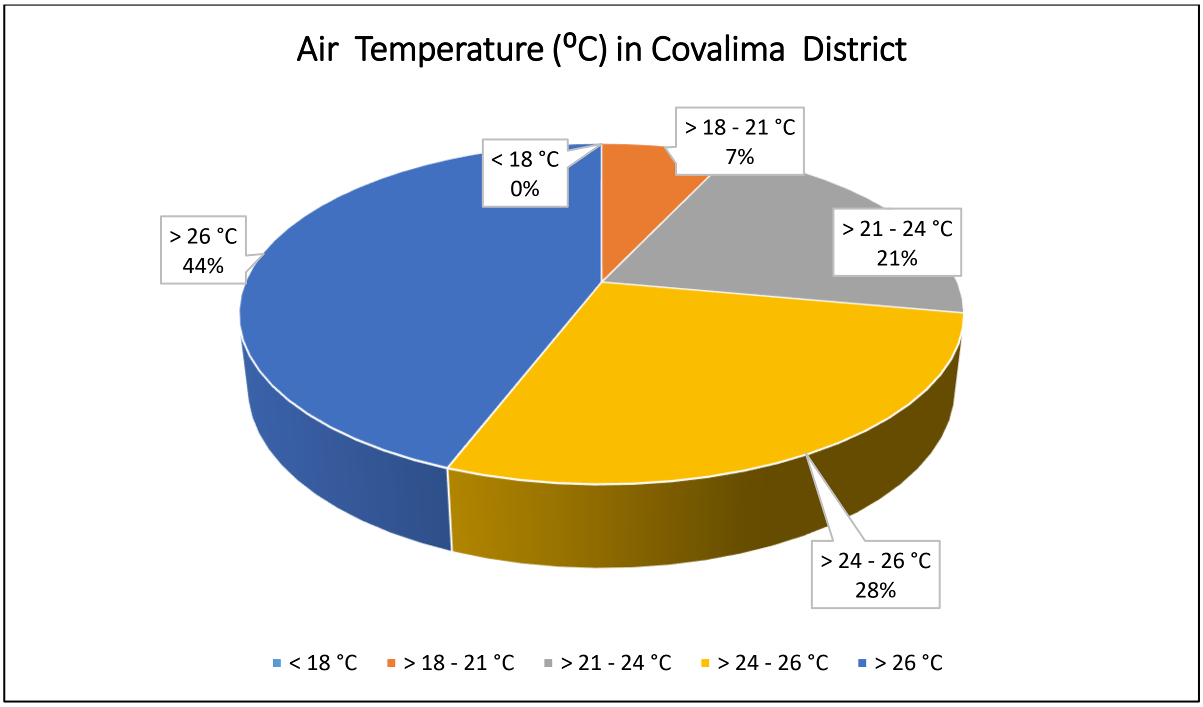


Figure 4.1 Temperature Data (°C) in Covalima District

The results of the air temperature analysis in Covalima District showed that the area was dominated by warm to hot conditions, with a varied temperature distribution **(Figure 4.1)**. Temperatures below 18 °C were not found (0%), indicating that the area did not experience very low temperatures. Temperatures of 18 to 21 °C accounted for only 7% of the total data, indicating that cool conditions occurred in a small portion of the area. Meanwhile, temperatures in the range of 21 to 24 °C comprised 21%, reflecting moderately common conditions. Temperatures of 24 to 26 °C accounted for 28 %, indicating that warm temperatures were fairly dominant. The highest temperature category, above 26 °C, was the most prevalent at 44 %, showing that most of the area experienced hot conditions.

This temperature distribution has implications for the agricultural sector, particularly in selecting crop types and land management strategies. Temperatures predominantly above 24 °C are advantageous for tropical crops such as rice (*Oryza sativa* L.), corn (*Zea mays* L.), and soybean (*Glycine max* L.) that can grow optimally under warm conditions. However, high temperatures can also increase evaporation and plant transpiration rates, which may raise irrigation requirements and necessitate more efficient water management strategies. Therefore, adaptation in farming systems is required, including the use of heat-tolerant crop varieties and the application of water conservation techniques to enhance agricultural productivity sustainably.

4.2 RAINFALL

Rainfall is an essential element in land suitability evaluation, particularly for determining an area's potential to support agricultural productivity, soil conservation, and water resource management. This analysis covered rainfall distribution by category totals and ranges per District, integrating field observations with geospatial data from the CHIRPS satellite dataset.

Based on field observations, Fatululic Sub-District had rainfall >2,000 mm/yr across its entire area. Fatumean Sub-District was dominated by rainfall of 1,500 to 2,000 mm/yr. Forohem Sub-District had rainfall >2,000 mm/yr across only 67% of its area, while 33% received 1,500 to 2,000 mm/yr. In Suai Sub-District, 64% of the area received 1,500 to 2,000 mm/yr, 27% received 1,000 to 1,500 mm/yr, and 9% received >2,000 mm/yr. Tilomar Sub-District had 1,500 to 2,000 mm/yr across most of its area (57%), with 1,000 to 1,500 mm/yr across 43%. In Zumalai Sub-District, 47% of the area received >2,000 mm/yr, 41% received 1,500 to 2,000 mm/yr, and 12% received 1,000 to 1,500 mm/yr. Maucatar Sub-District had 1,500 to 2,000 mm/yr across its entire area. Differences in rainfall characteristics among areas lead to differences in water availability; each area therefore needs to optimize its resources to adequately support improved agricultural development. A complete presentation of the rainfall distribution is shown in **Figure 4.2.**

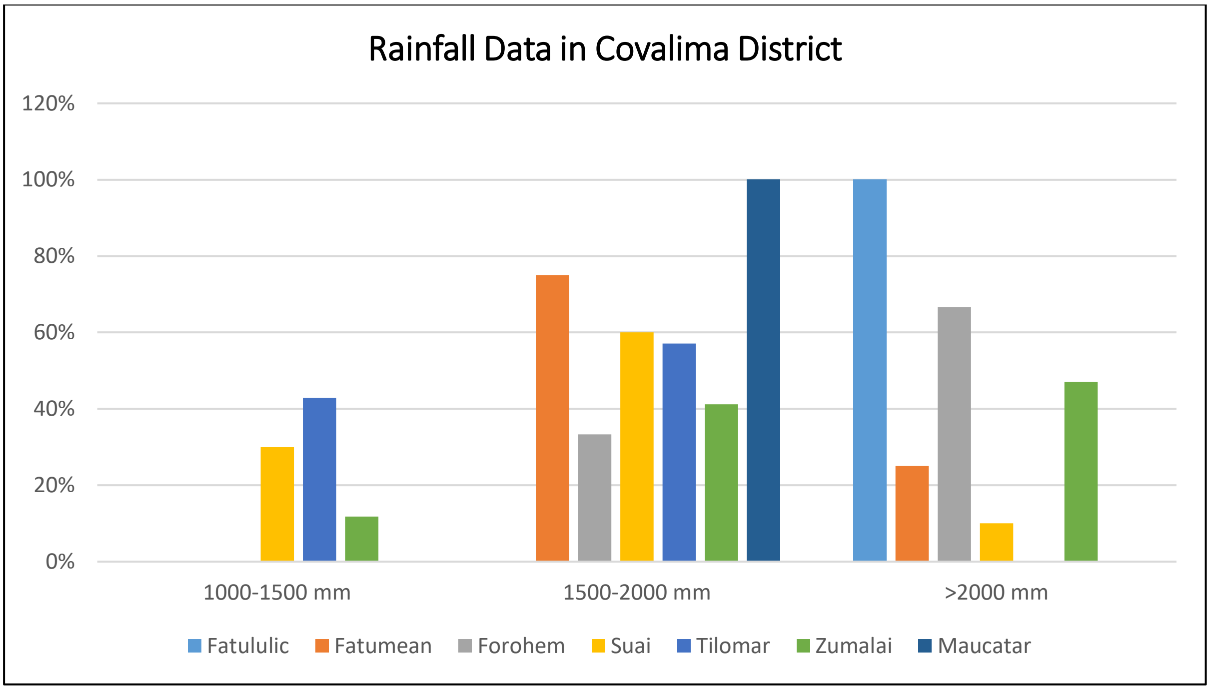


Figure 4.2 Rainfall Data in Covalima District

Figure 4.3 Irrigated Field Rice in Covalima District
(Source: Researcher Documentation, 2024)

4.3 DRY MONTHS

The analysis of the distribution of the duration of dry months in the study area provided an in-depth depiction of microclimatic conditions that influence land potential in Covalima District. Land characteristics based on dry months also varied among areas. Fatululic Sub-District had 5 to 6 dry months across its entire area. Forohem Sub-District had 5 to 6 dry months across most of its area (67%), while 33% had 3 to 4 dry months. Fatumean Sub-District had 4 to 5 dry months across nearly all of its area (75%). Suai Sub-District had 5 to 6 dry months in part of its area and >6 dry months across 45% of its area. Tilomar Sub-District was dominated by 5 to 6 and >6 dry months, with 0 to 1 dry month in some areas. Zumalai Sub-District exhibited variation: 35 % of its area had 5 to 6 dry months, 24% had 4 to 5, 6% had 3 to 4, 12% had 2 to 3, and 24% had >6 dry months. Maucatar Sub-District had 5 to 6 dry months across 100% of its area **(Figure 4.4).**

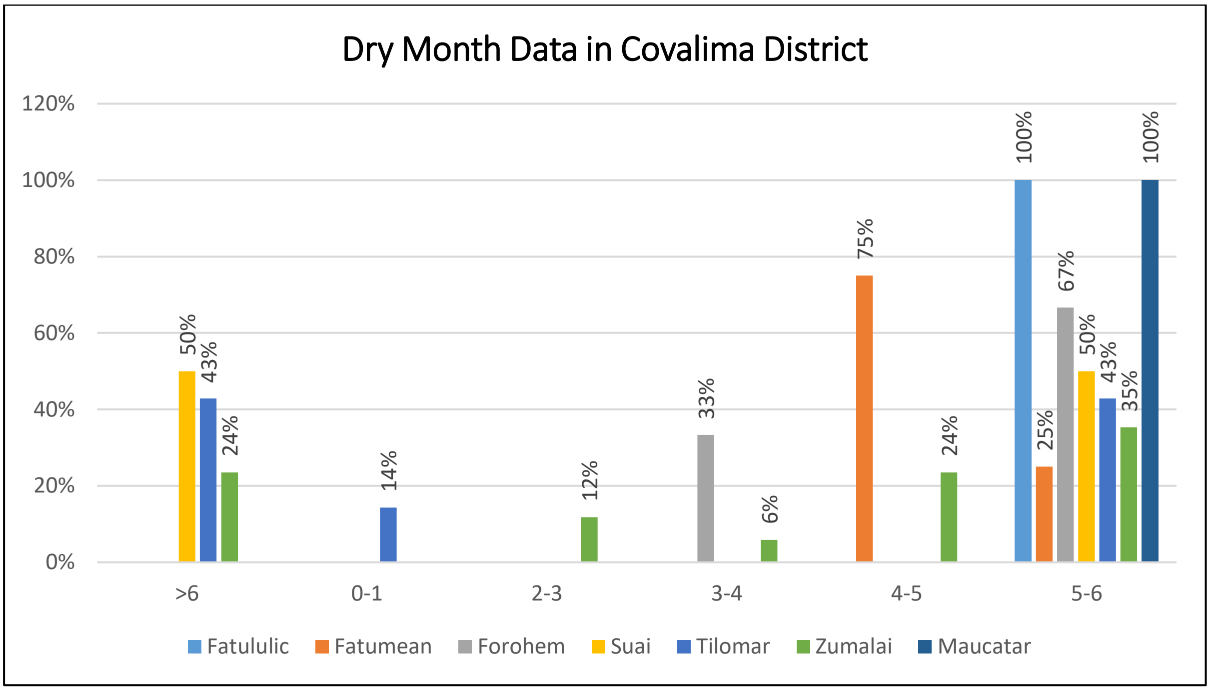


Figure 4.4 Chart of Dry Month in Covalima District

Figure 4.5 Drought Occuring in Paddy Fields (Top) and in Dry Land Agriculture (Bottom)
(Source: Researcher Documentation, 2024)

4.4 DRAINAGE

Land characteristics based on drainage varied among areas. Fatululic, Fatumean, and Forohem Sub-Districts had well drained conditions across their entire areas. In Atsabe Sub-District, 73% of the area was well drained, 29% was poorly drained, and 9% was somewhat poorly drained. Tilomar Sub-District had

71% well drained and 29% poorly drained. Zumalai Sub-District was mostly well drained (82%), with 12% somewhat poorly drained and 6% poorly drained. Maucatar Sub-District had 100 % well drained conditions **(Figure 4.6).** The most dominant drainage class in Covalima District was well drained; this condition influences oxygen availability in the soil and water movement to meet crop water requirements.

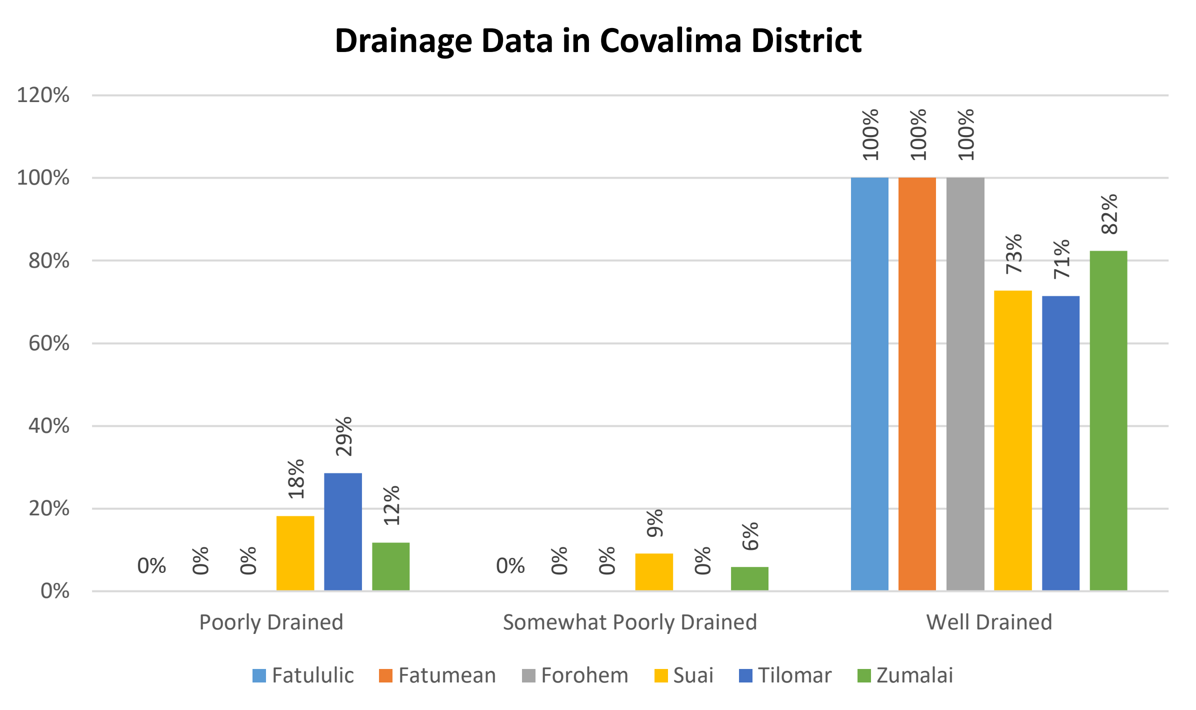


Figure 4.6 Drainage Data in Covalima District

4.5 SOIL TEXTURE

Soil texture classes also varied among areas of Covalima District. Fatululic Sub-District had fine textures across its entire area, while Fatumean Sub-District had fine textures across almost all of its area. Forohem Sub-District had moderately fine textures over 67% of its area, with the remaining 33% fine textured. Suai Sub-District was predominantly fine textured; in addition, 18% of the area was reported as fine, and medium and coarse textures each accounted for 9% of the area. Suai Sub-District largely had fine and moderately fine textures, with some areas of medium texture. Zumalai Sub-District had varied textures: 41% moderately fine, 24% fine, 18% medium, 12% moderately coarse, and 6% coarse. Maucatar Sub-District had fine textures across its entire area **(Figure 4.7).**

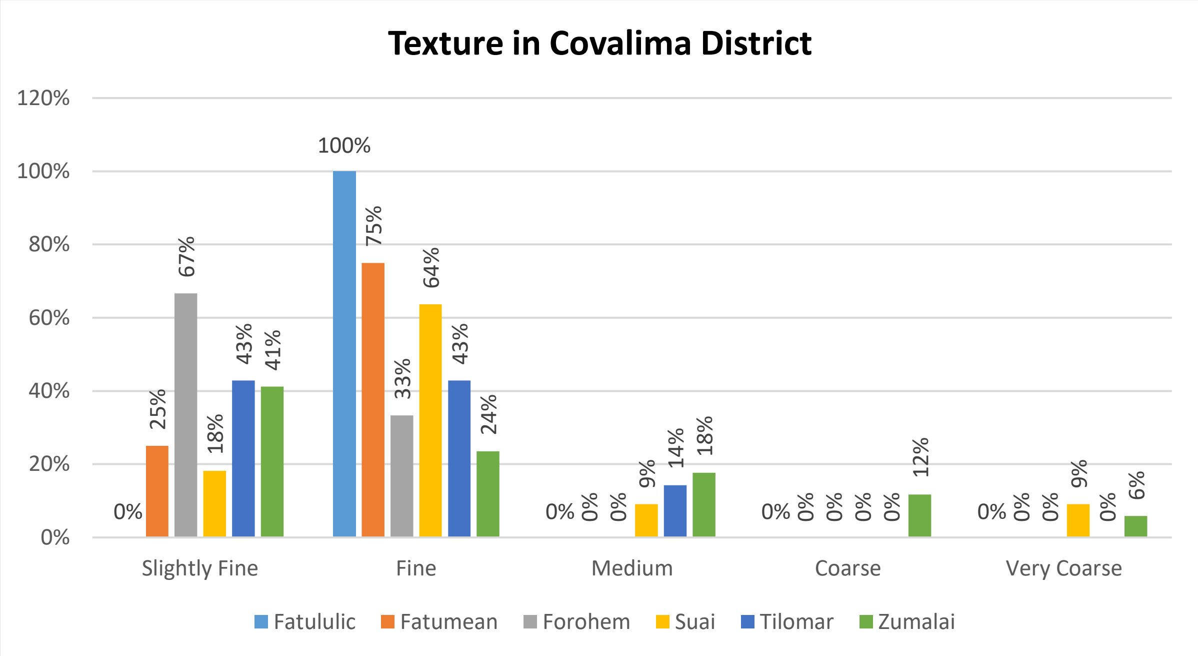


Figure 4.7 Soil Texture in Covalima District

The relationship between soil texture, geology, and soil types in each District reflects the diversity of physical soil conditions that influence land management strategies. Different lithologies, such as Sedimentary, Metamorphic rocks, and Alluvial deposits, form unique soil characteristics, which are reflected in variations in soil texture and dominant soil suborders. A data-driven approach, combining geological data, soil types, and texture, provides a scientific basis for designing sustainable land management practices, supporting location-specific agricultural potential, and reducing the risk of soil degradation. This approach is essential for optimizing land use in the study area and ensuring the sustainability of agricultural ecosystems.

4.6 COARSE FRAGMENTS

The analysis of coarse fragment percentages in Covalima District showed that most of the area had low coarse fragment content **(Figure 4.8).** Approximately 60% of the area had less than 5% coarse fragments, indicating that most of the soil in this area has relatively fine textures and is suitable for agriculture with good fertility levels. The 5-10% category accounted for 9%, while the 10-15% category was only 2%, indicating that a small portion of the area has slightly coarser soil.

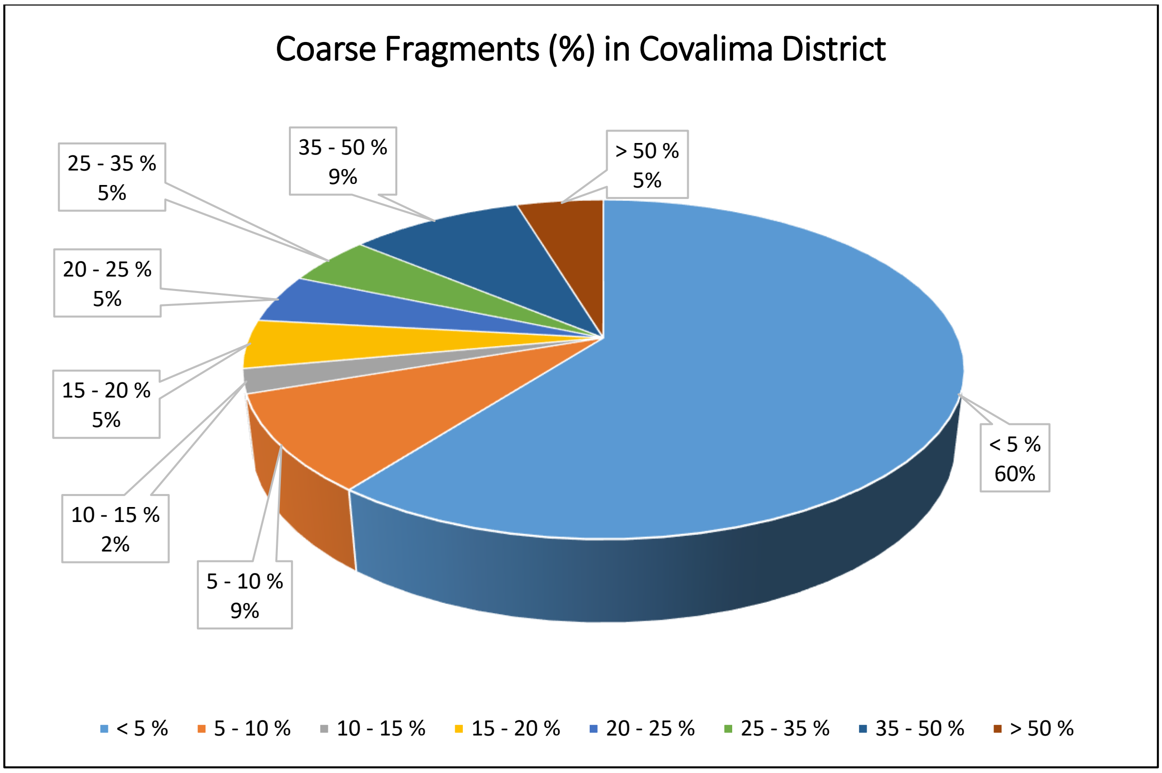


Figure 4.8 Data Coarse Fragments (%) in Covalima District

The 15-20 % and 20-25 % categories each accounted for 5%, indicating that there are small areas with moderate coarse fragment content. The 25-35% category also accounted for 5%, while areas with coarse fragments higher than 35% covered 9%. Only 5% of the area had more than 50% coarse fragments, indicating that only a small portion of the land has very coarse structure, which may not be suitable for intensive agriculture without proper management.

This distribution of coarse fragments has implications for the agricultural sector in Covalima District. Areas with low coarse fragment content (<5%) tend to have better water and nutrient retention, making them more suitable for food crop farming, such as rice and vegetables. However, areas with higher coarse fragment content (>25%) may have faster drainage rates, leading to drought during the dry season and requiring efficient irrigation systems. Therefore, proper land management strategies are needed to enhance agricultural productivity in these areas.

4.7 SURFACE ROCKS

The presence of surface rocks is a critical parameter in determining land potential and the challenges in land management. Surface rocks can affect land suitability for agriculture, as high surface rock content can hinder soil cultivation and reduce effective soil fertility.

The surface rock content analysis in Covalima District showed that most of the area had low surface rock content **(Figure 4.9).** About 49% of the area had surface rock content between 0-5 %, indicating that most of the soil in this region is relatively free of surface rocks and is easier to work with for agricultural activities. The 5-10 % and 10-20 % categories each accounted for 16%, suggesting that approximately 32% of the area has moderate surface rock content, which may affect soil fertility and ease of land preparation.

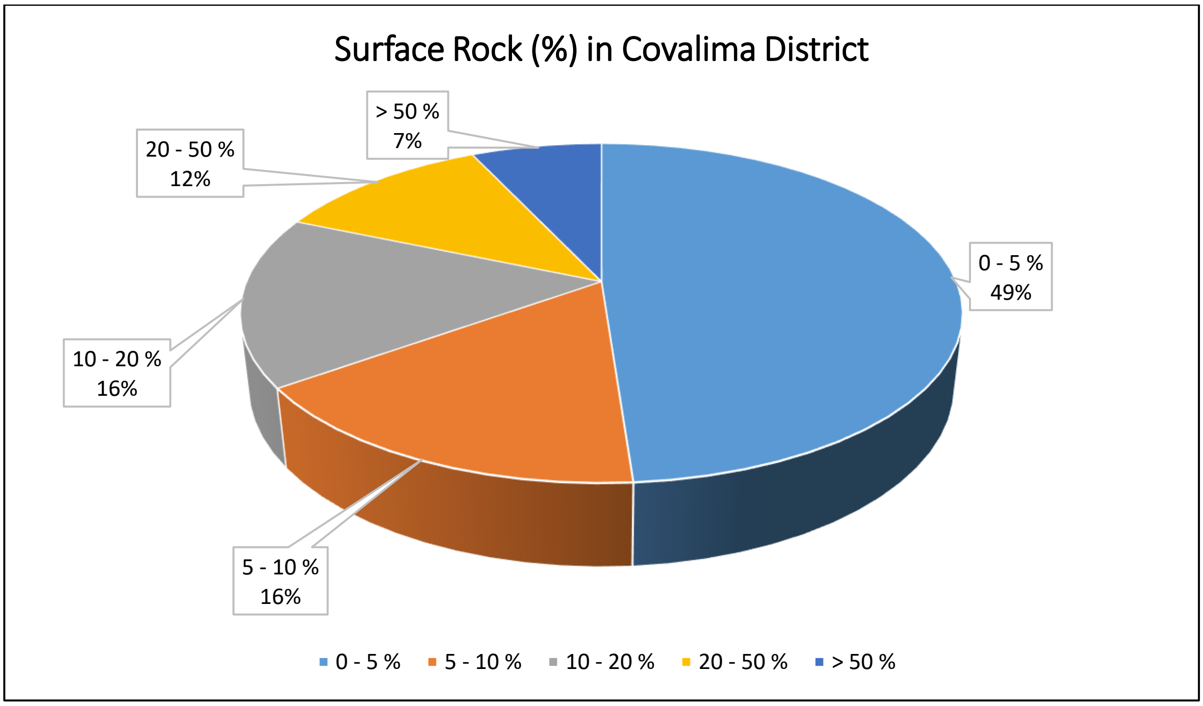


Figure 4.9 Data Surface Rocks (%) in Covalima District

The 20-50% category covered 12%, indicating that some areas had relatively high surface rock, which could influence soil drainage and the availability of productive agricultural land. Areas with more than 50% surface rocks accounted for 7% of the region, suggesting that these areas may face limitations in conventional farming activities and may be better suited for other uses such as conservation or forestry. This distribution of surface rocks impacts land suitability for agriculture in Covalima District. Areas with low surface rock content (< 5%) are more ideal for intensive agriculture, while regions with higher surface rock content (>20%) may require special land management techniques, such as the use of heavy equipment for soil preparation or the adoption of more adaptive farming systems, such as agroforestry or dryland farming. Therefore, appropriate land management strategies are essential to optimize land use for agriculture in this area.

4.8 ROCK OUTCROPS

Rock outcrops are an important indicator in assessing geological conditions and land suitability. The presence of rock outcrops can affect soil physical properties, water retention capacity, and erosion rates. The analysis of rock outcrop percentages in Covalima District showed that most of the area has low rock outcrop levels **(Figure 4.10)**. Approximately 56% of the area had rock outcrops in the range of 0-5 %, indicating that most of the area has relatively clear soil surfaces, making it more suitable for agriculture and other development activities. The 5-10 % category accounted for 16%, suggesting that a small portion of the area has scattered rocks, but still in manageable quantities.

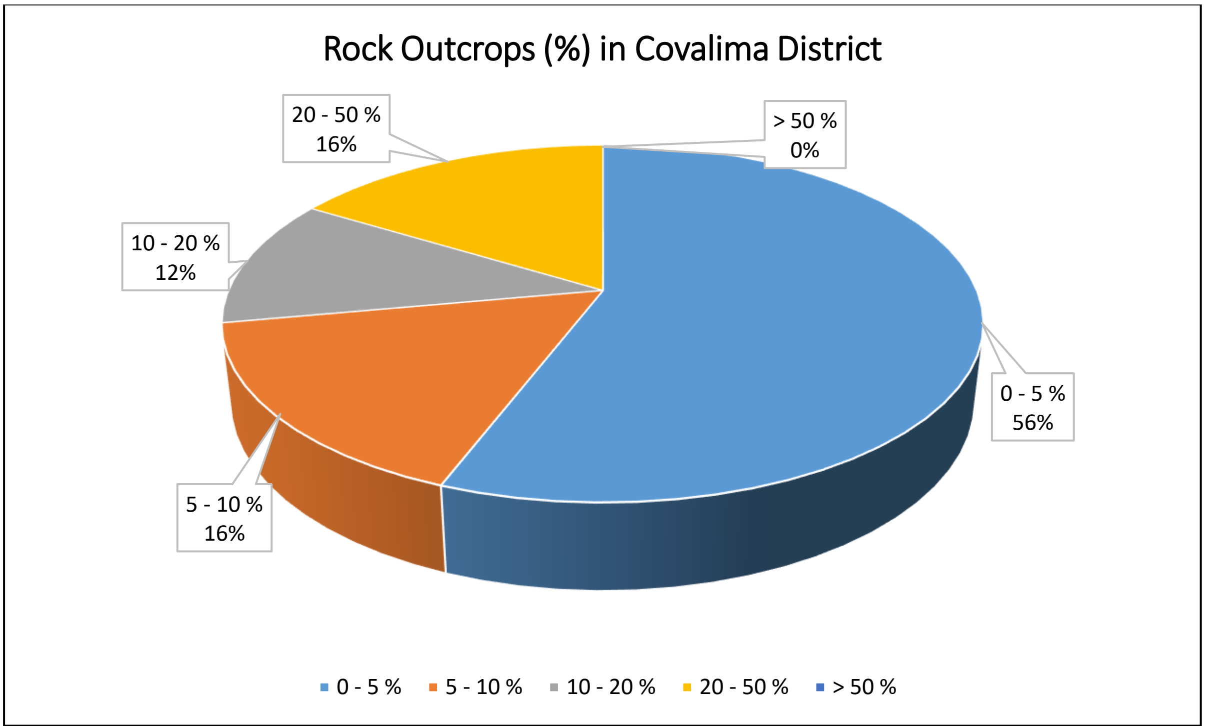


Figure 4.10 Data Rock Outcrops (%) in Covalima District

The 10-20% category covered 12%, indicating that some areas had significant rock outcrops that could limit land use for intensive agriculture. The 20-50% category also accounted for 16%, showing that there are areas with relatively dominant rock outcrops, which may be more suitable for conservation, forestry, or other uses that do not require large amounts of land. No areas were found with rock outcrops exceeding 50% (0%), indicating that no area was completely dominated by rock rocks. This distribution of rock outcrops has implications for land use in Covalima District. Areas with low rock outcrops (< 5 %) are highly suitable for agriculture and settlement, while areas with higher rock outcrop percentages (>20%) require more specialized land management strategies, such as soil conservation techniques, terracing-based cultivation, or utilization for forestry and ecotourism. Therefore, proper mapping and land management are essential to optimize sustainable land use in this area.

V. SOIL FERTILITY STATUS

Soil fertility is the ability of soil to provide nutrients in the appropriate amount and balance, within an environment that supports plant growth (Yuwono, 2007). The goal of soil fertility is to ensure high plant productivity, including fruits, seeds, leaves, flowers, tubers, and others. Soil fertility varies depending on soil-forming factors such as parent material, relief, organisms, and time dominating the location. The soil is the primary focus in soil fertility, while plants serve as the main indicator of soil fertility quality (Yuwono, 2007).

Evaluating soil fertility status is essential to determine the type and amount of nutrients needed. This evaluation involves diagnosing nutrient problems within the soil and making fertilization recommendations. The diversity in soil chemical characteristics supports plant life as agricultural commodities, alongside the availability of nutrients in the soil. This is why soil is classified as either fertile or not (Utomo *et al.*, 2016). Evaluating soil fertility status is crucial for assessing and monitoring soil fertility, identifying nutrients that may be limiting plant growth. Soil fertility status is determined by assessing soil characteristics and identifying key fertility constraints, following the criteria set by the Soil Research Center (PPT, 1995).

Soil fertility status in Covalima District was evaluated using several parameters, including Cation Exchange Capacity (CEC), Base Saturation (BS), organic carbon, P_2O_5, and K_2O. The results of the soil fertility evaluation in Covalima District revealed three categories: low fertility (red), moderate fertility (yellow), and high fertility (green), as shown in **Figure 5.1**.

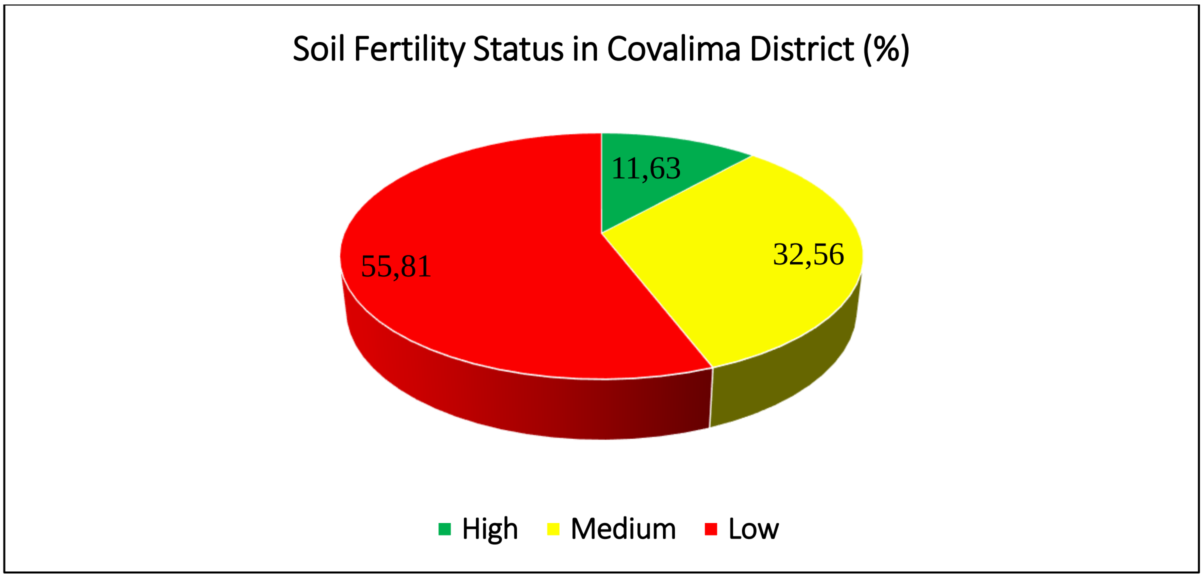
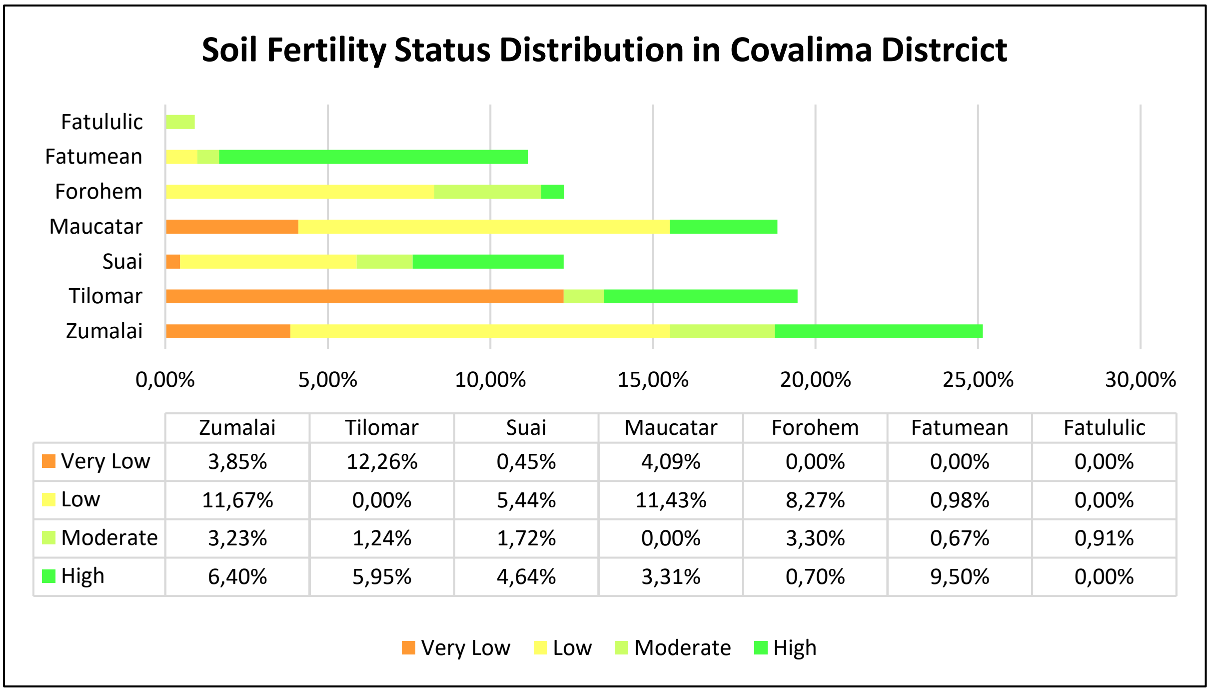


Figure 5.1 Soil Fertility Status in Covalima District

Based on the analysis of soil fertility status in Covalima District, it was found that the majority of the area (55.81%) had low fertility, while 32.56% of the area had moderate fertility, and only 11.63% had high fertility. This indicates that most of Covalima District requires more attention to improve soil quality in order to support optimal agricultural productivity. Efforts such as the implementation of soil conservation techniques, the use of organic fertilizers, and sustainable farming systems can be solutions to enhance soil fertility in this area.



	Zumalai	Tilomar	Suai	Maucatar	Forohem	Fatumean	Fatululic
Very Low	3,85%	12,26%	0,45%	4,09%	0,00%	0,00%	0,00%
Low	11,67%	0,00%	5,44%	11,43%	8,27%	0,98%	0,00%
Moderate	3,23%	1,24%	1,72%	0,00%	3,30%	0,67%	0,91%
High	6,40%	5,95%	4,64%	3,31%	0,70%	9,50%	0,00%

Figure 5.2 Soil Fertility Status Disribution in Covalima District

Based on the soil fertility status distribution data in Covalima District, it is evident that most of the sub-districts (Postu) have more land with low fertility compared to moderate or high fertility levels. Zumalai Sub-District stands out with relatively high fertility, with a dominant high fertility category of 6.40 % and low fertility at 11.67%. Tilomar Sub-District, however, has predominantly low fertility, with the highest percentage in the very low fertility category (12.26%), and high fertility is only 5.95%. Suai Sub-District has 5.44% low fertility and 4.64% high fertility, while Maucatar has 11.43% low fertility and 3.31% high fertility. In Forohem, the land is mostly dominated by low fertility status (8.27%) and moderate fertility (3.30%), with high fertility covering only 0.70%. Fatumean has a high fertility percentage of 9.50%, while Fatululic shows relatively small values, possibly due to limited data or a smaller land area. Overall, Zumalai and Fatumean stand out with higher soil fertility, while Tilomar tends to have lower fertility, reflecting the variation in biophysical conditions and the potential for land management in Covalima District.

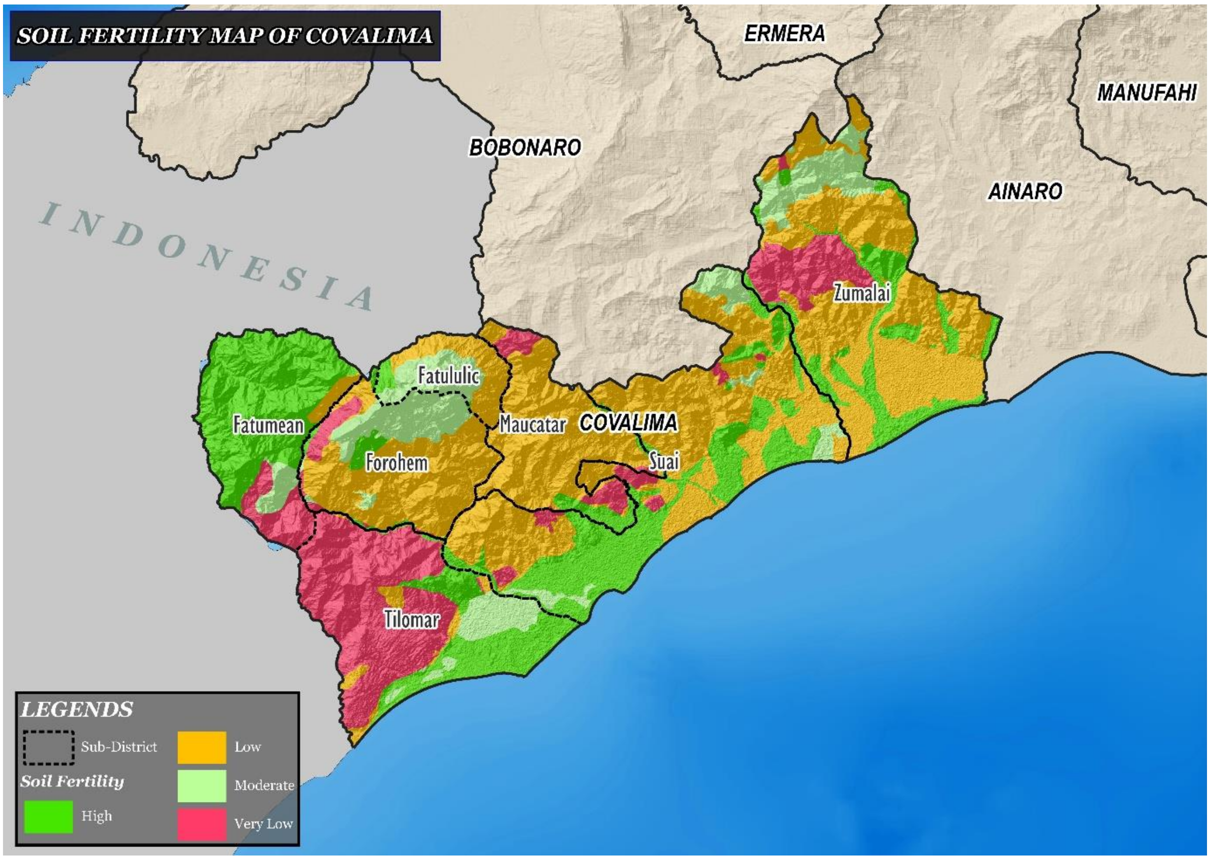


Figure 5.3 Soil Fertility Status Map in Covalima District

Based on the Soil Fertility Status Map of Covalima District, Timor-Leste, it is clear that most of the area has low soil fertility, particularly in Forohem, Suai, Tilomar, Maucatar, and Zumalai Sub-district, which are dominated by the red zone. This indicates that the land in these regions requires more attention in terms of management and soil fertility restoration to improve agricultural productivity. Meanwhile, areas with moderate soil fertility are scattered in parts of Fatumean, Fatululic, and a small portion of Tilomar, showing potential for better agricultural outcomes if managed with appropriate agricultural methods. High fertility areas, marked in green, are predominantly found in Fatumean and parts of Fatululic, which can be utilized for sustainable agricultural production. Given these conditions, strategic efforts are required to improve soil quality in areas with low fertility, such as applying organic fertilization, improving irrigation management, and using sustainable farming techniques such as crop rotation and agroforestry. Additionally, areas with moderate to high soil fertility should be optimized to increase crop yields and support food security in Covalima District. Collaboration among the government, academia, and local farmers is also essential to create the right solutions for land management to ensure long-term productivity.

VI. EROSION AND CONSERVATION

6.1 SOIL EROSION

Soil erosion analysis plays a critical role in land suitability evaluation, particularly for agricultural commodity development. Soil erosion not only affects land productivity but also impacts ecosystem sustainability, environmental degradation, and the loss of the land's capacity to retain nutrients and water. In the context of agricultural land management, erosion analysis serves as the foundation for designing appropriate soil conservation strategies to mitigate negative impacts and maintain the sustainability 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: rainfall erosivity, soil erodibility, slope length and gradient, vegetation cover, and land management practices. In Timor-Leste, most of these factors are characterized by conditions that trigger high erosion rates. The topography, dominated by steep slopes, low land conservation efforts, unstable soil structure due to geological influences, and minimal vegetative cover, are primary factors accelerating erosion. As Morgan (2005) noted, uncontrolled soil erosion can result in the loss of the topsoil layer, the most fertile component of the soil, thus limiting its productivity capacity.

Covalima District has a very severe erosion rate of 18.70%, a severe erosion rate of 52.14%, a moderate erosion rate of 6.92%, and a light erosion rate of 22.24%. Covalima District records the highest severe erosion rate among all regions at 52.14%, with very severe erosion at 18.70%. The geological factor, with the dominance of alluvial formations and unstable soil structures, makes this area vulnerable to surface runoff, especially in flat areas that frequently experience waterlogging. Erosion data for Covalima District is presented in **Figure 6.1**. The map of soil erosion distribution in Covalima District is presented in **Figure 6.2.**

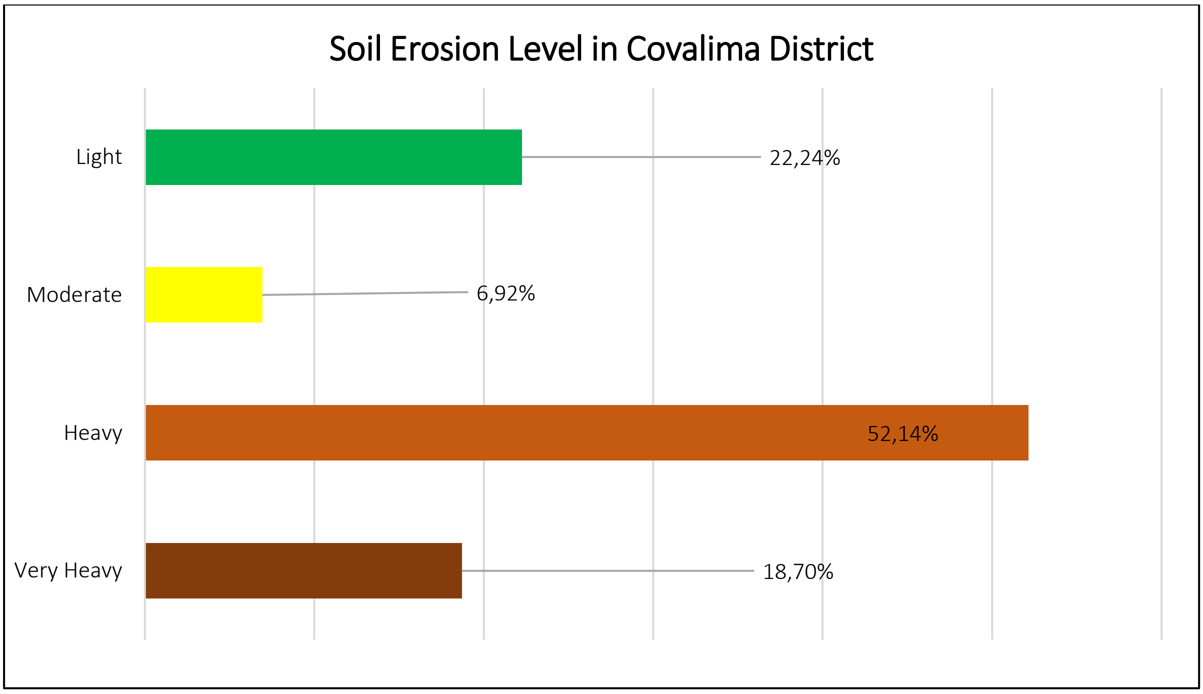


Figure 6.1 Soil Erosion Levels in Covalima District

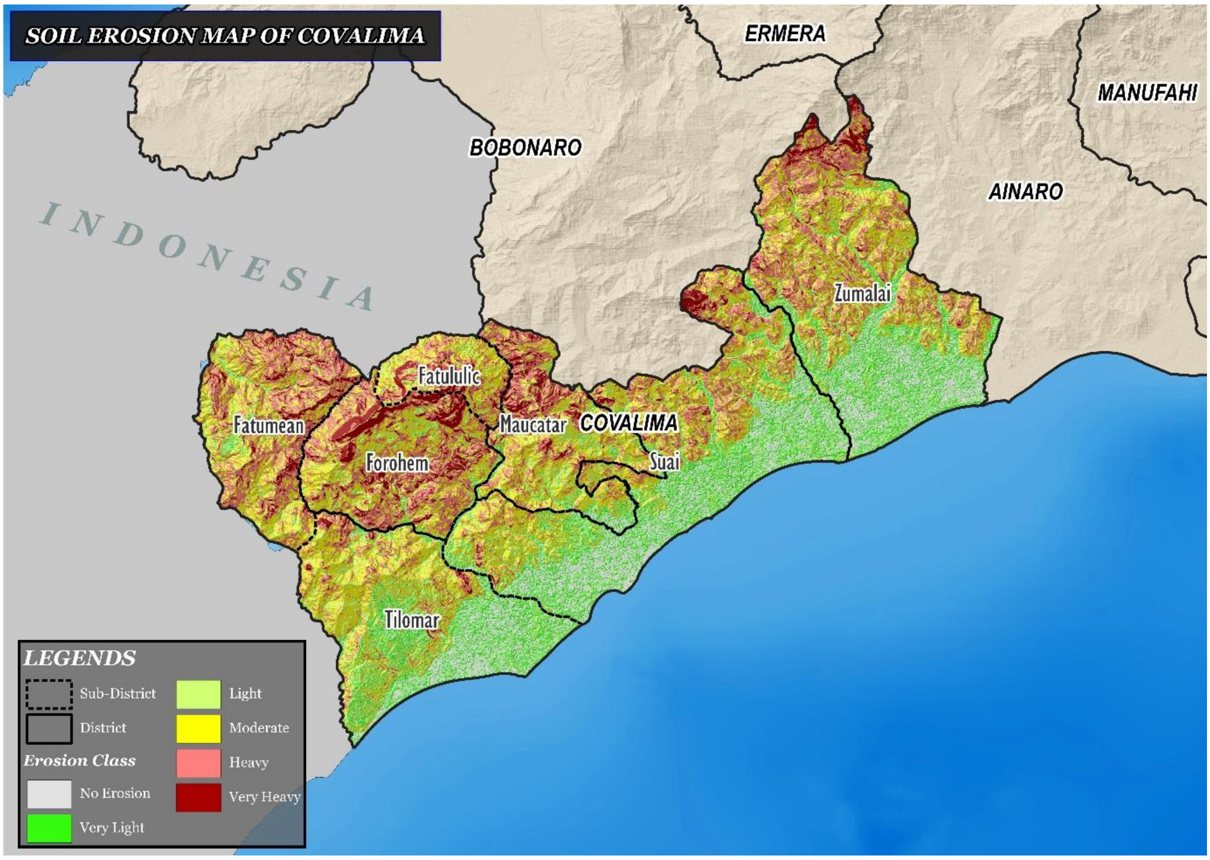


Figure 6.2 Map of Soil Erosion in Covalima District

6.2 SOIL DAN WATER CONSERVATION

Conservation is a long-term natural resource management effort aimed at maintaining land quality and productivity. It plays a crucial role in protecting soil from degradation, rehabilitating degraded soils, improving infiltration, and maintaining soil fertility. Conservation practices consist of mechanical, vegetative, and chemical methods.

In Covalima District, conservation is based on slope gradient, ranging from flat to very steep (0–45%). On flat to gently sloping land (0–8%), it is recommended to grow food crops, annual crops, and horticultural crops. These crops can also be cultivated on land with a slope gradient of up to 40%, provided that terraces are built to increase rainwater infiltration into the soil, thereby reducing erosion and surface runoff. If the slope exceeds 45%, the land should be used for perennial crops (such as timber trees like banyan trees, mahogany, Charcoal Tree, teak, gamal, and lamtoro). The reason is that on very steep slopes, terraces would create narrow planting areas, and the land would be prone to erosion and even landslides during rainfall. The Slope Gradient Data for Covalima District is presented in **Table 6.1**, and the Slope Gradient Map for Covalima District is shown in **Figure 6.3**.

Table 6.1 Slope Gradient Data in Covalima District

Sub District	Slope	Potential Class	Area (ha)	Area (%)
Fatululic	15-25%	Moderately Potential	1625.24	1.35
Fatululic	25-45%	Agroforestry	539.62	0.45
Fatululic	>45%	Agroforestry	2341.53	1.95
Fatululic	0-8%	Highly Potential	49.18	0.04
Fatumean	15-25%	Moderately Potential	3394.58	2.82
Fatumean	25-45%	Agroforestry	9628.09	8.01
Fatumean	>45%	Agroforestry	120.9	0.1
Fatumean	0-8%	Highly Potential	67.32	0.06
Forohem	15-25%	Moderately Potential	960.63	0.8
Forohem	25-45%	Agroforestry	5817.48	4.84
Forohem	>45%	Agroforestry	6096.75	5.07
Forohem	0-8%	Highly Potential	357.39	0.3
Maucatar	15-25%	Moderately Potential	959.05	0.8
Maucatar	25-45%	Agroforestry	3449.32	2.87
Maucatar	>45%	Agroforestry	5680.93	4.72
Maucatar	0-8%	Highly Potential	1327.75	1.1
Suai	15-25%	Moderately Potensial	4463.9	3.71
Suai	25-45%	Agroforestry	1341.52	1.12
Suai	8-15%	Potential	1468.78	1.22

Suai	>45%	Agroforestry	9713.08	8.08
Suai	0-8%	Highly Potential	13171.93	10.95
Tilomar	15-25%	Moderately Potential	4554.33	3.79
Tilomar	25-45%	Agroforestri	7785.06	6.47
Tilomar	8-15%	Potensial	3904.07	3.25
Tilomar	>45%	Agroforestry	1131.25	0.94
Tilomar	0-8%	Highly Potential	2020.44	1.68
Zumalai	15-25%	Moderate Potential	1250.71	1.04
Zumalai	25-45%	Agroforestry	9960.6	8.28
Zumalai	8-15%	Potential	745.21	0.62
Zumalai	>45%	Agroforestry	6749.47	5.61
Zumalai	0-8%	Highly Potential	9578.2	7.96

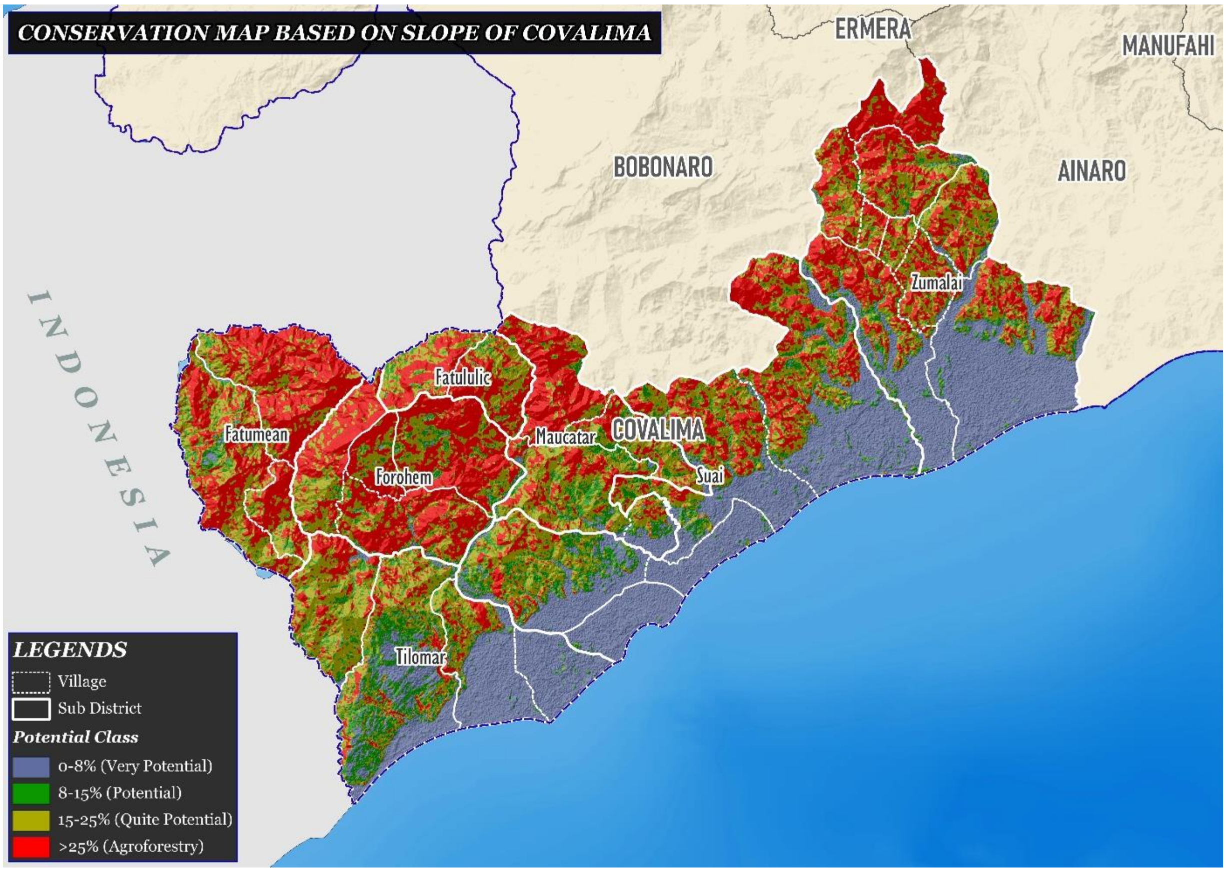


Figure 6.3 Slope Gardient Map in Covalima District

Covalima District has a uniform slope gradient across all its Sub-Districts, with varying land areas. The Sub-District with the largest area of slopes over 45% is Suai Sub-District, with an area of 9,713.08 ha or 8.08%. This means that lands with very steep slopes can only be used for perennial crops or agroforestry. The most extensive area with gentle slopes (0–8%) is also found in Suai Sub-District, covering 13,171.93 ha or 10.95%. Suai Sub-District has potential for developing food crops, horticulture, and plantation crops.

The land area with very high potential for use on gentle slopes (0–8%) is 26,572.21 ha (22.09%), while the area with potential land use on slopes of 8–15% covers 6,118.06 ha or 5.09%. The area with moderately potential land use on slopes of 15–25% totals 17,208.44 ha or 14.31%. The area with slopes greater than 25% covers 70,355.6 ha or 58.51%.

Based on the Slope Gradient Map of Covalima in **Figure 6.3,** the coastal or central areas with gentle slopes (0–8%) to moderate slopes (8–25%) are suitable for cultivating food crops, annual crops, plantation crops, and horticulture to enhance growth, lands with moderate to slightly steep slopes need to be terraced to reduce erosion. In areas with red coloration on the map, which are very steep (>45%), only perennial crops or timber trees should be developed, and the land should be designated 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) can enhance soil fertility, improve physical, biological, and chemical soil properties, provide specific habitats, increase biodiversity, reduce runoff, slow down rainfall water, bind soil particles, improve water retention, and control erosion.

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

1. Agro-silviculture System: integration of trees and specific food crops on the same land.
2. Silvopastoral System: combination of tree cultivation and forage crops to support livestock management.
3. Agrosilvopastoral: planting of trees, food crops, pastures, and livestock on the same land. This system aims to optimize land production functions but requires intensive management at the subsystem level.
4. Home Garden System: characterized by the intensive cultivation of perennial and seasonal crops, generally consisting of vegetables, cereals, fruit trees, grasses, and livestock management.
5. Other Systems: this includes the cultivation of multipurpose trees, beekeeping, aquaculture, and forests, all of which can be used for various agricultural and non-agricultural purposes. The Agroforestry Conservation Model is presented in **Figure 6.4**.

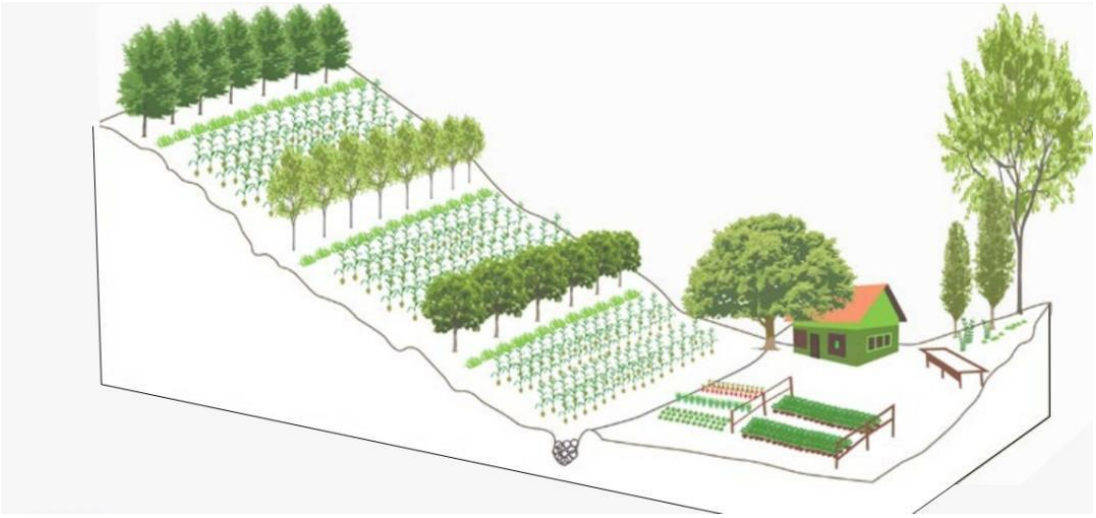


Figure 6.4 Agroforestry Conservation Model
(Source: La *et al*., 2016)

A. The Importance of Agroforestry Concept

Agroforestry plays a crucial role in the production of both local commodities (firewood, timber, fruits, and animal feed) and global commodities (coffee, tea, cocoa, rubber, and resin). Agroforestry also has a strategic role in assisting countries in the fight against poverty, food security, and environmental sustainability. It helps enhance farmer resilience and improve household income through diverse harvests at different times of the year. The combination of trees, food crops, and livestock helps mitigate environmental risks, creates permanent ground cover to combat erosion, minimizes flood damage, and enhances water storage, benefiting both crops and pastures.

Agroforestry provides various benefits, including:

1. Enhancing Food Security and Nutritional Enrichment

   Agroforestry provides plant species diversity that produces various food types, contributing to improved food security. The integration of different agroforestry components enhances agricultural productivity and increases nutritional diversity for consumers.

2. Resilient Livelihoods

   The integration of trees, food crops, and livestock can reduce production vulnerabilities to climate disasters and market shocks. In addition, agroforestry can reduce pest attacks in monoculture systems by creating a better microclimate. Agroforestry mitigates the climate impacts that hinder agricultural systems and creates resilient livelihoods.

3. Climate Change Mitigation and Adaptation

   The integration of various crops helps mitigate the impact of climate change on the agricultural sector. The use of trees in agroforestry systems plays a role in carbon sequestration, regulating the microclimate, which helps reduce the rate of climate change, and influences plant growth.

4. Environmental Protection

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

5. Poverty Alleviation

   Agroforestry can increase income diversification through the cultivation of commercial crops, timber sales, and livestock income. Diversification enhances sustainable agricultural productivity by increasing farmer incomes, creating job opportunities, and contributing to poverty alleviation and improved community well-being.

B. Agroforestry And Agro-Ecology in Covalima Dsitrict

The most successful agroforestry systems in Covalima District generally involve mixed cultivation of fruit trees, timber-producing trees, and spices. Key fruit trees selected include jackfruit, banana, mango, pineapple, and orange. The timber-producing trees commonly planted alongside fruit trees are 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) described the agroforestry model commonly applied in Timor-Leste, including in Covalima District. These include:

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

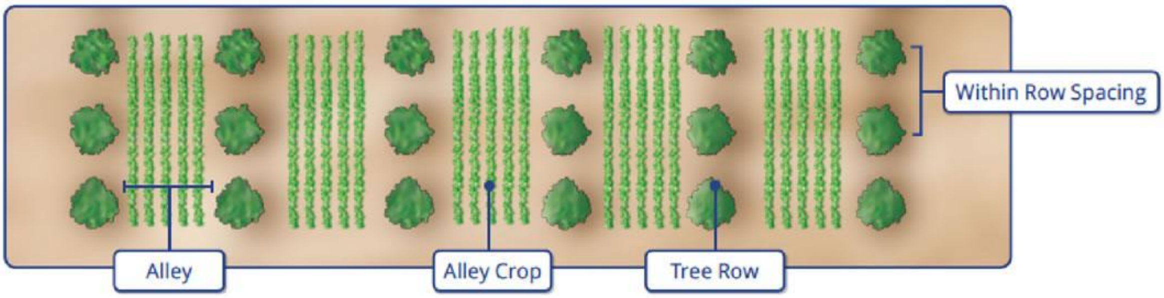


Figure 6.5 Alley Cropping System Concept
(Source: https://www.fs.usda.gov/nac/practices/alley-cropping.php)

2. Fence planting creating boundaries or fences using trees or shrubs. This is commonly applied in steep hill areas to conserve soil. The concept is presented in **Figure 6.6**.

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

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

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

4. Alternating Row Planting regularly spaced planting rows with seasonal crops planted between rows on flat and extensive land. An example of an agroforestry model that can be established in Covalima District is vanilla (wood + fruit + spices + staple food), with vanilla as the main crop and supporting crops such as casuarina, albizia, wild pepper, jackfruit, cassava, mango, banana, and cocoa. This agroforestry model can be applied at elevations between 500 - 1500 m with an average annual rainfall of 1500–3000 mm/yr.

Cogné & Lescuyer (2024) combined agro-ecological and socio-technical data to identify the types of agroforestry systems (AFS) in Covalima District, including home gardens that integrate perennial crops, spices, and small livestock; the integration of crops and fallow land for developing food crops and trees with specific spacing; planting perennial crops (papaya, banana, chili, etc.) combined with timber trees (palm trees); forest gardens usually located near water sources; and silvopastoral systems that combine trees, shrubs, and grazing livestock on the same land.

Covalima District has three agro-ecological zones (AEZ) based on agroclimatic zones. These zones have biophysical parameters such as elevation, average rainfall, and soil types, which are crucial in selecting appropriate crops and agroforestry models for Covalima District. The agro-ecological zone data and main crop types are presented in **Table 6.2**, and the agroclimatic zone map for Covalima District is shown in **Figure 6.8**.

Table 6.2 Agro-ecological Zones Data and Main Crop Types

Zone	Altitudes (m)	Rainfall (mm/year)	Main Crops
Zone D	500-1500	500-1500	Corn, cassava, rice, sweet potatoes, cowpea
Zone E	100-500	500-1500	corn, cassava, rice, sweet potatoes, cowpea
Zone F	<100	1500-3500	Rice, Corn, cassava, coconut

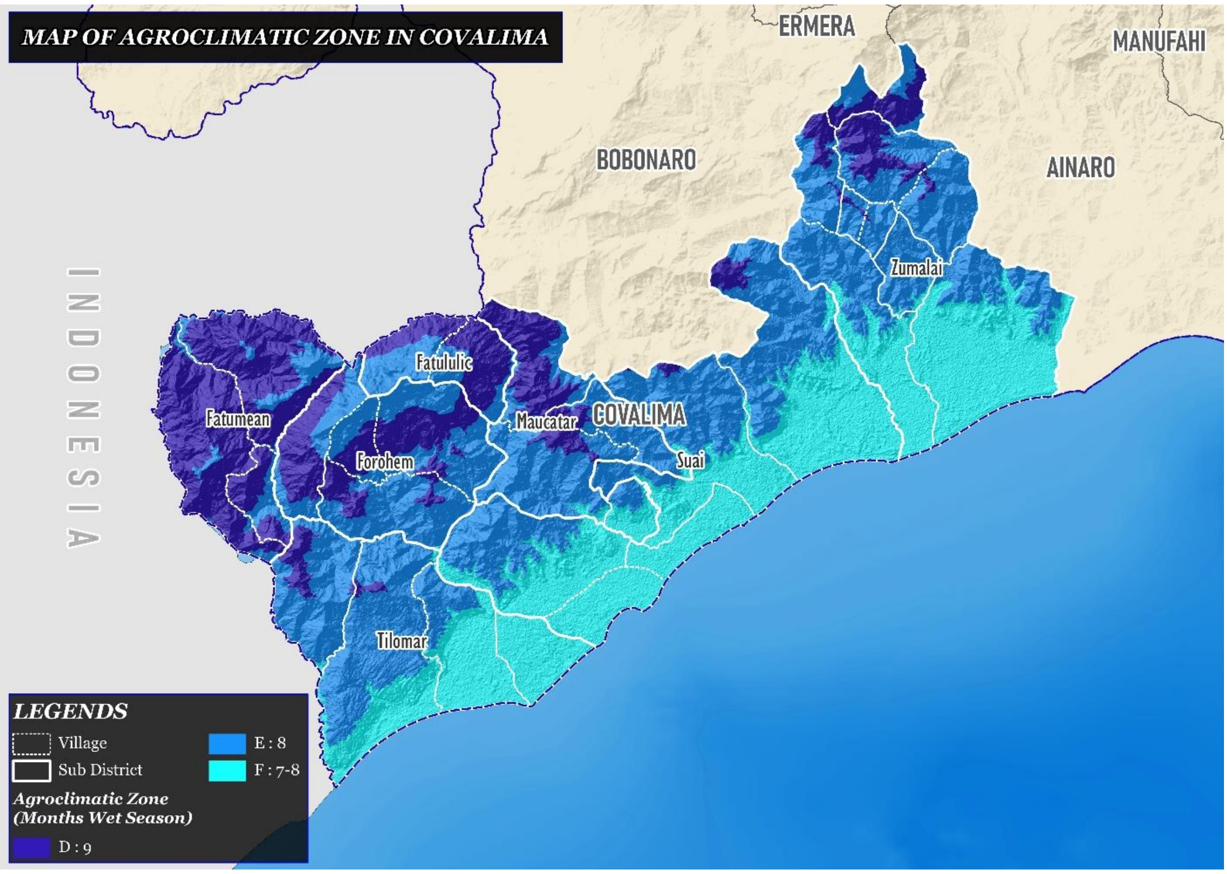


Figure 6.8 Agroclimatic Zone Map in Covalima Dsitrict

The following are recommendations for applying agroforestry based on agro-ecological zones according to the agroclimatic zone.

1. Zone D

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

2. **Zone E**

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

3. **Zone F**

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

C. Conservation Techniques in Covalima District

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

1. Check Dam

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

a. **Brushwood**, A brushwood dam is made from wood or branches and is typically used in small river channels. It usually has an effective height of around 1 m above the ground surface, and the minimum foundation depth for the posts is 0.75–1 m. The brushwood conservation model is shown in **Figure 6.9**. Steps in building a brushwood dam*:*
   1) Dig a trench about 5 cm wide, and insert wooden posts (150-200 cm) to a depth of about one-third to half the length of the post, with a distance of 30-50 cm between each post.
   2) The center should be made lower than the sides to create a gap used to hold the maximum water flow.
   3) Branches from trees (mahogany, rosewood, sesbania) and shrubs are woven between the wood to reach the desired height.

4) The ends of the tied materials must extend into the riverbed at least 30 cm.
5) The back of the check dam should be filled with soil.
6) The edges of the brushwood, about 1.5-2.0 times the height of the dam, should be protected from erosion and reinforced with galvanized wire.
7) Side walls should be built to direct water flow toward the dam.
8) Correct the steep gradient of the riverbed head.

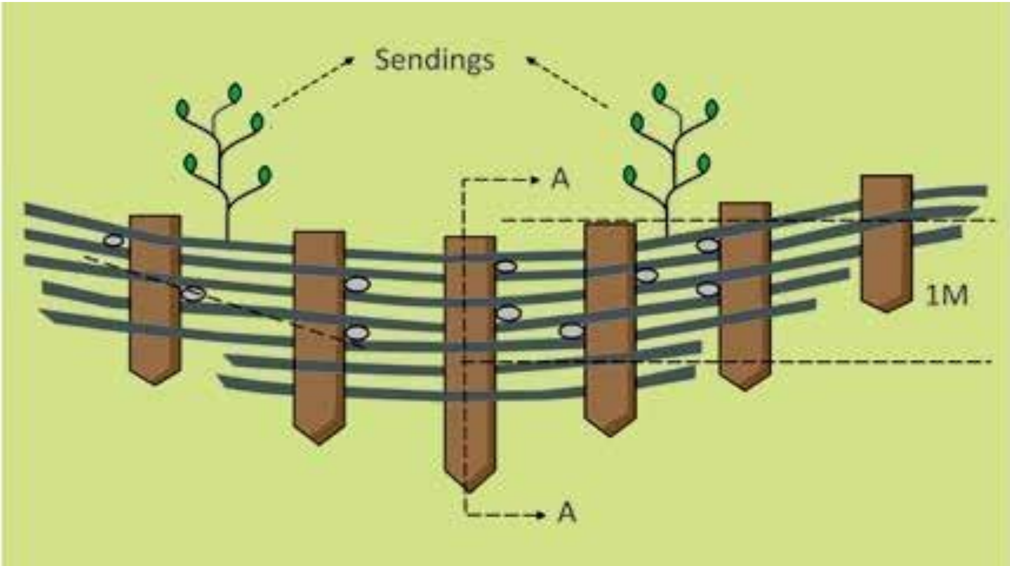


Figure 6.1 Brushwood Check Dam
(Source: Godinho *et al*., 2023)

b. **Loose Stone**, The loose stone dam is made from loose rocks to block small to medium-sized river channels, while the boulder dam uses large rocks as the barrier, following the same principle as the loose stone dam. Typically, this dam has an effective height of 1–2 m, a minimum foundation depth of half the effective height, and the thickness of the dam at the spillway is between 0.5–1 m. The loose stone model is shown in **Figure 6.10**. Steps in building a loose stone or boulder dam:
1) Clear the site and mark the construction line using a rope.
2) Cut the riverbed slope with a 1:1 gradient. The foundation of the wing walls should be >0.5 m. The height of the wing walls should match the depth of the spillway.
3) The foundation of the dam should be longer than the spillway.

4) For larger dams, build two wing walls with foundations that match the height to direct the water flow into the spillway or gap and prevent damage to the riverbed edges.
5) Boulder stones are used at the gap and downstream side of the spillway. The center section should be kept lower for the spillway.
6) If there is a large volume of water flow, concrete may need to be used at the gap and the top of the dam or cover everything with wire mesh.
7) An apron made of stones should be built under the dam.
8) Large stones should be placed at the bottom of the dam, with stones about 50 x 30 cm used throughout the dam.
9) On the upstream side, the dam should receive soil filling to increase its stability.

Figure 6.2 Loose Stone Check Dam
(Source: Flickr Loose Stone Check Dam)

c. **Gabion**, A gabion dam is constructed using hexagonal or square wire baskets filled with stones. The general specifications for gabions include a maximum effective height of <5 m, a maximum foundation depth of half the effective height, and a dam thickness at the spillway of <1 m. The gabion conservation concept is shown in **Figure 6.11.** Steps in building a gabion dam:
1) The structure must extend at least 0.5 m into the riverbed and must be protected from floodwaters with wing walls.
2) Wing walls with suitable foundations must be built on top to direct the water flow into the spillway or gap and prevent damage to the riverbed

edges. The space between the dam and wing walls should be filled with soil.

3) The foundation of the retaining dam should be longer than the spillway.
4) Large stones should be placed along the sides of the gabion box, while smaller stones are used to fill the center. The size of the stones used for construction should be larger than the size of the wire mesh (mesh size of 10 x 10 cm and 15 x 15 cm).
5) If there is debris, a concrete layer may be needed in front of the dam to protect the gabion wire from damage.
6) The spillway dimensions should be calculated based on the maximum flow from the river catchment area.
7) An apron should be built under the dam.
8) The back of the retaining dam needs to be filled with soil to enhance the dam's strength.
9) The gabion boxes should be tied with 12 gauge wire.

Figure 6.3 Gabion Check Dam
(Source: Pinterest Gabion Check Dam)

2. Terracing

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

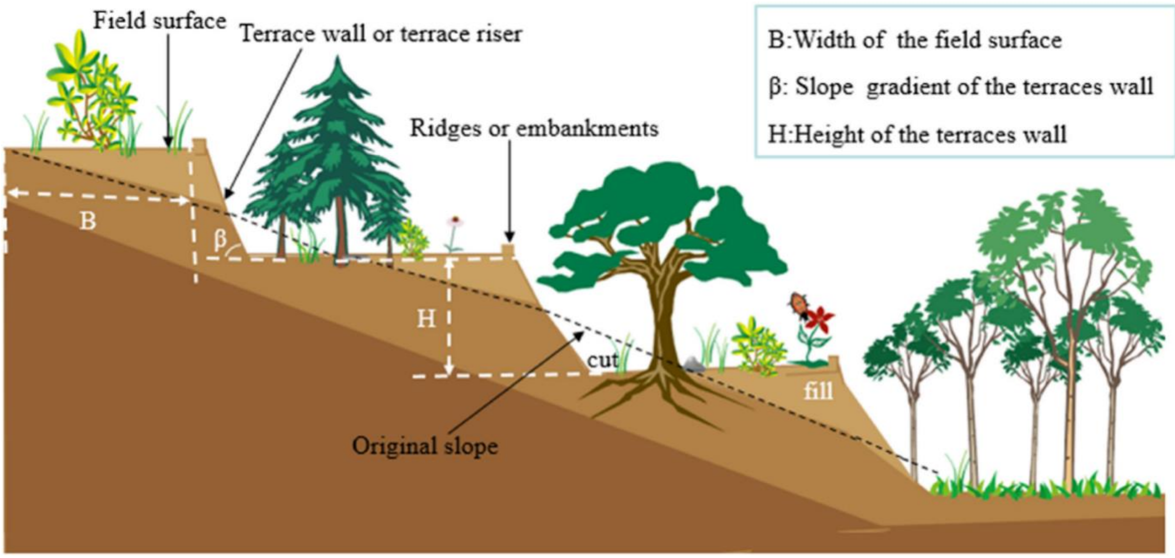
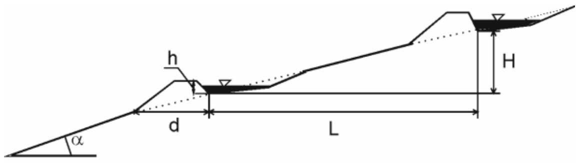


Figure 6.4 Terracing Conservation Concept
(Source: Deng *et al*., 2021)

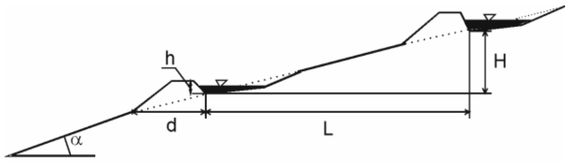
Some types of terraces based on their suitability for different slopes include:

a. **Broad Channel Terraces**, These are typically made to capture and direct excess water from fields. This type of terrace is suitable for wet areas and slopes not exceeding 20%.
b. **Ridge Terraces**, These are made to capture and hold excess water by spreading it across the land between hill ridges. These terraces are commonly applied on flat slopes (<3%) because the water spreads more widely without requiring tall ridges. Ridge terraces have water channels at the back of the ridge (embankment) to drain surface water into drainage channels and improve water absorption into the soil. The ridge terrace divides the slope into smaller hydrological units, reducing water flow paths and influencing water circulation across the slope and within the entire catchment area. According to Prochal (1984) in Baryła & Pierzgalski (2008), ridge terraces can be divided into two types: with and without water outflow. Ridge Terraces without Water Outflow, These have a parallel

shape with the contours and are built on water-permeable soil with relatively low rainfall. The flowing water is retained by the embankments and absorbed into the soil. Ridge Terraces with Water Outflow, These terraces have surface or subsurface drainage. For subsurface drainage, water is discharged through wells or underground pumps into ditches, rivers, or reservoirs. These terraces are used in areas with high precipitation and on soils with low water absorption capacity. The concept of ridge terrace division is shown in **Figure 6.13.**



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



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

Figure 6.5 Concept of Ridge Terraces: Without Outflow (Left); With Outflow (Right) (Source: Baryła & Pierzgalski, 2008)

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

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

1) **Terrace Length:** Typically a maximum of 100 m in one direction of the drainage channel for humid tropical climates. Terrace length is limited by the size and shape of the land, degree of cutting, and soil type.

2) **Terrace Width:** The optimal width ranges from 2.5 - 5 m (manual construction) and 3.5 - 8 m (machine/tractor construction). The width is adjusted according to soil depth, land preparation tools, plant types, and other needs.
3) **Terrace Gradient:** The horizontal gradient of the terrace ranges from 0.5 - 1%, depending on the climate and soil type.
4) **Height and Slope of Subterraces:** Subterraces are made from compacted soil and protected with grass or stones. The height of the sub-terraces should not exceed 2 m. The Vertical Interval (VI) between two successive terraces can be calculated using the following formula:

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

Descriptions:
S = Slope (%)
Wb = Bench Width (m)
U = Slope of the sub-terrace (m)

Figure 6.6 Application of Terracing Conservation
(Source: Freepik)

3. Biopore Infiltration Holes

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

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

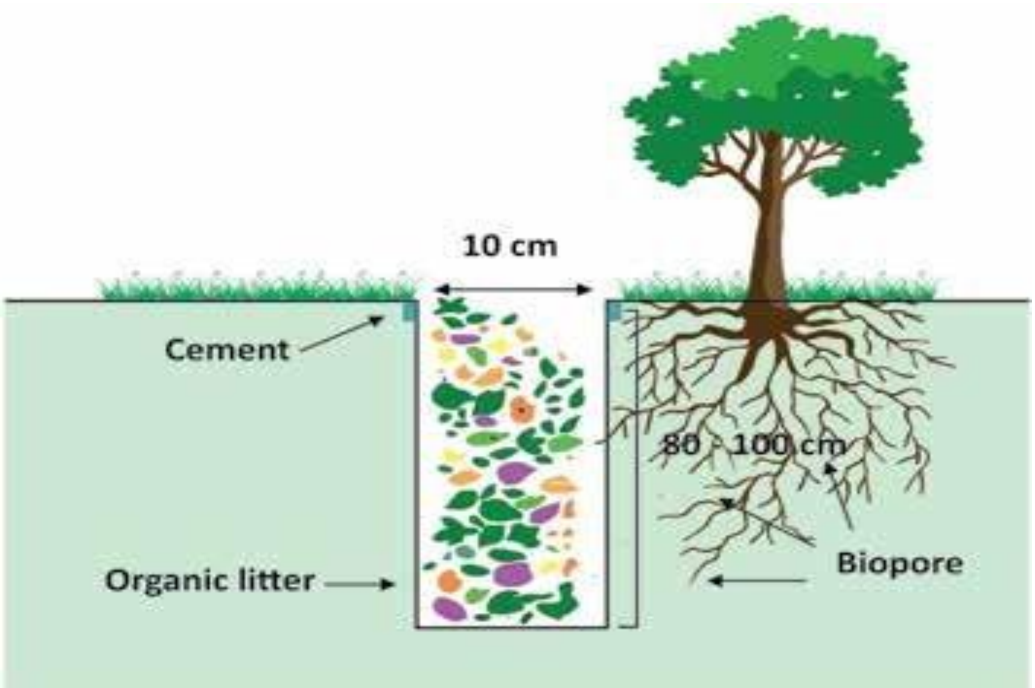


Figure 6.7 Biopore Infiltration Holes
(Source: Godinho *et al.*, 2023)

4. Riverbank Protection

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

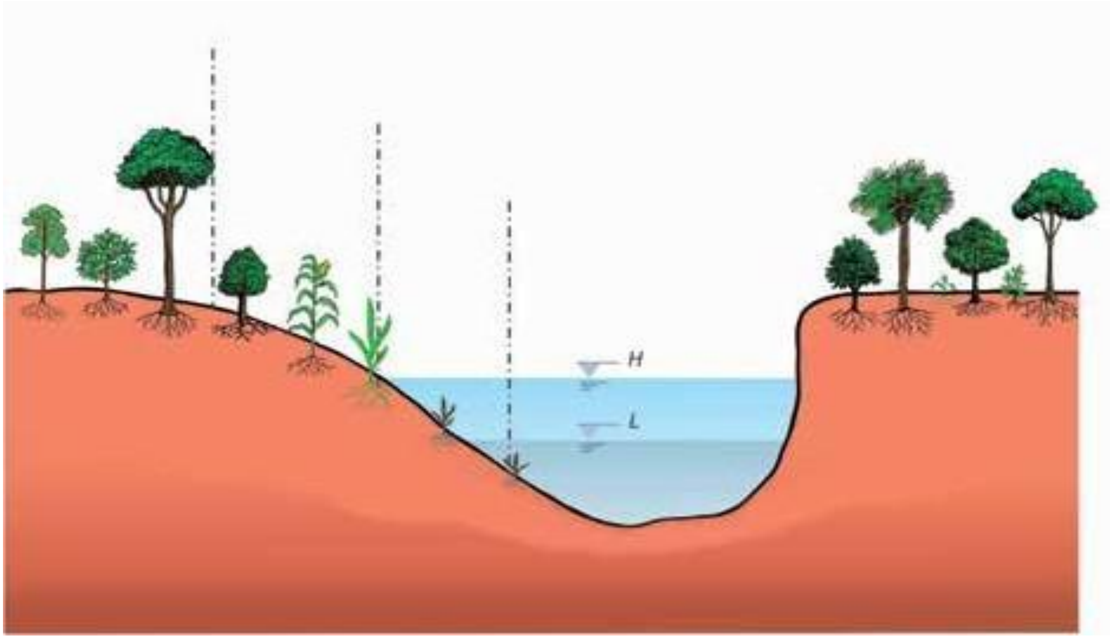


Figure 6.8 Riverbank Protection with Various Layers of Trees, Shrubs, and Grasses (Source: Godinho *et al*., 2023)

5. **Grass Planting**

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

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

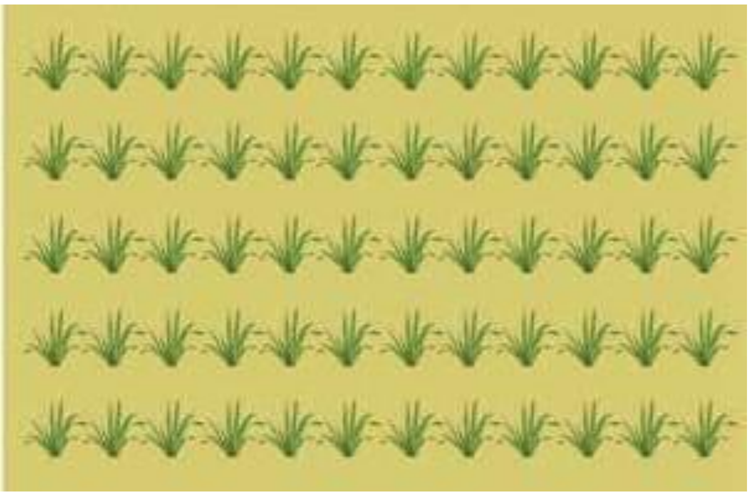


Figure 6.9 Horizontal Grass Planting
(Source: Godinho *et al.*, 2023)

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

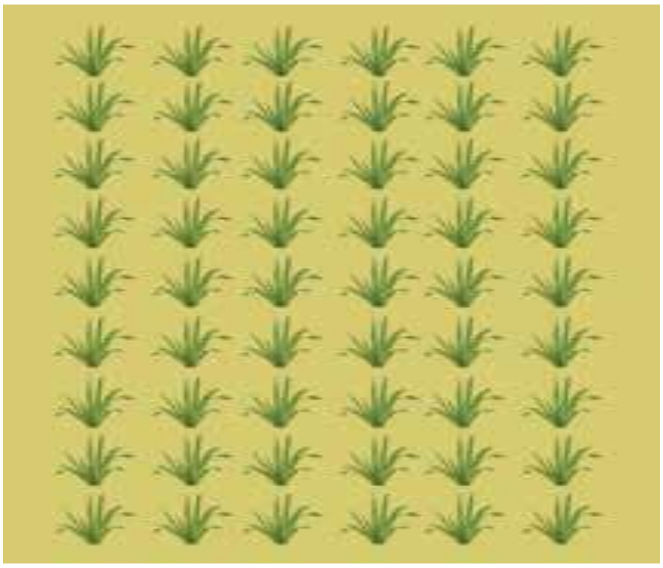


Figure 6.10 Vertical Grass Planting
(Source: Godinho *et al.*, 2023)

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

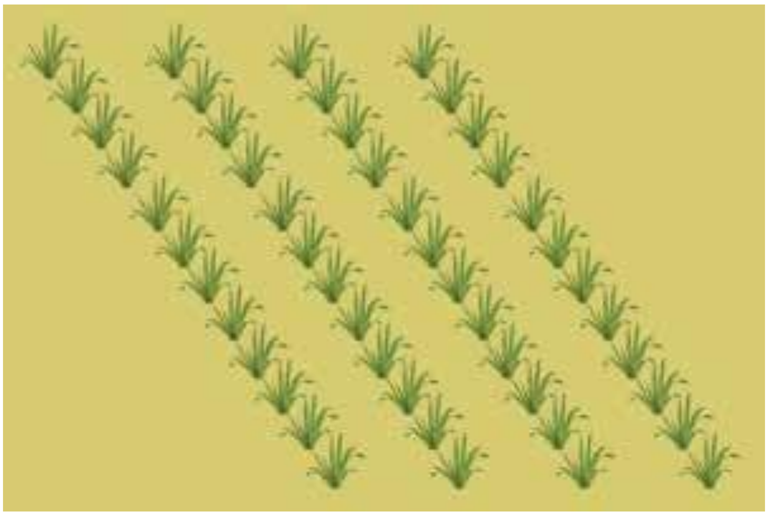


Figure 6.11 Diagonal Grass Planting
(Source: Godinho *et al*., 2023)

6. Rainwater Reservoir

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

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

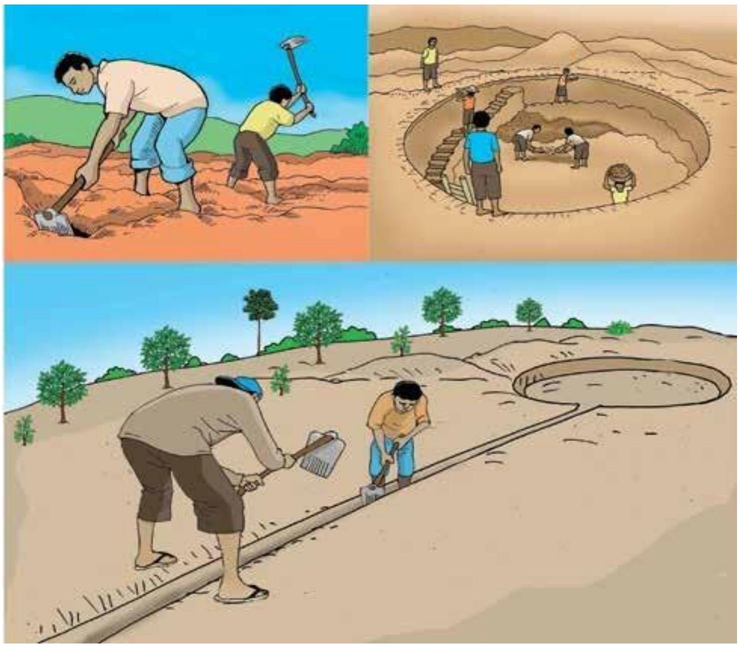


Figure 6.12 Rainwater Reservoir Construction
(Source: Godinho *et al*., 2023)

7. Drainage Channel Construction

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

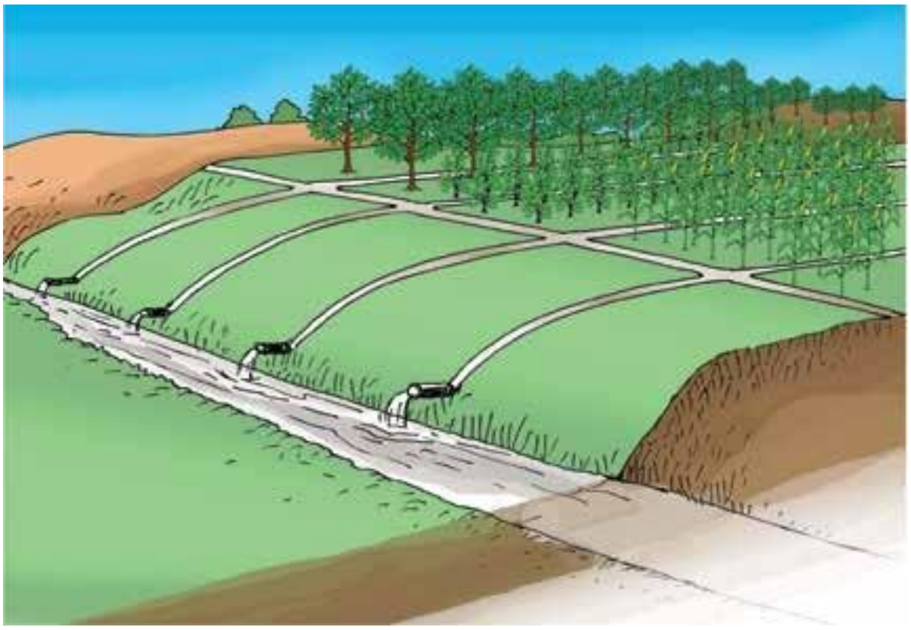


Figure 6.13 Drainage Channel
(Source: Godinho *et al*., 2023)

8. Wattle Fence / Live Check Dam

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

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

Figure 6.14 Wattle Fence

9. Vegetative Measures

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

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

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

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

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

Figure 6.15 Reservoir Application

VII. AGRICULTURAL LAND SUITABILITY EVALUATION

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

7.1 LAND SUITABILITY FOR AGRICULTURE

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

Potential land suitability refers to land suitability after improvements are made. For instance, land that is marginally suitable (S3) due to nutrient deficiencies can become moderately suitable (S2) or even highly suitable (S1) after improvements such as fertilization. The potential land suitability assessment involves improving the limiting land characteristics so that land suitability can increase. With technology, lands that naturally have a low suitability class (current land suitability) can be upgraded to a higher suitability class (potential land suitability) after improvements. However, not all land qualities or characteristics can be improved with current technology, or they may require a high level of management to achieve improvements. In land use planning, the main focus is on potential land suitability because this assessment provides an overview of the maximum potential of the land for various uses after improvements. The efforts to improve actual land characteristics to potential suitability according to management levels are presented in **Table 7.1.**

Table 7.1 Types of Efforts to Improve Actual Land to Potential Suitability Based on Management Level

No	Land Quality/Charachteristic	Improvement Efforts	Management Level
1	**Radiation regime** (sunlight duration)	No improvement possible	-
2	**Temperaturee Regime** Average annual Temperaturee Average coldest monthly Temperaturee Average hottes monthly Temperaturee	No improvement possible No improvement possible No improvement possible	- - -
3	**Humidity regime** Relative humidity	No improvement possible	-
4	**Water availability** Dry month Rainfall	Irrigation system Drainage	Medium, High Medium, High
5	**Root Medium** Drainage Texture Effective depth	Improvement of drainage system, such as masking drainage channels. Addition of organic material No improvement possible. Generally cannot be improved expect in soft and thin bedrock layers, which can be broken during land preparation	
6	**Nutrient retention:** CEC pH	Lime application or addition of organic material	Medium, High
7	**Nutrient availability:** Total Nitrogen Available Phosphorus Available Potassium	Urea and ZA fertilization SP36 and TSP fertilization KCl fertilization	Medium, High
8	**Diversity:** Salinity	Addtion of organic materials	Medium, High
9	**Erosion Hazard**	Erosionon control measures, terracing, contour planting, cover crop planting	Medium, High
10	**Flood hazard** Frequency period	Construction of water barriers and drainage channels to improve water management	High
11	**Toxicity:** Aluminium saturation Pyrite layer	Liming Water management system	Medium, High Medium, High

		regulation, groundwater level must be above the sulfide layer	
12	**Ease of cutivation**	Soil moisture management to ease land prepaation	Medium, High
13	**Terrain/potential mechanisms**	No improvement possible	-

Explanation:

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

Table 7.2 Assumptions for the Improvement of Actual Land Quality to Potential Based on Management Level

No	Land Quality and Characteristics	Management Level Medium	Management Level High	Improvement Type
1	**Radiation regime**	-	-	-
2	**Temperaturee Regime**	-	-	-
3	**Humidity regime**	-	-	-
4	**Water availability**			
	Dry month	+	++	Crop combination
	Rainfall	+	++	Irrigation
5	**Root Medium**			
	Drainage	+	++	Drainage channels*)
	Texture	-	+	Addition of organic material
	Effective depth	-	+	Making planting holes and adding organic materials
	Peat, maturity	-	-	-
	Peat, thickness	-	-	-
6	**Nutrient retention:**			
	CEC	-	+	Addition of organic material
	Base saturation	-	+	
	pH	+	+	
	Organic Carbon	+	++	
7	**Nutrient availability:**			
	Total Nitrogen	+	++	Urea fertilization
	Available Phosphorus	+	++	SP36 and TSP fertilization
	Available Potassium	+	++	KCl fertilization
8	**Flood hazard**			
	Period	+	++	-
	Frequency	+	++	-
9	**Diversity**			Irrigation and additional oforganic material
	Salinity	+	++	
10	**Toxicity**			
	Aluminuin saturation	+	++	lime
	Pyrite layer	-	+	regulating groundwater level
11	**Ease of cutivation**	-	+	Mechanization
12	**Terrain/potential mechanisms**	-	+	Terracing
13	**Erosion Hazard**	+	++	Soil conservation efforts

Explanation:

- No Improvement possible

\+ Improvement can be made, resulting in an increase of one suitability class (S3 to S2)

++ A two class increase in suitability (S3 to S1)

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

7.2 LAND SUITABILITY CLASSIFICATION STRUCTURE

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

Table 7.3 Land Suitability Classification System (FAO, 1976)

Order	:	Indicates whether a land is suitable or not for a spesific use.
Class	:	Indicates the degree of suitability of a land.
Sub-classes	:	Indicates the type of limitation or the kind of improvement that must be carried out within each class.
Unit	:	Indicates the differences in the magnitude of limiting factors that affect the management of sub-classes.

Order and class are typically used in land reconnaissance mapping, sub-classes in semi-detailed land mapping, and units in detailed land mapping. Order is also used in coarse-scale (exploratory) land mapping:

Suitability Order

Suitability order describes the general suitability of land, indicating whether a land is suitable or not for a specific land use that has been considered. At the orderr level, land is categorized into suitable (S) and not suitable (N) land.

Suitable Order (S)

Land classified in this orderr can be used for long-term purposes for a particular use without or with minimal risk of degradation, and the benefits from land management will be satisfactory after considering the inputs.

Not Suitable Order (N)

Land classified in this orderr has significant difficulties or constraints, either physical (e.g., very steep slopes, rocky terrain) or economic (e.g., inputs do not balance with output, preventing the land from being used for the intended purpose).

Suitability Class

Suitability class indicates the level of land suitability within the orderr. At the class level, lands classified as suitable (S) are divided into highly suitable (S1), moderately suitable (S2), and marginally suitable (S3) lands. On the other hand, lands classified as not suitable (N) are not further subdivided.

Highly Suitable Class (S1)

Land with no significant limiting factors or only minor limiting factors that do not notably reduce productivity, allowing for sustainable land use.

Moderately Suitable Class (S2)

Land with some moderate limitations, which require a higher level of management. These limitations reduce productivity or profits and increase the necessary inputs.

Marginally Suitable Class (S3)

Land with significant limitations that require careful management. These limitations can reduce productivity and profits, requiring additional inputs to achieve the expected output.

Not Suitable Class (N1)

Land with severe limiting factors that are difficult to overcome, preventing sustainable use in the long term.

Class N2: Land with permanent limitations that prevent any possible sustainable land use in the long term.

Suitability Sub-class

This reflects the type and intensity of the limiting factors that hinder land use or the types of improvements needed. Each class can consist of one or more sub-classes depending on the types of limitations present. The limitations are represented by small letters placed after the class symbol. For example, class S2 with a limitation of effective depth (s) can become sub-class S2s. A sub-class can have one, two, or at most three limitation symbols, with the most dominant limitation written first. For example, in the sub-class S2ts, the dominant limitation is topographic condition (t), while the effective depth limitation (s) is secondary.

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 similar suitability levels and share the same type of limitations at the sub-class level.

Table 7.4 Land Suitability Classification Structure (FAO, 1976)

No	Order	Class	Sub-class	Unit
		S1	-	
			S2s	S2r-1
1.	S	S2	S2e	S2e-2
			S2se	Dsb..
		S3	Dsb.	
		N1	N1s	-
2.	N		N1e	-
		N2	Dsb.	

The differences between one unit and another typically lie in their production capacity or additional management aspects required, and they are often a more detailed distinction based on the limiting factors. Detailed knowledge of these limitations facilitates interpretation and planning in farm management. At the unit level, labeling is done 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 not limited. The symbol at the unit level is formed by adding Arabic numerals separated by a hyphen from the sub-class symbol. For instance, S2e-1, S3e-2, and so on. The number of units within a sub-class is unlimited.

7.3 LAND SUITABILITY ASESSMENT RESULT

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 physical and chemical soil analysis in the laboratory. This approach enables the identification of the potential and limitations of the land for the development of various agricultural, horticultural, and forestry commodities.

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

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

This scientific approach serves as the basis for the land suitability assessment in Covalima District. The analysis results provide strategic guidance for maximizing land productivity while ensuring the sustainability of natural resources in each area.

Covalima District, located in the southwestern part of Timor-Leste, has significant potential for the development of agriculture and forestry. The region offers varied topography, ranging from lowlands to steep hills. With annual rainfall between 1,500 and 2,000 mm and average annual Temperatures between 21°C and 27°C, the area supports the growth of various high-value commodities. Commodities such as irrigated rice, rainfed rice, sorghum, corn, cassava, sweet potatoes, and various horticultural crops like chili, tomatoes, papaya, mango, jackfruit, and coconut show great potential for development, although there are several limiting factors that require improvement.

Some of the limiting factors in Covalima include shallow effective soil depth, poor soil drainage, Erosion Hazard s, and surface rocks that may interfere with plant growth. Additionally, the long dry season is also a constraint for certain crops. To maximize land potential, improvements such as terracing, organic matter addition, biopore hole creation, and proper planting distance arrangements are needed. Furthermore, the implementation of agroforestry systems, combining perennial crops with horticulture, spices, and forest plants, can be an effective solution to enhance land productivity sustainably. The land suitability evaluation in each Sub-District of Covalima is also crucial for determining the appropriate management steps.

A. Land Suitability Evaluation of Fatululic Sub-District

Fatululic Sub-District has a hilly topography with an average slope of around 33% and annual rainfall exceeding 2,000 mm. This area is more suitable for forest plantation development and agroforestry systems than for intensive food crop cultivation.

Horticultural crops such as mango, rambutan, and guava are moderately suitable (S2) with a limiting factor of effective depth, which can be improved by creating planting holes. The agroforestry system, combining avocado, jackfruit, Arabica coffee, ginger, candlenut, and cardamom, can help improve land efficiency and reduce Erosionon risk. Additionally, soil cover with mulch can enhance moisture retention and improve soil physical properties.

B. Land Suitability Evaluation of Fatumean Sub-District

Fatumean Sub-District has slopes ranging from 23% to 32% and relatively high annual rainfall, making it more suitable for mixed gardens integrating industrial crops, spices, and horticulture. Food crops such as maize, mung beans, and groundnuts are moderately suitable (S2) due to limiting factors such as effective depth and slope gradient. To improve suitability, interventions such as planting holes and adding organic matter, as well as planting along contour lines, are required. Crops such as coconut, cacao, clove, and tobacco are moderately suitable (S2) to marginally suitable (S3) due to non-ideal Temperaturees for growth.

Horticultural crops like potatoes, eggplant, vegetable tomatoes, grapes, avocado, and bananas have potential for development, with moderate suitability (S2), limited by Temperaturee and effective depth, requiring improvements such as NPK fertilization and planting along contours. Spices like pepper, candlenut, and lemongrass are marginally suitable (S3) for combination with other crops, as their strong root systems can help anchor the soil and enhance fertility.

C. Land Suitability Evaluation of Forohem Sub-District

Forohem Sub-District is characterized by hilly topography with steep slopes ranging from 23% - 40% and annual rainfall between 1,500 - 2,000 mm. These bio-physical conditions make staple food crops like maize, cassava, and sweet potatoes only marginally suitable. The dominant limiting factor is low

Temperaturees, which are difficult to improve and directly affect the physiological processes and productivity of these crops.

To improve land suitability, appropriate soil and water conservation techniques need to be applied. Steps such as planting along contour lines to reduce Erosionon, creating deeper planting holes to improve root development, and using shade plants to regulate Temperaturee and maintain soil moisture are recommended. Furthermore, applying an agroforestry system that integrates forest plants with fruit horticulture, such as durian, jackfruit, avocado, and candlenut, can improve soil stability and land utilization efficiency by diversifying outputs and increasing economic value.

D. Land Suitability Evaluation of Suai Sub-District

Suai Sub-District has varied topography, from flat to very steep (5%–49%). Food crops such as irrigated rice, rainfed rice, maize, and sorghum are moderately suitable (S2) with limiting factors such as effective depth and slope gradient. Land suitability improvements such as planting holes and planting according to contours are recommended.

Horticultural and industrial crops like carrots, shallots, garlic, papaya, bananas, mangoes, jackfruit, coconut, Robusta coffee, and tobacco are moderately suitable (S2), with limiting factors including high Temperaturee for Robusta coffee and shallow effective soil depth. Recommended improvements include creating planting holes and providing plant mulch to maintain Temperature and soil moisture.

Spices like turmeric, kencur, and galangal are also potential for polyculture development with perennial crops. However, surface rocks and rock outcrops in some villages remain difficult limitations to overcome.

E. Land Suitability Evaluation of Tilomar Sub-District

Food crops such as irrigated rice, rainfed rice, maize, groundnuts, cassava, and sweet potatoes are moderately suitable (S2) with the main limiting factors being low nitrogen, phosphate, and potassium content in the soil and the risk of Erosionon. Recommended improvements include terracing and applying NPK fertilizer.

Various crops such as coconut, Robusta coffee, cacao, tobacco, chili, tomatoes, durian, papaya, and bananas show good potential (S2) for cultivation in this region. However, surface rocks remain a permanent constraint that needs to be addressed. Additionally, horticultural crops such as eggplant, vegetable tomatoes, chili, cucumber, bitter melon, mango, jackfruit, and banana are also suitable for development in this area. To maintain soil stability, combining spices like turmeric and galangal with forest plants could be an effective solution. With proper management, this region has the potential to become a productive and sustainable agricultural area.

F. Land Suitability Evaluation of Zumalai Sub-District

Zumalai Sub-District, with topography ranging from flat to steep (5%–39%), has potential for the development of food crops, horticulture, and spices. Irrigated rice, rainfed rice, maize, tobacco, tomatoes, eggplant, bitter melon, papaya, bananas, and jackfruit are moderately suitable (S2). The main limiting factors include Temperaturee, coarse soil texture, coarse materials, shallow effective depth, and Erosionon risk. Recommended improvements are creating planting holes and adding organic materials, adjusting planting distances, terracing for irrigated and rainfed rice, and planting along contours.

Horticultural crops like long beans, cucumbers, and bitter melon are moderately suitable (S2), with limiting factors including effective depth, slope gradient, and Erosionon risk. Improvements include creating planting holes, planting along contours, and applying soil and water conservation to minimize Erosionon.

Spices like turmeric, aromatic ginger, and galangal are very suitable for development in polyculture systems with perennial crops. While challenges like slope gradient and Erosionon risk exist, improvements such as planting along contours can increase productivity.

G. Land Suitability Evaluation of Maucatar Sub-District

Maucatar Sub-District has a hilly topography with an average slope of around 33% and relatively high annual rainfall of over 2,000 mm. These agroclimatic conditions support the cultivation of staple food crops like irrigated rice, rainfed rice, maize, and sorghum, which are moderately suitable (S2). The main limiting factor is the relatively shallow effective soil depth, but this can be improved through simple conservation techniques, such as creating deeper planting holes to support root development.

Additionally, applying an agroforestry system that combines avocado, candlenut, Arabica coffee, and spices like ginger, turmeric, and kencur could enhance land use efficiency while reducing Erosionon risk on steep slopes. Integrating forestry, horticulture, and spices not only strengthens soil stability but also provides diversified outputs with economic value. Furthermore, soil cover with organic mulch plays a crucial role in maintaining moisture, reducing evaporation rates, and improving soil physical properties, particularly structure and porosity, thereby supporting the sustainability of the agricultural production system in this region.

Table 7.5 Land Suitability Evaluation Matrix in Covalima District

Commodities	Sub-District	Limiting Factors	Potential Land Suitability/ Improvement Efforts
FOOD COMMODITIES			
Irrigated Rice Upland Rice	• Fatumean • Suai • Tilomar • Zumalai • Maucatar	**S2:** Temperature, Coarse Fragments, pH, Available Phosphorus **S3:** N-total, K- Available, Surface Rock Cover, Rock Outcrops **N:** Gradient Slope, Erosion Hazard	**S2:** Temperature, Coarse Fragments, Gradient Slope, Erosion Hazard **S3:** Surface Rock Cover, Rock Outcrops
Corn	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S2:** Temperature, Coarse Fragments, Available Phosphorus **S3:** Rainfall, Available Pottasium, Surface Rock Cover, Rock Outcrops **N:** Gradient Slope, Erosion Hazard	**S2:** Temperature, Coarse Fragments, Gradient Slope, Erosion Hazard **S3:** Surface Rock Cover, Rock Outcrops
Sorghum	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S2:** Temperature, Coarse Fragments, Available Phosphorus, Available Pottasium **S3:** N-total, Surface Rock Cover, Rock Outcrops **N:** Rainfall, Gradient Slope, Erosion Hazard	**S2:** Temperature, Rainfall, Coarse Fragments, Gradient Slope, Erosion Hazard **S3:** Surface Rock Cover, Rock Outcrops
Wheat	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S2:** Coarse Fragments, Available Phosphorus, Available Pottasium **S3:** N-total, Surface Rock Cover, Rock Outcrops **N:** Rainfall, Gradient Slope, Erosion Hazard	**S2:** Rainfall, Coarse Fragments, Gradient Slope, Erosion Hazard **S3:** Surface Rock Cover, Rock Outcrops

Cassava	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S2:** Soil Texture, Coarse Fragments, pH, Available Phoosphorus **S3:** Temperature, N-total, Available Pottasium **N:** Effective Depth, Gradient Slope, Erosion Hazard	**S2:** Soil Texture, Coarse Fragments, Gradient Slope, Erosion Hazard **S3:** Temperature, Effective Depth
Sweet Potatoes	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S2:** Temperature, Rainfall, Available Poosphorus, Available Pottasium **S3:** Effective Depth, N-total, Surface Rock Cover, Rock Outcrops **N:** Gradient Slope, Erosion Hazard	**S2:** Temperature, Effective Depth, Gradient Slope, Erosion Hazard **S3:** Surface Rock Cover, Rock Outcrops
Taro	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S2:** Temperature, pH, P Available Phosphorus, Available Pottasium **S3:** Effective Depth, N-total, Rock Outcrops **N:** Gradient Slope, Erosion Hazard	**S2:** Temperature, Effective Depth, Gradient Slope, Erosion Hazard **S3:** Rock Outcrops
Soybeans	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S2:** Temperature, Effective Depth, N-total, Available Phosphorus, Available Pottasium **S3:** Surface Rock Cover, Rock Outcrops **N:** Gradient Slope, Erosion Hazard	**S2:** Temperature, Effective Depth, Gradient Slope, Erosion Hazard **S3:** Surface Rock Cover, Rock Outcrops
Peanuts	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S2:** Temperature, Soil Texture, Coarse Fragments, pH, N-total, Available Phosphorus, Available Pottasium **S3:** Effective Depth, Surface Rock Cover **N:** Gradient Slope, Erosion Hazard	**S2:** Temperature, Soil Texture, Coarse Fragments, Effective Depth, Gradient Slope, Erosion Hazard **S3:** Surface Rock Cover
Mung Beans	• Fatululic • Fatumean • Forohem • Suai • Tilomar	**S3:** Rainfall, Effective Depth, N-total, Available Pottasium **N:** Gradient Slope, Erosion Hazard	**S2:** Effective Depth, Gradient Slope, Erosion Hazard

	• Zumalai • Maucatar		
Cowpea	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S3:** Effective Depth, N-total, Available-K **N:** Gradient Slope, Erosion Hazard	**S2:** Effective Depth, Gradient Slope, Erosion Hazard
INDUSTRIAL CROPS			
Rubber	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S3:** Temperature, Rainfall, Base Saturation, pH, N-total, Available Pottasium, Gradient Slope **N:** Effective Depth, Erosion Hazard	**S2:** Gradient Slope, Erosion Hazard **S3:** Temperature, Effective Depth
Coconut	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S3:** Temperature, N-total, K-tersedia, Gradient Slope **N:** Effective Depth, Erosion Hazard	**S2:** Gradient Slope, Erosion Hazard **S3:** Temperature, Effective Depth
Oil Palm	• Fatululic • Fatumean • Suai • Tilomar • Zumalai • Maucatar	**S3:** Temperature, pH, N-total, Available Pottasium, Gradient Slope **N:** Effective Depth, Erosion Hazard	**S2:** Gradient Slope, Erosion Hazard **S3:** Temperature, Effective Depth
Arabica Coffee	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S3:** Temperature, N-total, K-tersedia, Gradient Slope **N:** Effective Depth, Erosion Hazard	**S2:** Gradient Slope, Erosion Hazard **S3:** Temperature, Effective Depth
Robusta Coffee	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S2:** Rainfall, Dry Month, Coarse Fragments, pH, N-total, Available Phosphorus, Available Pottasium **S3:** Surface Rock Cover, Rock Outcrops **N:** Effective Depth, Gradient Slope, Erosion Hazard	**S2:** Dry Month, Coarse Fragments, Gradient Slope, Erosion Hazard **S3:** Surface Rock Cover, Rock Outcrops
Cocoa	• Fatululic • Fatumean • Forohem • Suai	**S2:** Temperature, Coarse Fragments, pH **S3:** Rainfall, N-total, Available Phosphorus, Available Pottasium	**S2:** Temperature, Coarse Fragments, Gradient Slope, Erosion Hazard **S3:** Effective Depth

	• Tilomar • Zumalai • Maucatar	**N:** Effective Depth, Gradient Slope, Erosion Hazard	
Clove	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S3:** Dry Month, N-total, Available Phosphorus, Available Pottasium, Gradient Slope **N:** Effective Depth, Erosion Hazard	**S2:** Dry Month, Gradient Slope, Erosion Hazard **S3:** Effective Depth
Tea	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**N:** Dry Month **S3:** Temperature, Rainfall, Slope, Rock Outcrops, N-total, Available Phosphorus, Available Pottasium **S2:** Erosion, Effective Depth, Surface Rock Cover	**S3:** Dry Month, Temperature **S2:** Rock Outcrops, Effective Depth, Surface Rock Cover
Tobacco	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S2:** Coarse Fragments, pH, N-total, Available-K **S3:** Rainfall, Effective Depth, Bse Saturation **N:** Gradient Slope, Erosion Hazard	**S2:** Coarse Fragments, Effective Depth, Gradient Slope, Erosion Hazard
Sugarcane	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S3:** Temperature, Rainfall, N-total, Available-K **N:** Effective Depth, Gradient Slope, Erosion Hazard	**S2:** Gradient Slope, Erosion Hazard **S3:** Temperature, Effective Depth
Melinjo	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S3:** Dry Month, N-total, K-tersedia, Gradient Slope **N:** Effective Depth, Erosion Hazard	**S2:** Gradient Slope, Erosion Hazard **S3:** Dry Month, Effective Depth
Cotton	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S3:** Rainfall, Effective Depth, N-total, Available Pottasium, Erosion Hazard **N:** Gradient Slope	**S2:** Effective Depth, Gradient Slope, Erosion Hazard
Kapok	• Fatululic • Fatumean • Forohem	**S3:** Rainfall, N-total, P- tersedia, Gradient Slope, Erosion Hazard	**S2:** Gradient Slope, Erosion Hazard

	• Suai • Tilomar • Zumalai • Maucatar	**N:** Effective Depth	**S3:** Effective Depth
Quinine	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S3:** N-total, Available Phosphorus, Gradient Slope, Erosion Hazard **N:** Effective Depth	**S2:** Gradient Slope, Erosion Hazard **S3:** Effective Depth
FRUIT HORTICULTURAL COMMODIITIES			
Papaya	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S2:** Temperature, Rainfall, CEC, Available Pottasium **S3:** Effective Depth, N-total, Gradient Slope, Erosion Hazard	**S2:** Temperature, Effective Depth, Gradient Slope, Erosion Hazard
Mango	• Fatululic • Fatumean • Forohem • Suai • Zumalai	**S2:** Rainfall, Available Pottasium, Surface Rock Cover, Rock Outcrops **S3:** Effective Depth, N-total, Gradient Slope, Erosion Hazard	**S2:** Gradient Slope, Erosion Hazard, Surface Rock Cover, Rock Outcrops **S3:** Effective Depth
Rambutan	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S3:** Temperature, Effective Depth, N-total, Available Pottasium, Gradient Slope, Erosion Hazard, Surface Rock Cover, Rock Outcrops	**S2:** Gradient Slope, Erosion Hazard **S3:** Temperature, Effective Depth, Surface Rock Cover, Rock Outcrops
Guava	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S3:** C-organic, Effective Depth, N-total, Available Pottasium, Gradient Slope, Erosion Hazard, Surface Rock Cover, Rock Outcrops	**S2:** Gradient Slope, Erosion Hazard **S3:** Effective Depth, Surface Rock Cover, Rock Outcrops
Durian	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S2:** Temperature, Rainfall, N-total, Available Pottasium **S3:** Gradient Slope, Erosion Hazard, Surface Rock Cover, Rock Outcrops	**S2:** Temperature, Gradient Slope, Erosion Hazard **S3:** Surface Rock Cover, Rock Outcrops
Water Melon Melon	• Fatululic • Fatumean • Forohem	**S2:** Soil Texture, Available Phosphorus, Available Pottasium	**S2:** Soil Texture, Effective Depth, Gradient Slope, Erosion Hazard

	• Suai • Tilomar • Zumalai • Maucatar	**S3:** Rainfall, Effective Depth, Surface Rock Cover, Rock Outcrops **N:** Gradient Slope, Erosion Hazard	**S3:** Surface Rock Cover, Rock Outcrops
Jackfruit	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S2:** CEC, Available Pottasium **S3:** Effective Depth, N-total, Gradient Slope, Erosion Hazard, Surface Rock Cover	**S2:** Gradient Slope, Erosion Hazard **S3:** Effective Depth, Surface Rock Cover
Soursop	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S2:** CEC, Available Pottasium **S3:** Effective Depth, N-total, Gradient Slope, Erosion Hazard, Surface Rock Cover	**S2:** Gradient Slope, Erosion Hazard **S3:** Effective Depth, Surface Rock Cover
Custrad Apple	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S2:** Coarse Fragments Available Pottasium **S3:** Effective Depth, CEC, N-total, Gradient Slope, Erosion Hazard	**S2:** Coarse Fragments, Effective Depth, Gradient Slope, Erosion Hazard
Breadfruit Snakefruit	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S2:** CEC, Available Pottasium **S3:** Effective Depth, N-total, Gradient Slope, Erosion Hazard, Surface Rock Cover	**S2:** Effective Depth, Gradient Slope, Erosion Hazard **S3:** Surface Rock Cover
Longan	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S3:** Effective Depth, N-total, Available Pottasium, Gradient Slope, Erosion Hazard, Surface Rock Cover	**S2:** Gradient Slope, Erosion Hazard **S3:** Effective Depth, Surface Rock Cover
Pineapple	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S2:** Rainfall, Effective Depth, Available Pottasium **S3:** CEC, Gradient Slope, Erosion Hazard	**S2:** Effective Depth, Gradient Slope, Erosion Hazard

Strawberry	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S2:** Temperature, Effective Depth **S3:** N-total, Available Pottasium, Surface Rock Cover **N:** Gradient Slope, Erosion Hazard	**S2:** Temperature, Effective Depth, Gradient Slope, Erosion Hazard **S3:** Surface Rock Cover
Banana	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S2:** Rainfall, N-total, Available Pottasium **S3:** Effective Depth, Gradient Slope, Erosion Hazard	**S2:** Effective Depth, Gradient Slope, Erosion Hazard
Orange	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S2:** Soil Texture, N-total, P-tersedia, Available Pottasium **S3:** Effective Depth, Gradient Slope, Erosion Hazard, Surface Rock Cover	**S2:** Soil Texture, Effective Depth, Gradient Slope, Erosion Hazard **S3:** Surface Rock Cover
Avocado	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S2:** Coarse Fragments, pH, Available Pottasium **S3:** Effective Depth, N-total, Gradient Slope, Erosion Hazard	**S2:** Coarse Fragments, Effective Depth, Gradient Slope, Erosion Hazard
Passion Fruit	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S3:** Temperature, Dry Month, Surface Rock Cover	**S3**: Temperature, Dry Month, Surface Rock Cover
Grapes	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S2:** Temperature, N-total, Available Phosphorus, Available Pottasium **S3:** Effective Depth, Gradient Slope, Erosion Hazard	**S2:** Temperature, Effective Depth, Gradient Slope, Erosion Hazard
VEGETABLE HORTICULTURA COMMODITIES			
Potatoes	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai	**S3:** Temperature, Surface Rock Cover **N:** Gradient Slope, Erosion Hazard	**S2:** Gradient Slope, Erosion Hazard **S3:** Temperature, Surface Rock Cover

	• Maucatar		
Eggplant	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S3:** Effective Depth, N-total, Available Pottasium, Surface Rock Cover **N:** Gradient Slope, Erosion Hazard	**S2:** Effective Depth, Gradient Slope, Erosion Hazard **S3:** Surface Rock Cover
Vegetable Tomatoes	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S3:** Effective Depth, N-total, Available Pottasium, Surface Rock Cover **N:** Gradient Slope, Erosion Hazard	**S2:** Effective Depth, Gradient Slope, Erosion Hazard **S3:** Surface Rock Cover
Carrots	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S3:** Temperature, N-total, Available Pottasium, Surface Rock Cover **N:** Gradient Slope, Erosion Hazard	**S2:** Gradient Slope, Erosion Hazard **S3:** Temperature, Surface Rock Cover
Shallot	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S2:** Soil Texture , Effective Depth, N-total, Available Phosphorus, Available Pottasium **S3:** Surface Rock Cover, Rock Outcrops **N:** Rainfall, Gradient Slope, Erosion Hazard	**S2:** Rainfall, Soil Texture , Effective Depth, Gradient Slope, Erosion Hazard **S3:** Surface Rock Cover, Rock Outcrops
Gralic Radish	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S3:** Temperature, Surface Rock Cover	**S3:** Temperature, Surface Rock Cover
Red Chili	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S2:** Effective Depth, Available Phosphorus, Available Pottasium **S3:** Rainfall, N-total **N:** Gradient Slope, Erosion Hazard	**S2:** Effective Depth, Gradient Slope, Erosion Hazard
Bell Pepper	• Fatululic • Fatumean • Forohem • Suai	**S2:** Coarse Fragments, Available Phosphorus, Available Pottasium **S3:** Rainfall, Effective Depth, N-total	**S2:** Effective Depth, Gradient Slope, Erosion Hazard

	• Tilomar • Zumalai • Maucatar	**N:** Gradient Slope, Erosion Hazard	
Cabbage	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S2:** Soil Texture , Coarse Fragments, Available Pottasium **S3:** Rainfall, N-total **N:** Gradient Slope, Erosion Hazard	**S2:** Soil Texture , Coarse Fragments, Gradient Slope, Erosion Hazard
Green Beans Long Beans	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S3:** Effective Depth, N-total, Available Pottasium **N:** Gradient Slope, Erosion Hazard	**S2:** Effective Depth, Gradient Slope, Erosion Hazard
Peas	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S2:** Temperature, Rainfall, Available Pottasium **S3:** Effective Depth, N-total **N:** Gradient Slope, Erosion Hazard	**S2:** Temperature, Effective Depth, Gradient Slope, Erosion Hazard
Cucumbers Bitter Melon	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S3:** Rainfall, Effective Depth **N:** Gradient Slope, Erosion Hazard	**S2:** Effective Depth, Gradient Slope, Erosion Hazard
Broccoli	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S3:** Rainfall, Effective Depth, N-total, Available Pottasium **N:** Gradient Slope, Erosion Hazard	**S2:** Effective Depth, Gradient Slope, Erosion Hazard
FLOWER HORTICULTURA COMMODITIES			
Roses Asters Sunflowers	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S2:** Coarse Fragments, C-organik, N-total, P Available Phosphorus, Available Pottasium **S3:** Effective Depth, Surface Rock Cover, Rock Outcrops **N:** Gradient Slope, Erosion Hazard	**S2:** Coarse Fragments, Effective Depth, Gradient Slope, Erosion Hazard **S3:** Surface Rock Cover, Rock Outcrops

SPICES AND MEDICINAL PLANTS			
Pepper	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S3:** Rainfall, Dry Month, Effective Depth **N:** Gradient Slope, Erosion Hazard	**S2:** Effective Depth, Gradient Slope, Erosion Hazard **S3:** Dry Month
Candlenut	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S2:** Dry Month, Coarse Fragments, CEC, N-total, Available Phosphorus, Available Pottasium **S3:** Gradient Slope, Erosion Hazard **N:** Effective Depth	**S2:** Dry Month, Coarse Fragments, Gradient Slope, Erosion Hazard **S3:** Effective Depth
Vanilla	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S3:** Effective Depth, N-total, Available Pottasium **N:** Gradient Slope, Erosion Hazard	**S2:** Effective Depth, Gradient Slope, Erosion Hazard
Lemongrass Vetiver	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S3:** Dry Month, Effective Depth, N-total, Available Pottasium, Gradient Slope, Erosion Hazard	**S2:** Effective Depth, Gradient Slope, Erosion Hazard **S3:** Dry Month
Ginger	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S3:** Temperature, Effective Depth, N-total, Available Pottasium **N:** Gradient Slope, Erosion Hazard	**S2:** Effective Depth, Gradient Slope, Erosion Hazard **S3:** Temperature
Aromatic Ginger Tumeric	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S2:** Soil Texture, CEC, N-total, Available Pottasium **S3:** Effective Depth **N:** Gradient Slope, Erosion Hazard	**S2:** Soil Texture , Effective Depth, Gradient Slope, Erosion Hazard
Galangal	• Fatululic • Fatumean • Forohem • Suai • Tilomar	**S2:** Coarse Fragments, CEC, N-total, Available Pottasium **S3:** Effective Depth	**S2:** Coarse Fragments, Effective Depth, Gradient Slope, Erosion Hazard

	• Zumalai • Maucatar	**N:** Gradient Slope, Erosion Hazard	
Cadarmon	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S2:** Dry Month, Coarse Fragments, CEC, N-total, Available Pottasium **S3:** Effective Depth **N:** Gradient Slope, Erosion Hazard	**S2:** Dry Month, Coarse Fragments, Effective Depth, Gradient Slope, Erosion Hazard
Jatropha	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S2:** Temperature, Rainfall, CEC **S3:** Effective Depth, N-total, Available Pottasium **N:** Gradient Slope, Erosion Hazard	**S2:** Temperature, Effective Depth, Gradient Slope, Erosion Hazard
Sesame	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**N:** Dry Month, Slope **S3:** Erosion, Effective Depth, Rock Outcrops **S2:** Drainase	**S3:** Dry Month **S2:** Slope, Effective Depth, Rock Outcrops
GRAZING AND LIVESTOCK AREAS			
Elephant Grass Setaria	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S3:** Rock Outcrops, Slope **S2:** Surface Rock Cover, Drainase, Erosion, KB, pH, N-total, Available Phosphorus, Available Pottasium	**S3:** Rock Outcrops **S2:** Surface Rock Cover
Legumes	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**N:** Slope **S3:** Rock Outcrops, Erosion **S2:** Surface Rock Cover, Drainase, N-total, Available Phosphorus, Available Pottasium	**S3:** Rock Outcrops **S2:** Slope, Surface Rock Cover
Grazing	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**N:** Dry Month **S3:** Rock Outcrops, Slope **S2:** Erosion, Surface Rock Cover, pH, N-total, Available Phosphorus, Available Pottasium	**S3:** Dry Month, Rock Outcrops **S2:** Surface Rock Cover

VIII. FORESTRY POTENTIAL

8.1 LAND SUITABILITY ASSESSMENT RESULTS

Land suitability analysis is a fundamental step in designing strategies for the sustainable management of land resources. This evaluation process is based on an integrated approach that includes the use of geospatial data, field observations, and physical and chemical soil analysis in the laboratory. This approach allows for the identification of the potential and bio-physical 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 the bio-physical conditions of the land, such as slope gradient, vegetation cover, and drainage quality. Laboratory soil sample analysis complements this process by providing data on macronutrient content (N, P, K), organic matter, cation exchange capacity (CEC), pH, and soil texture.

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

This scientific approach serves as the basis for the land suitability evaluation in Covalima District. The analysis results provide strategic guidance for maximizing land productivity while ensuring the sustainability of natural resources in each area.

In **Table 8.1**, the results of the land suitability assessment show that several crops are grouped together in the same column, indicating that these crops have similar growth requirements and limiting factors. Crops placed in different columns have different growth requirements and limiting factors, and thus require a management approach tailored to the specific needs of each crop commodity.

A. Land Suitability Evaluation of Fatululic Sub-District

The area of Fatululic Sub-District has a hilly topography with an average slope of around 33% and annual rainfall exceeding 2,000 mm. These characteristics make the area more suitable for the development of forestry and agroforestry systems than for intensive food crop cultivation.

Forest species such as teak and mahogany are considered moderately suitable (S2), with the main limitation being relatively shallow effective soil depth. Other species, such as Agathis, Leucaena, Altingia, Sengon, Acacia, Eucalyptus, Gelam, Pine, and Sandalwood, fall into the marginally suitable category (S3), primarily due to limiting factors such as rock outcrops, dry season duration, effective soil depth, and surface rock.

The implementation of an agroforestry system has the potential to increase land use efficiency while reducing the risk of Erosion. Additionally, the presence of mulch as ground cover can help maintain moisture and improve the physical properties of the soil.

B. Land Suitability Evaluation of Fatumean Sub-District

Fatumean Sub-District has the potential for the development of forestry commodities with varying land suitability levels, specifically moderately suitable (S2) and marginally suitable (S3). Tree species classified as S2 include teak and mahogany, while species categorized as S3 include Agathis, Leucaena, Altingia, Sengon, Acacia, Eucalyptus, Gelam, Pine, and Sandalwood. The main limiting factors for the development of forestry commodities in this area include Temperaturee conditions, slope gradient, effective soil depth, surface rock, rock outcrops, dry season duration, and coarse fragments.

With these characteristics, Fatumean Sub-District still holds opportunities for sustainable agricultural development. In addition to the tree species mentioned, **Table 8.1** presents alternative commodities that have potential for development in this area.

C. Land Suitability Evaluation of Forohem Sub-District

Forohem Sub-District is characterized by hilly topography with steep slopes (23–40%) and annual rainfall ranging from 1,500–2,000 mm. Under these conditions, certain tree species such as Agathis, Leucaena, and Eucalyptus are classified as moderately suitable (S2), with the main limiting factors being shallow effective soil depth and a relatively long dry season.

Other species, such as Agathis, Leucaena, Altingia, Sengon, Acacia, Eucalyptus, Gelam, Pine, and Sandalwood, are classified as marginally suitable (S3). The limiting factors affecting land suitability for these species include slope gradient, effective soil depth, surface rock, rock outcrops, dry season duration, and coarse material content. The implementation of an agroforestry system that integrates forestry species with horticultural commodities has the potential to improve soil stability while promoting more efficient land use.

D. Land Suitability Evaluation of Suai Sub-District

Suai Sub-District has varied topography, ranging from flat to very steep slopes (5–49%). Based on the land suitability evaluation, this area has potential for forestry commodity development with suitability categories of moderately suitable (S2) and marginally suitable (S3). Tree species classified as S2 include teak and mahogany, while species categorized as S3 include Agathis, Leucaena, Altingia, Sengon, Acacia, Eucalyptus, Gelam, Pine, and Sandalwood.

The main limiting factors for forestry development in Suai Sub-District include slope gradient, effective soil depth, surface rock, rock outcrops, dry season duration, and coarse fragments. Given this potential, Suai Sub-District still offers opportunities for sustainable agricultural development. In addition to the tree species mentioned, **Table 8.1** presents alternative commodities that could be developed in this area.

E. Land Suitability Evaluation of Tilomar Sub-District

Tilomar Sub-District has potential for forestry commodity development with varying land suitability levels, ranging from moderately suitable (S2) to marginally suitable (S3). Tree species classified as S2 include teak and mahogany, while species categorized as S3 include Agathis, Leucaena, Altingia, Sengon, Acacia, Eucalyptus, Gelam, Pine, and Sandalwood.

The main limiting factors for forestry development in this area include slope gradient, effective soil depth, surface rock, rock outcrops, dry season duration, and coarse fragments. Overall, Tilomar Sub-District still has relatively good land suitability potential to support sustainable agricultural development. In addition to the tree species mentioned, **Table 8.1** presents alternative commodities that can be developed in this area.

F. Land Suitability Evaluation of Zumalai Sub-District

Zumalai Sub-District has potential for forestry commodity development with varying land suitability levels, ranging from moderately suitable (S2) to marginally suitable (S3). Tree species classified as S2 include teak and mahogany, while species categorized as S3 include Agathis, Leucaena, Altingia, Sengon, Acacia, Eucalyptus, Gelam, Pine, and Sandalwood.

The main limiting factors for forestry development in this area include slope conditions, effective soil depth, surface rock, rock outcrops, dry season duration, and coarse fragments. Overall, Zumalai Sub-District still holds considerable prospects to support sustainable agricultural development. In addition to the tree species mentioned, **Table 8.1** presents alternative commodities that can be developed in this area.

G. Land Suitability Evaluation of Maucatar Sub-District

Maucatar Sub-District has hilly topography with an average slope of around 33%. Forestry species such as teak and mahogany are classified as moderately suitable (S2), with the main limiting factors being Temperature and relatively shallow effective soil depth. On the other hand, other species such as Agathis, Leucaena, Altingia, albizia, Acacia, Eucalyptus, Gelam, Pine, and Sandalwood fall into the marginally suitable class (S3), influenced by limitations such as slope gradient, effective soil depth, surface rock, rock outcrops, dry season duration, and coarse fragements.

The implementation of an agroforestry system has the potential to improve land use efficiency while reducing Erosion risk. Additionally, soil cover with mulch can help maintain moisture and improve soil physical properties, thereby supporting the sustainability of land productivity.

Table 8.1 Land Suitability Evaluation Matrix in Covalima District

Commodity	Sub-District	Limiting Factors	Potential Land Suitability/ Improvement Efforts
Teak	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S2:** Temperature, pH, K_2O **S3:** N-total, Gradient Slope **N:** Effective Depth, Erosion Hazard	**S2:** Temperature, Gradient Slope, Erosion Hazard **S3:** Effective Depth
Mahogany	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S2:** Temperature, Soil Texture, pH, K_2O **S3:** N-total, Gradient Slope **N:** Effective Depth, Erosion Hazard	**S2:** Temperature, Gradient Slope, Erosion Hazard **S3:** Effective Depth
Agathis Leucaena	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**N:** Rainfall, Effective Depth, Erosion Hazard	**S2:** Rainfall, Erosion Hazard **S3:** Effective Depth
Agathis	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**S3:** Dry Month, Gradient Slope **N:** Effective Depth, Erosion Hazard	**S2:** Gradient Slope, Erosion Hazard **S3:** Dry Month, Effective Depth
Sengon Acacia Eucalyptus Melaleuca Pine	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**N:** Effective Depth, Erosion Hazard	**S2:** Erosion Hazard **S3:** Effective Depth
Sandal Wood	• Fatululic • Fatumean • Forohem • Suai • Tilomar • Zumalai • Maucatar	**N:** Rock Outcrops **S3:** Erosion, Lereng, Surface Rock, N, P, K **S2:** Rainfall, Coarse Fragments, pH, C-organik	**S3**: Rock Outcrops **S2:** Surface Rock, Coarse Fragments

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

8.2 LAND IMPROVEMENT MEASURES

The productivity and sustainability of agriculture in the district heavily depend on the proper and integrated handling of land limiting factors. Although the land faces challenges such as limited soil depth, surface rock, and rock outcropss, management can still be carried out through a technical forestry approach. Improvement efforts 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 rock outcropss and breaking rocks to support root growth.

In addition to physical constraints, soil chemical aspects show significant limitations. Organic carbon content is relatively low, which affects soil structure and microbial activity. Key nutrients such as nitrogen, phosphorus, and potassium are also at insufficient levels to support plant vegetative growth. Therefore, improving soil fertility through the addition of organic matter and balanced fertilization is a strategic step to increase production capacity and support the cultivation of forestry commodities that are adapted to marginal conditions.

Although most of the constraints are permanent, land management can still be implemented through an adaptive technical approach based on local bio-physical characteristics. Strategies that can be applied include Erosion control, selecting planting locations at appropriate elevations, planting under protective canopy trees to reduce thermal stress, and using superior varieties that are more tolerant of extreme Temperatures. This integrated approach allows for the sustainable optimization of land functions, supports vegetation rehabilitation, and strengthens the ecological functions of the area, such as runoff control, improved water infiltration, and biodiversity preservation. Therefore, marginal lands in Covalima District still hold strategic value for the development of conservation-based and adaptive forestry.

8.3 FOREST PLANT DEVELOPMENT ZONING

The zoning of forestry development in Covalima District reflects a systematic effort to manage forest resources sustainably. Covalima District has bio-physical characteristics that support the development of agroforestry and protected forest zones, covering a total of 31.18% of the total area. These two zones play a key role in maintaining ecological balance, while also providing a foundation for supporting food security, protecting natural resources, and enhancing the well-being of local communities.

A. Agroforestry

The Agroforestry zone covers an area of 318.55 km², or 26.49% of the total area of Covalima District, and is located at elevations above 500 meters above sea level with slope gradients ranging from 8%-25%. This topographical characteristic makes agroforestry an appropriate land management strategy, integrating forestry and agricultural components to maintain ecological balance and support sustainable land productivity. This area falls within agroclimatic zone D, which experiences a wet season lasting for 9 months. The long duration of rainfall provides advantages for the growth of various forest species managed in an integrated manner. The largest distribution of the Agroforestry area is found in Fatumean Sub-District (9.38%), followed by Forohem Sub-District (7.63%). Land use in these two districts demonstrates the role of agroforestry in supporting livelihoods while maintaining ecosystem balance.

One of the key commodities developed within the agroforestry system in this area is coffee, typically cultivated using a multistrata approach. Robusta coffee has potential for development in this region, classified as moderately suitable (S2), with limiting factors such as dry season duration, coarse fragments, surface rock, rock outcrops, and certain chemical parameters including pH, total nitrogen (N-total), available phosphorus (Available-P), and available potassium (Available-K). Arabica coffee, however, is classified as marginally suitable (S3), with permanent limiting factors such as Temperaturee, and manageable factors like effective depth, N-total, and Available-K.

Figure 8.1 Application of Agroforesty System and Coffe Development in Covalima District (Documentation Research, 2025)

B. Protected Forest

The Protected Forest area covers 56.45 km², or 4.69% of the total area of Covalima District, and is located at elevations between 100 and 500 meters above sea level, with slope gradients ranging from 8% to 25%. This area lies within agroclimatic zone E, which experiences a wet season lasting 8 months. The relatively high rainfall supports the growth of natural vegetation that serves as an ecosystem buffer and plays a role in maintaining water resource availability for surrounding areas. In addition, the protected forest serves as a habitat for various species of flora and fauna that require protection from the threats of deforestation and environmental degradation. The largest distribution of the Protected Forest area is found in Forohem Sub-District (1.74%), followed by Fatululic Sub-District (1.19%). The presence of this area underscores the importance of environmental conservation efforts through sustainable management. Conservation measures, such as reforestation, monitoring of illegal forest clearing, and community empowerment in forest management based on local wisdom, are key to maintaining the ecological functions of the protected forest in Covalima District.

The Reserva Tilomar area, spanning 5,733.05 ha, is one of the officially designated conservation areas. This area functions as a multifunctional protected space that supports ecosystem preservation, protection of endemic species, and provides resources for environmental education and research. With favorable bio-physical conditions, this area holds significant potential for development as an integrated conservation model that integrates ecological, scientific, and social dimensions. Its existence not only strengthens ecosystem resilience but also plays a role in increasing community awareness about the importance of environmental conservation efforts.

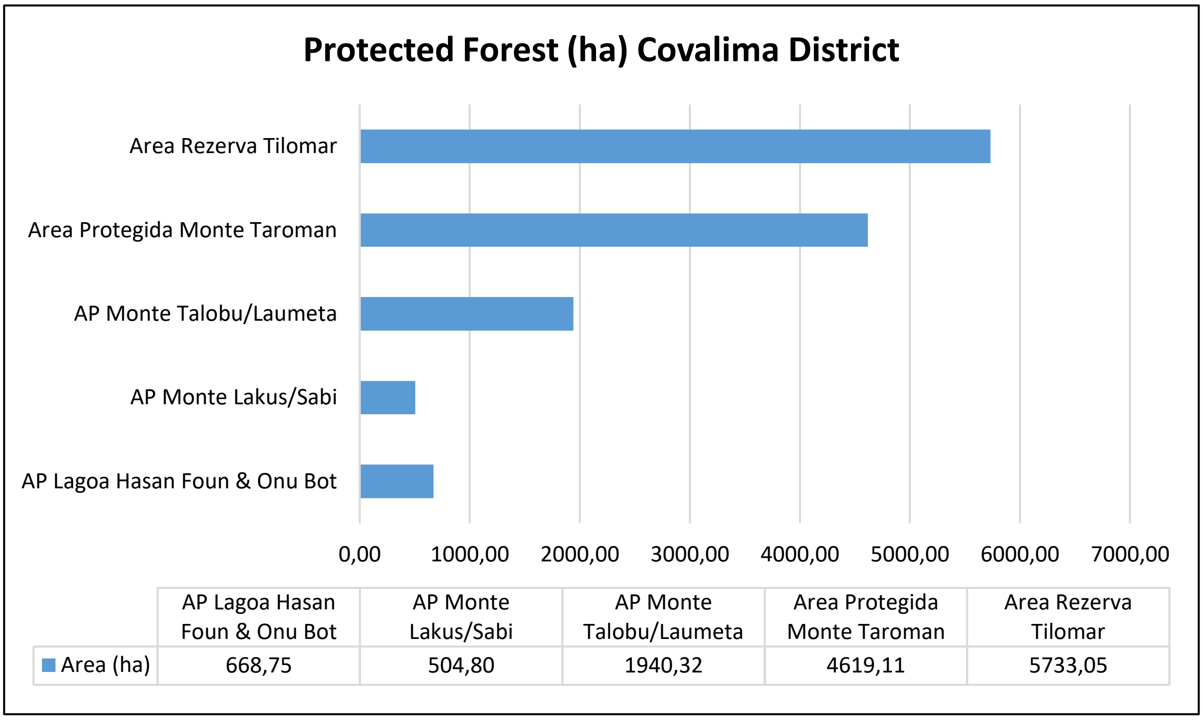


Figure 8.2 Protected Forest Area in Covalima District

The topography of Covalima, dominated by steep slopes and high Erosion levels, requires the implementation of strict and sustainable conservation strategies. Technical efforts that can be undertaken include contour planting to reduce surface runoff, using ground cover vegetation to strengthen soil structure and improve infiltration capacity, and constructing living fences as natural barriers against water runoff.

If properly managed, the protected forest areas in Covalima can function as ecological fortresses that support adaptation to climate change, facilitate landscape restoration, and encourage the development of conservation-based ecotourism. This approach not only provides ecological benefits but also yields simultaneous social and economic advantages for the local communities.

C. Mangrove Forest

The mangrove forests in Covalima District play a crucial ecological role for the coastal areas. The largest proportion is found in Suai Sub-District, covering approximately 0.89%, followed by Zumalai Sub-District (0.44%) and Tilomar Sub-District (0.19%). The presence of mangroves in these three areas acts as a natural protector of the coastline from abrasion and saltwater intrusion, sediment retention, and provides habitats for various coastal species. In addition to their ecological function, mangroves also offer social and economic benefits, such as supporting traditional fishing activities and providing potential for conservation-based ecotourism. From a global perspective, mangroves serve as effective blue carbon absorbers, contributing to climate change mitigation. With proper management through rehabilitation, replanting local species, and involving communities in community-based management, the mangrove forests in Covalima can provide sustained ecological, social, and economic benefits while strengthening coastal resilience against environmental pressures.

8.4 POTENTIAL FOR SANDALWOOD DEVELOPMENT

Sandalwood (*Santalum album* L.) is a high-value tree species that plays a significant ecological, economic, and cultural role. The essential oil derived from its wood is widely used in the perfume, cosmetics, and pharmaceutical industries and holds symbolic value in the traditions of Asian communities, including in Timor-Leste. Additionally, sandalwood is used as raw material for crafts, carvings, and high-value art products, making it a commodity with broad and sustainable market appeal.

The land suitability evaluation results indicate that the potential for sandalwood development in Covalima District falls under class S3 (marginally suitable). This means that the land is still viable for sandalwood cultivation, although there are some bio-physical constraints that require technical intervention. Recommended management strategies include selecting appropriate planting sites, maintaining host trees to support growth, and applying adaptive silvicultural techniques. With a conservation-based management strategy, these limitations do not pose a barrier to making sandalwood a key regional commodity.

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

IX. LIVESTOCK POTENTIAL

9.1 INTRODUCTION

Timor-Leste is a country largely composed of mountains and highlands. Administratively, Timor-Leste is divided into 14 districts: Ainaro, Aileu, Ataúro, Bobonaro, Baucau, Covalima, Dili, Ermera, Lautém, Liquiçá, Manufahi, Manatuto, Região Administrativa Especial da Oe-Cusse Ambeno (RAEOA), and Viqueque. The country has two distinct seasons: the dry season from June to November and the rainy season from December to May. The topography, dominated by hills, along with its proximity to the Australian continent, makes Timor-Leste susceptible to the influence of the dry easterly monsoon winds. As a result, much of the country experiences drought conditions. Additionally, the low rainfall further limits vegetation growth in various parts of the country.

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

Forage can come from both natural sources and cultivation, including from grazing lands (Priyanto, 2016). Optimal utilization of livestock land is determined by both anthropogenic factors and bio-physical land conditions. Therefore, the implementation of various technological innovations and institutional support is necessary to ensure that land resources are utilized effectively and optimally (Suryana and Rahman, 2006).

Generally, the livestock sector in Timor-Leste faces several challenges. One of the main causes is the traditional and extensive livestock management system, which has not yet yielded optimal production. Low levels of awareness, knowledge, and technology adoption among farmers also serve as significant barriers, especially regarding the availability of adequate and high-quality animal feed. Livestock is generally raised as household savings that can be sold in emergencies. Additionally, some communities still use livestock as draft animals for land cultivation under traditional management systems.

The success of livestock enterprises relies on three main factors: breeding, feed, and management (Aman *et al*., 2019). These factors are interconnected as part of a single system: if one aspect is neglected or receives insufficient attention, the handling of other aspects, no matter how well-managed, will not result in optimal output. The productivity of livestock, particularly ruminants, is highly dependent on effective feed management, including the quantity, quality, and sustainable availability of feed (Rokhayati and Evadewi, 2023). According to Winarni and Sukaesih (2015), feed plays a crucial role in supporting livestock development because it directly affects production, productivity, and animal health. The quality of animal feed itself is influenced by the variety of forage, genotype, harvest maturity, season, and the management practices applied (Adesogan *et al*., 2015).

One of the initial steps in the development of the livestock sector in Timor-Leste is the optimization of land use for the sustainable provision of animal feed. For the effective utilization of land, it is essential to match the characteristics of the land with the type of forage to be cultivated. Therefore, land suitability evaluation becomes an essential approach in assessing the potential and carrying capacity of land resources (Harahap *et al*., 2019). This evaluation not only assesses land potential but also determines its suitability for various uses based on the level of management applied (Nugroho *et al*., 2014). Land suitability evaluation requires environmental data and soil quality of a given area. The evaluation is carried out by identifying various land characteristics, such as topography, climate, soil conditions, quality, and other physical environmental attributes (Iswan *et al*., 2019). Through this evaluation process, information about bio-physical land resources, including climate and soil, can be obtained, thus determining the land suitability class and identifying limiting factors that need to be improved (Jawang *et al*., 2018).

9.2 RESEARCH METHOD

The research was conducted using survey methods and descriptive analysis on the study areas selected purposively, specifically the KTS Center (*Karau Timor Susubeen)* and the recommended livestock areas. The types of data collected include both quantitative and qualitative data sourced from primary and secondary data. Primary data includes interview data covering livestock production and socio-economic factors, as well as bio-physical land observations and soil characteristics for assessing the suitability of land for forage production. Bio-physical and soil characteristics were further analyzed according to laboratory standards. The secondary data used were from the 2019 agricultural census of Timor-Leste.

The interview data obtained were analyzed using the simple tabulation method from the Miles and Huberman model, which includes data reduction, data presentation, conclusion drawing, and verification. Bio-physical land data and soil characteristics were analyzed and presented using Geographic Information System (GIS) approaches, with GIS software applied in various ways depending on the data form and the objectives to be achieved (Rusdi *et al.*, 2015).

A. Procedure Research

1. Observation of Livestock Production and Socio-Economic Aspecta

Observations were conducted using interview techniques with the following parameters:

- Livestock types
- Livestock population
- Land area
- Husbandry/breeding system
- Feed and nutrition management system
- Water sources
- Breeding system
- Livestock health management system
- Livestock products
- Marketing
- Infrastructure
- Characteristics of farmers
- Customs/traditions

2. Suitability of Land For Forage Production

The research procedure for this aspect is detailed in **Chapter III (Methodology)**.

9.3 GENERAL OVERVIEW

A. General Existing Conditions

The livestock sector plays a crucial role in supporting the livelihoods of many households in Covalima District. The distribution of households engaged in livestock activities shows significant differences across each Sub-District. In Suai Sub-District, the number of households involved in the livestock sector reaches 706 households (62.76%). In contrast, Fatululic and Fatumean Sub-Districts have the fewest households engaged in livestock, with only 4 households (0.36%).

Nevertheless, their contribution remains significant in meeting local needs and preserving the livestock traditions that have become an integral part of the local community's way of life. With these differences, each Sub-District plays a distinct role in sustaining the livestock sector in Covalima. The number of agricultural households involved in livestock activities is presented in **Figure 9.1.**

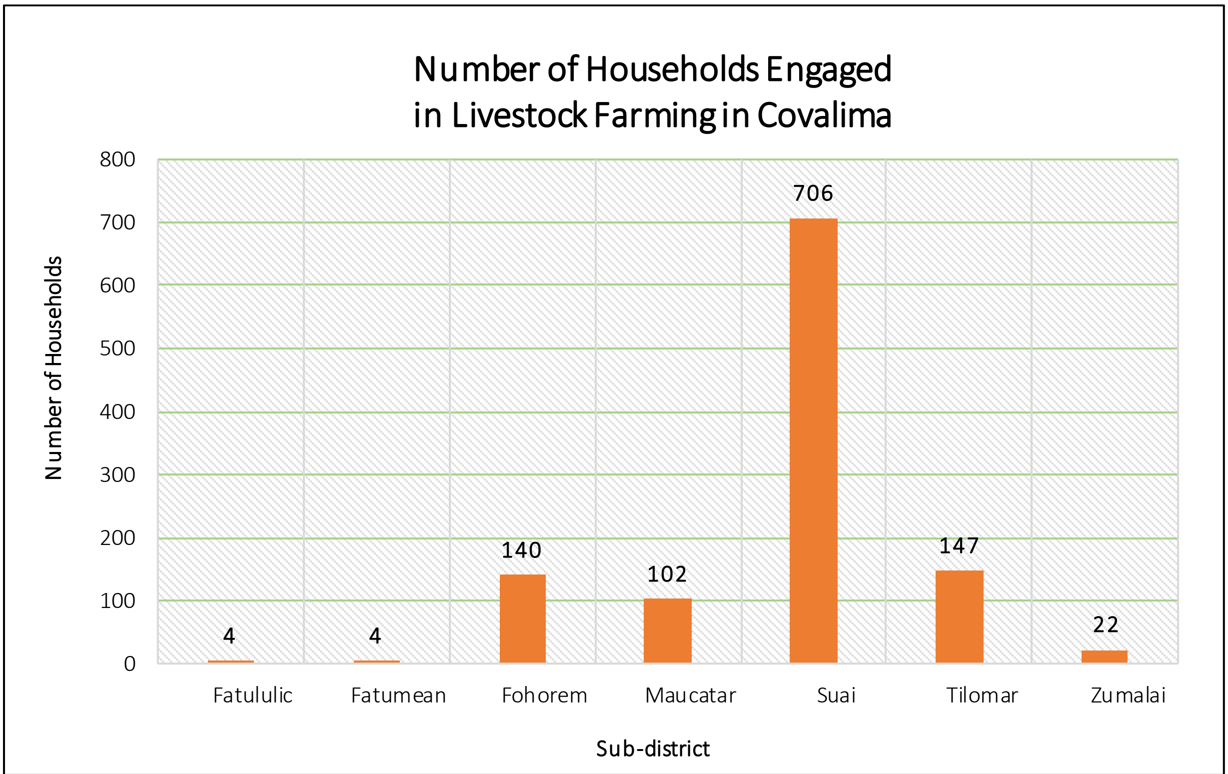


Figure 9.1 Number of Households Engaged in Livestock Activities
(Source: Timor-Leste Agriculture Census, 2019)

Cattle farming, which is the predominant type of livestock farming in Covalima District, involves the largest number of households. In Suai Sub-District, the highest number of cattle-keeping households is 2,177 households (32%), with a total cattle population of 10,814 animals. In contrast, Fatululic Sub-District has the fewest cattle-keeping households, with 339 households (5%) and a total population of 3,313 animals **(Figures 9.2 and 9.3).**

The largest population of horses is kept in Zumalai Sub-District, with 67 households (31%) and a population of 153 horses. Conversely, the fewest horse-keeping households are found in Tilomar Sub-District, with 8 households (4%) and a population of 31 horses **(Figures 9.2 and 9.3).**

For buffalo farming, Zumalai Sub-District shows dominance, with 341 households (74%) and a population of 1,744 buffaloes. In contrast, Fatululic Sub-District has the fewest buffalo-keeping households, with only 4 households (1%) and a population of 10 buffaloes **(Figures 9.2 and 9.3).** Dairy cattle are kept in only two Sub-Districts, Suai and Fatululic. In Suai Sub-District, there are 2 dairy cattle households, representing 67% of the dairy cattle population, while in Fatululic Sub-District, there is only 1 dairy cattle household, accounting for 33%.

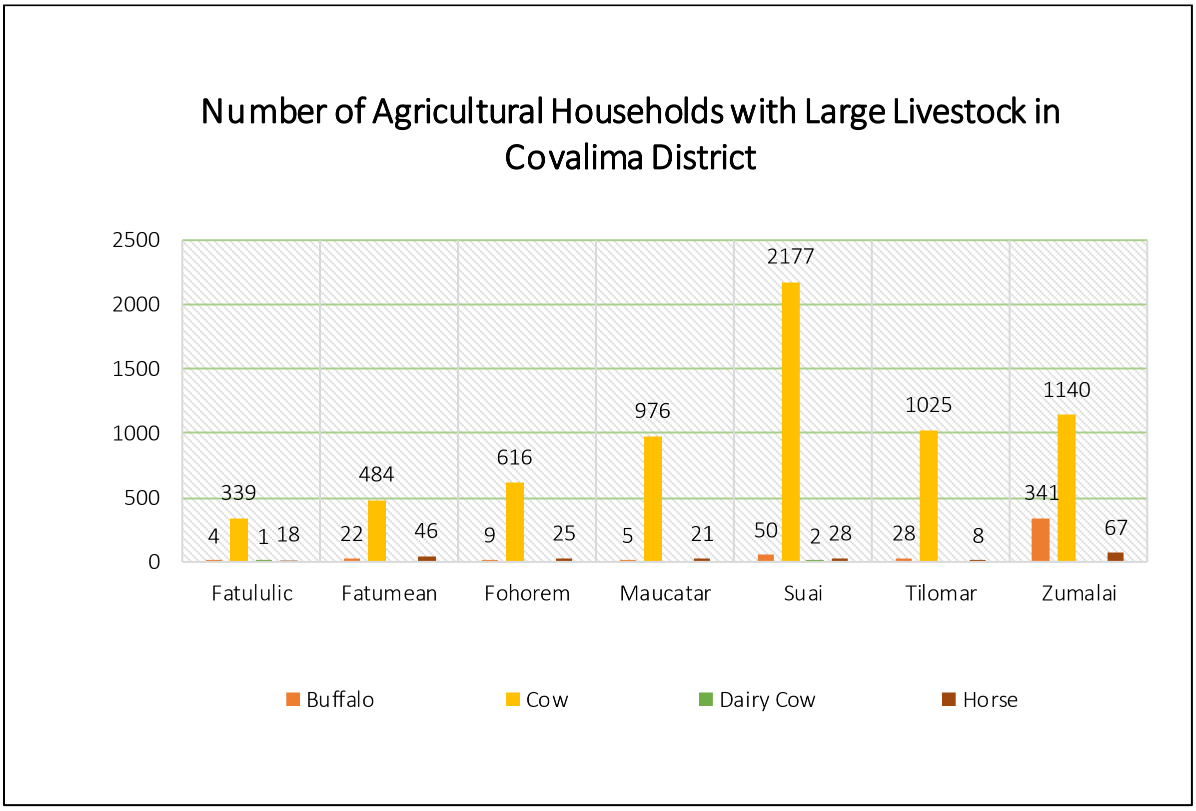


Figure 9.2 Number of Households with Large Livestock
(Source: Agriculture Timor-Leste Census, 2019)

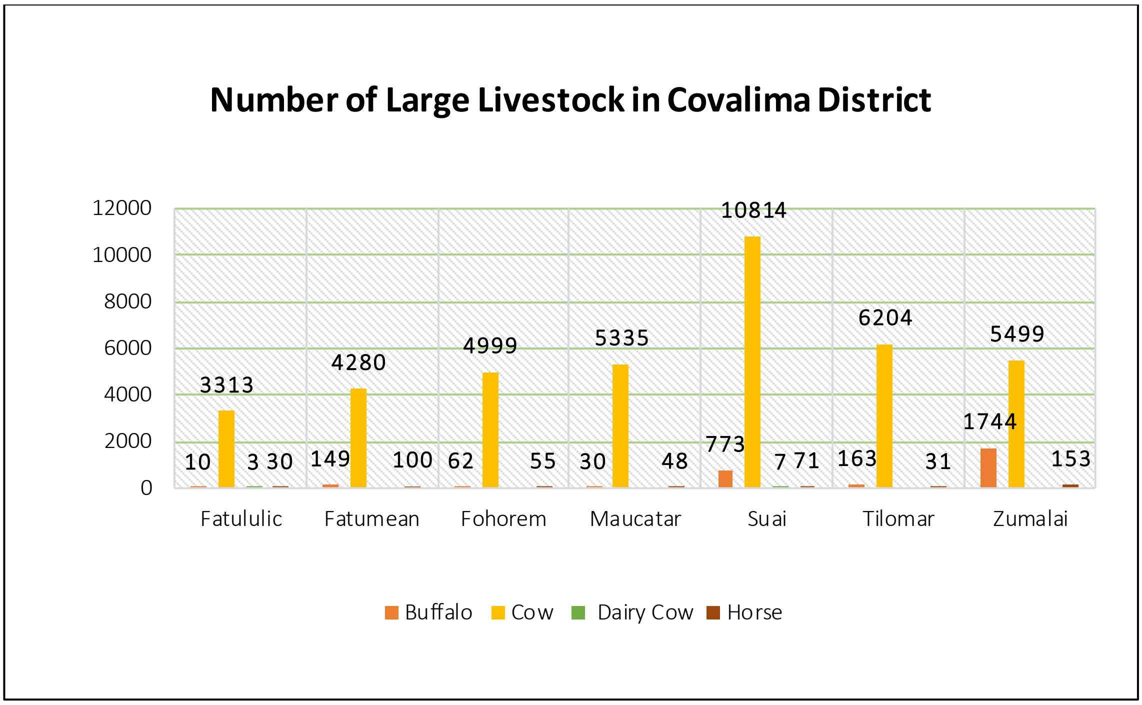


Figure 9.3 Number of Large Livestock
(Source: Timor-Leste Agriculture Census, 2019)

In Covalima District, pig farming is the most common type of small livestock farming. Suai Sub-District has the highest number of pig-keeping households, with 2,945 households (33%) and a population of 14,502 pigs. The lowest number of pig-keeping households is found in Fatululic Sub-District, with 358 households (4%) and a population of 1,544 pigs **(Figures 9.4 and 9.5).**

The number of households keeping goats varies across Sub-Districts. Zumalai Sub-District has the highest number of goat-keeping households, with 370 households (34%) and a population of 1,610 goats, while Fohorem Sub-District has the fewest goat-keeping households, with 42 households (4%) and a population of 232 goats **(Figures 9.4 and 9.5).** Sheep farming is also widespread, although in relatively small numbers. Suai Sub-District has 26 households (59%) keeping sheep, while the smallest numbers are found in Maucatar and Tilomar Sub-Districts, each with 2 households (5%).

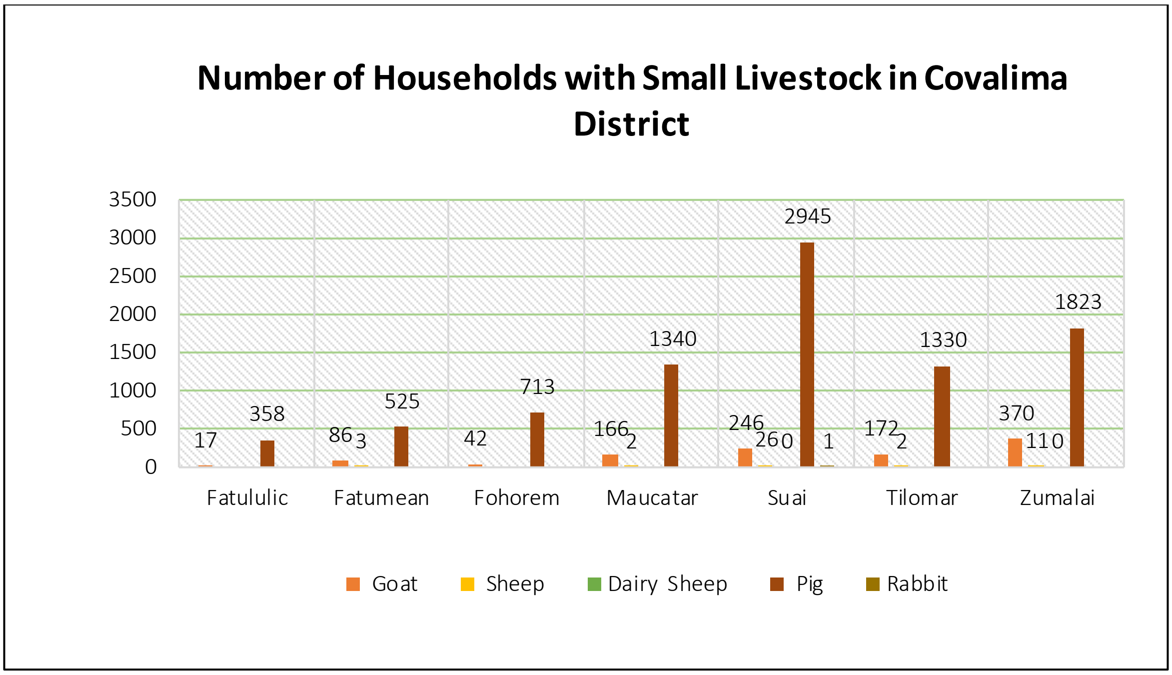


Figure 9.4 Number of Households with Small Livestock
(Source: Timor-Leste Agriculture Census, 2019)

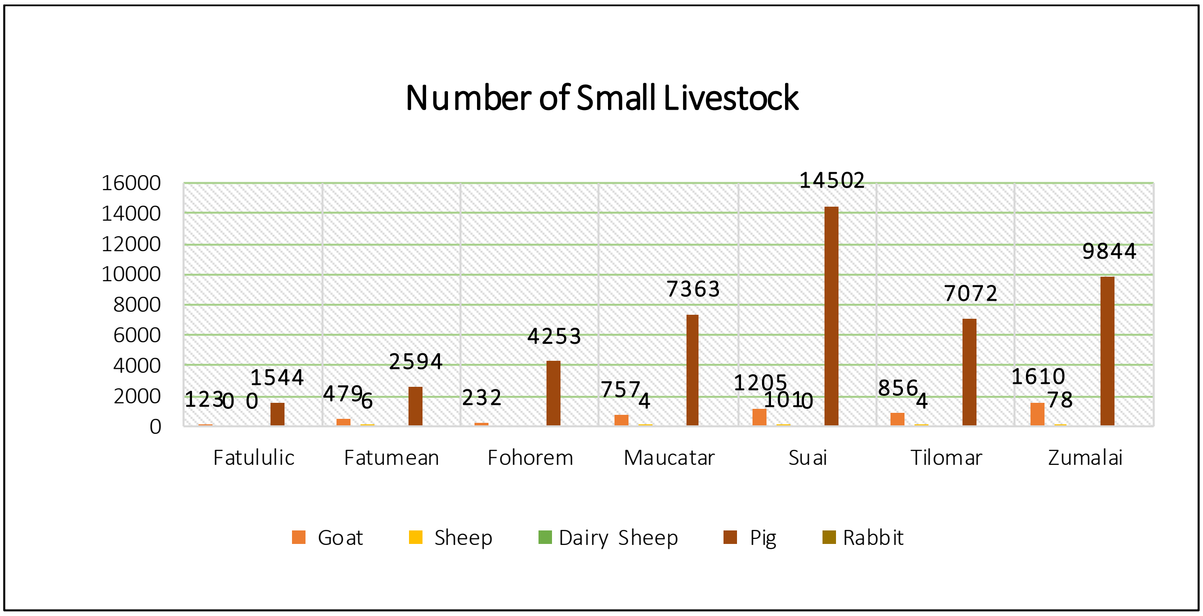


Figure 9.5 Number of Small Livestock
(Source: Timor-Leste Agriculture Census, 2019)

The number of households keeping poultry in Covalima District shows significant differences across Sub-Districts, with chickens being the most commonly raised poultry type **(Figure 9.6)**. Suai Sub-District has the highest number of poultry-keeping households, with 2,245 households, or about 31%, and a total of 25,583 birds. Meanwhile, Fatululic Sub-District has the smallest number of poultry-keeping households, with 369 households, or 5%, and a total of 5,556 birds **(Figures 9.6 and 9.7)**.

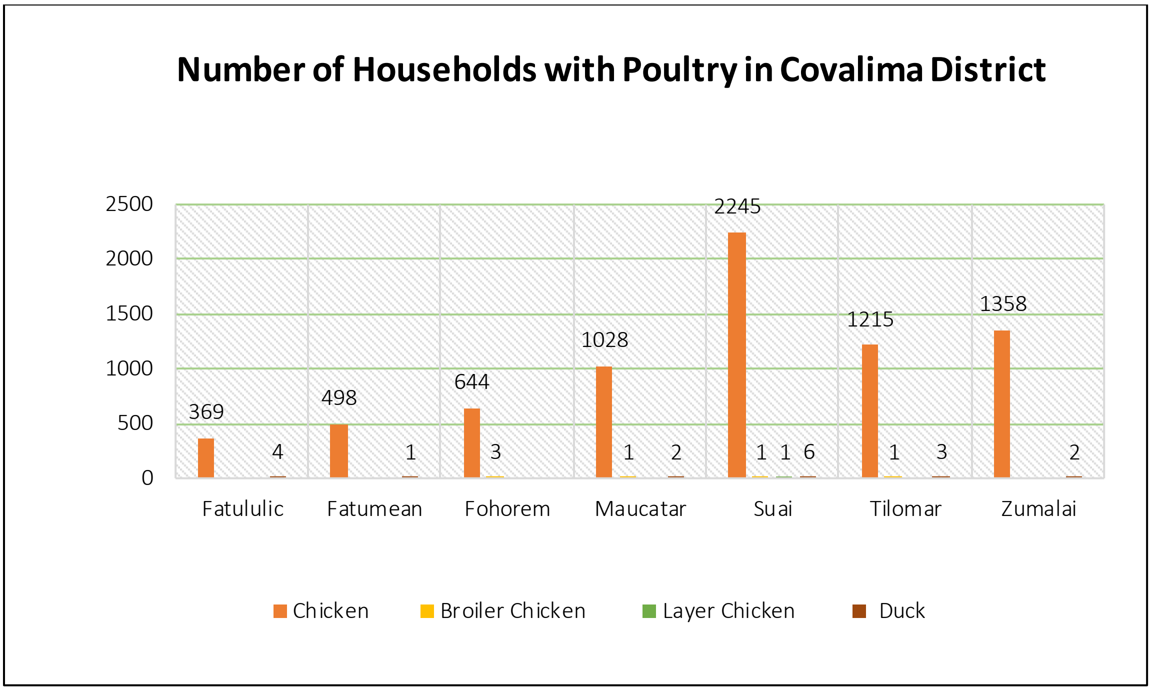


Figure 9.6 Number of Households with Poultry
(Source: Timor-Leste Agriculture Census, 2019)

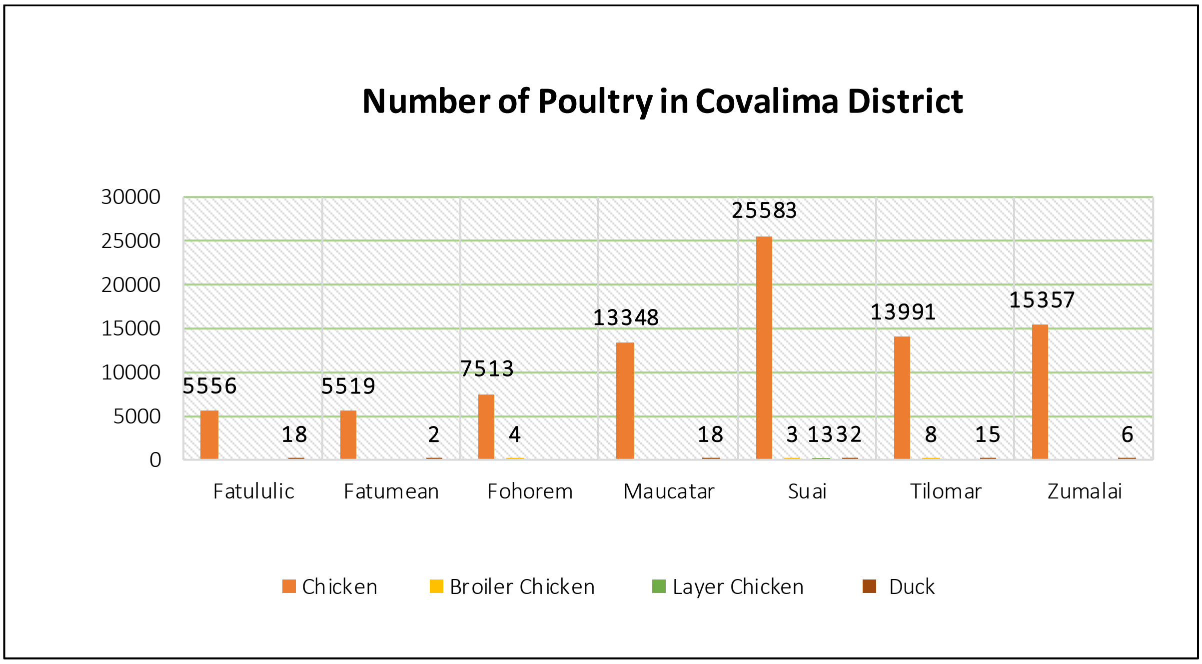


Figure 9.7 Number of Poultry
(Source: Timor-Leste Agriculture Census, 2019)

Grazing land is an important asset that can serve as a primary source of animal feed, particularly for livestock such as cattle, goats, and sheep, which require high-quality grass to support growth and production in a sustainable livestock sector. Covalima District has two types of grazing land: temporary and permanent.

The area of grassland and grazing land in Covalima District varies across Sub-Districts. Zumalai Sub-District has the largest area of permanent grazing land, with 59.01 ha (78.77%), followed by Suai Sub-District with 10.98 ha (14.66%), while other Sub-Districts, such as Fatululic and Maucatar, have no permanent grazing land at all. For temporary land, Suai Sub-District shows the highest area, with 6.71 ha (33.55%), followed by Tilomar and Zumalai, with 4.80 ha (24.01%) and 4.08 ha (20.38%), respectively. This indicates that the use of land for grazing and pasture in Covalima District is highly concentrated in a few Sub-Districts, such as Zumalai and Suai, while other Sub-Districts have smaller or no contributions. The area of grazing land is presented in **Figure 9.8.**

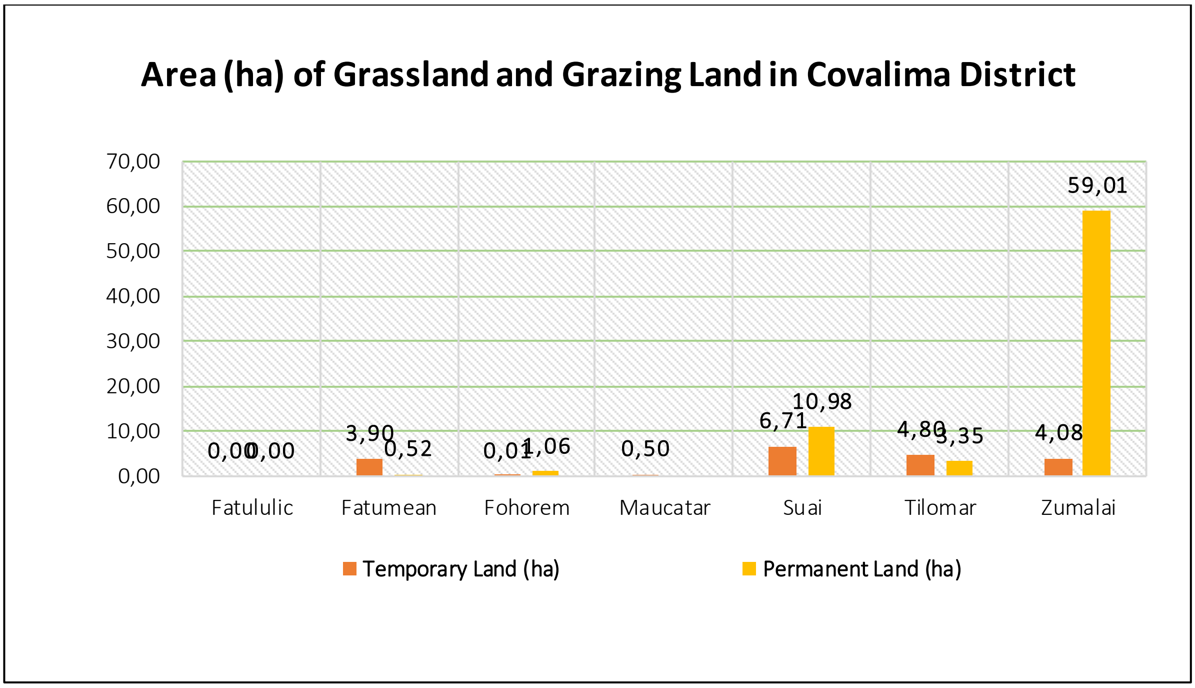


Figure 9.8 Grazing Land Area
(Source Timor-Leste: Agriculture Census, 2019)

B. Existing Conditions of Survey Locations

Observations were conducted at four different locations: Suai, Lactos, Tilomar, and Suailoro. In Kunain Village, Suai Sub-District, there is an active livestock group managing an area of 2 ha. This land has been planted with *Lamtoro taramba* and is used for fattening five bali cattle. In the future, this location is planned to be further developed with the planting of other forage crops, such as king grass and elephant grass, to increase feed availability.

In the Lactos, Calobor, and Fohorem areas, the observation locations show that the area previously functioned as a center for bali cattle development, but activities were halted due to a strong wind disaster. Currently, there are plans to reactivate the center. The land, located in a hilly area with rocky soil characteristics, requires a more in-depth land suitability study. The land evaluation results are expected to provide accurate information to support effective and sustainable reactivation.

In Kasabauk, Tilomar, more than 9 ha of land is utilized by individual farmers for the development of bali cattle, goats, village chickens, and pigs. Integrated farming activities have also been carried out through the cultivation of horticultural crops and forage such as Leucaena Future plans include the expansion of the area for planting king grass and elephant grass to improve feed productivity.

Meanwhile, in Manaikun Village, Suailoro, Suai Sub-District, there is a livestock group consisting of 10 farmers with a total of 15 bali cattle focused on fattening activities. Of the total land area of 1 ha, approximately 5,000 m² (50 x 100 m) is used for planting *Leucaena* Therefore, expanding the forage area is a priority to ensure continuous feed availability and the sustainability of the livestock business.

Figure 9.9 Existing Conditions of Survey Location in Covalima District
(Source: Researcher's Documentation, 2025)

9.4 DISCUSSION

A. Evaluation of Land Suitability for Forage Corps

The land suitability analysis for forage crops in Covalima District is a method used to evaluate the compatibility of various types of forage crops and grasses for pasturelands in a specific area. This analysis aims to facilitate the development of livestock feed resources while ensuring their optimal availability. According to Djaenudin *et al*. (2003), land suitability is defined as the degree of compatibility of land for a specific use. Land suitability can be assessed based on current conditions (actual land suitability) or after improvements have been made (potential land suitability). The land suitability evaluation in Timor-Leste uses a matching method, comparing land characteristic and quality data with land suitability criteria based on the growth requirements of the evaluated crops. Several forage crops that have been mapped according to the land resource potential include elephant grass (*Pennisetum purpureum*), leguminous plants, and field grasses.

The results of the land suitability evaluation in Covalima District, Sub-Districts of Fatululic, Fatumean, Forohem, Maucatar, Suai, Tilomar, and Zumalai show potential for the development of forage crops, including elephant grass, Setaria, leguminous plants, and pastures, as presented in **Table 7.3** of this report. The table shows that, in terms of actual land suitability for forage crops and grazing areas, the land varies from S2 (moderately suitable) to N (not suitable), with limiting factors including rainfall, slope, erosion, pH, total nitrogen (N-total), and available potassium (K-available) for elephant grass and Setaria. Additionally, limiting factors such as effective soil depth for leguminous plants and dry months for grazing areas are present. These factors can still be technically improved, such as by implementing irrigation systems (e.g., sprinklers), planting soil stabilizer plants on terraces, constructing terraces, adding sulfur, ZA/urea fertilizers, potassium fertilizers, and creating planting holes to improve effective soil depth.

To improve the development of livestock areas, particularly forage crops in Covalima District, several actions need to be taken to enhance both the quantity and quality of forage, including:

1. **Planting leguminous forage corps**

The planting of leguminous forage crops should be prioritized, as legumes generally have higher nutritional content compared to grasses. However, since legumes have certain limitations in their use, the proportion of legumes to grasses must be carefully considered. As a guideline, Susetyo (1980) recommends that an ideal pasture should consist of 60% grass and 40% legumes. Furthermore, according to Skerman (1977), legumes also help in controlling erosion, often more effectively than forests, due to their strong and deep root systems.

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

Increasing the diversity of forage species, both legumes and grasses, is a key aspect of developing livestock feed. The greater the diversity of forage species consumed by livestock, particularly ruminants, the more likely it is that their nutritional needs will be met. Several high-nutrient legume species that have potential for development include *Indigofera*, *Calliandra*, *Tamarindus indica*, and *Stylosanthes*. A commonly found local legume is *Leucaena*. It is important to note that *Leucaena* should be fed to pregnant livestock cautiously. Despite its high nutritional content, *Leucaena* leaves contain anti-nutritional substances such as mimosine and cyanogenic acid, which are toxic if consumed in large amounts. This issue can be addressed by feeding *Lamtoro* in moderation, mixed with other feeds, and ensuring that it is wilted (air-dried) to reduce the concentration of anti-nutritional substances.

B. Potential and Ecological Suitability for Livestock

Covalima District has a total area of 120,168.72 ha, with 67,973 ha allocated for livestock development. This potential must be optimally utilized through human resource empowerment and effective use of available land. One critical factor 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 considered less potential for livestock development. Therefore, the development of livestock activities in Covalima District must consider ecological suitability.

After obtaining measurements for each parameter in the field, including geophysical parameters such as temperature and rainfall, and soil chemical parameters such as organic carbon (C-organic), base saturation, cation exchange capacity, soil texture, and others, these data were analyzed using Geographic Information System (GIS) applications to determine the ecological suitability for five types of livestock: sheep, beef cattle, dairy cattle, pigs, and buffalo. The ecological land suitability map for livestock in Covalima District is shown in **Figure 9.10**.

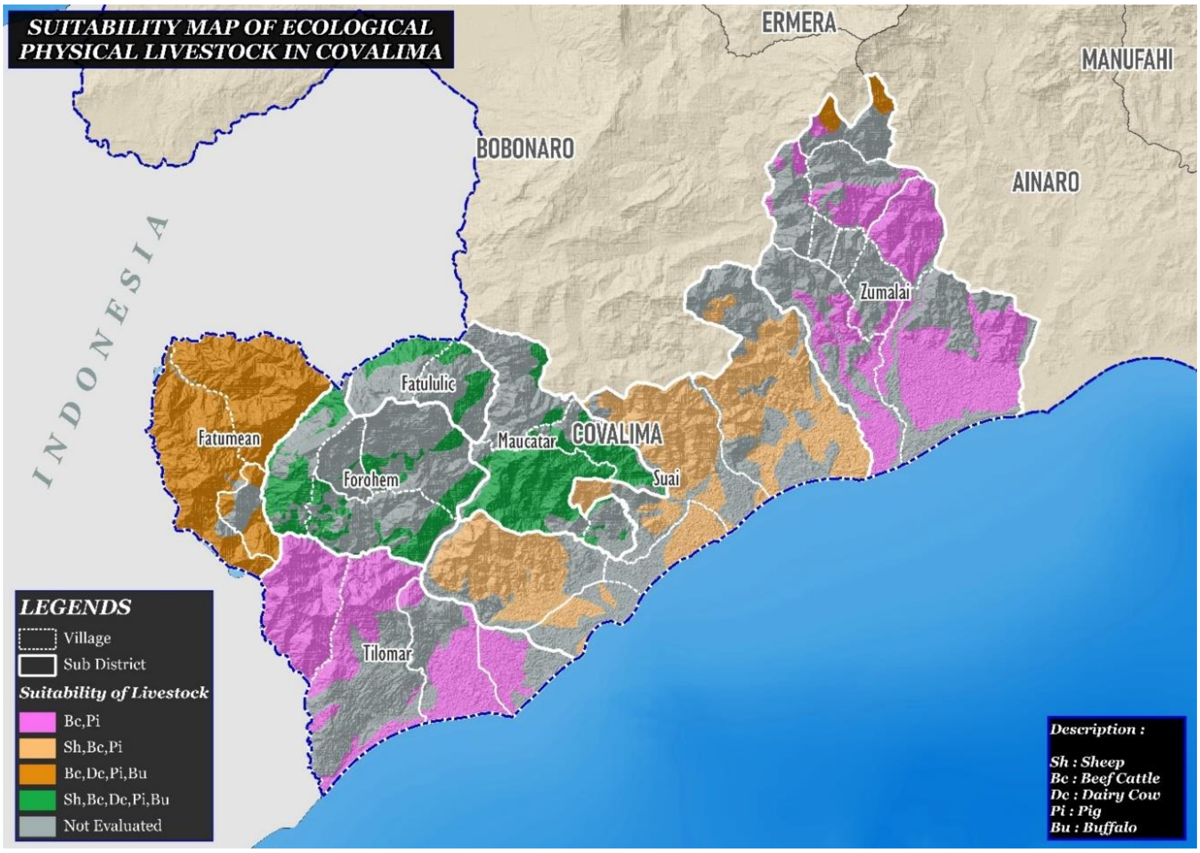


Figure 9.10 Ecological Physical Suitability Map for Livestock in Covalima District

The land available for livestock development in Covalima District consists of mixed gardens and grazing land. These areas are categorized as available because they are assumed to be capable of producing livestock forage in the form of grasses, legumes, or agricultural crop residues. Land categorized as unavailable for livestock development includes forests and paddy fields. From a technical perspective, this limitation can be addressed by constructing livestock enclosures with proper air circulation and ventilation systems. However, for dairy cattle, temperature is a critical factor that must be met for successful breeding.

Table 9.1 Area Available for Livestock development in Covalima District

Sub-District	Livestock Development Suitability Results					Area (ha)
	Sheep	Beef Cattle	Dairy Cattle	Pig	Bufallo	
Fatululic	S	S	S	S	S	1.370
Fatumean	N	S	S	S	S	12.396,36
Forohem	S	S	S	S	S	4.256,10
Maucatar	S	S	S	S	S	6.108,39
Suai	S	S	N	S	N	18.414,28
Tilomar	N	S	N	S	N	11.961,12
Zumalai	N	S	N	S	N	13.466,75

Table 9.1 shows the area available for livestock development in Covalima District. According to the data analysis presented in **Table 9.1**, the ecological suitability for large livestock development, which includes sheep, beef cattle, dairy cattle, pigs, and buffalo, shows varying spatial distribution across the study area. Sub-District Suai is the most dominant area for large livestock development in Covalima District, followed by Sub-Districts Zumalai, Fatumean, Tilomar, Maucatar, and Forohem. Sub-District Fatululic has the smallest area allocated for livestock development.

Sub-Districts Fatululic, Forohem, and Maucatar are suitable for the development of sheep, beef cattle, dairy cattle, pigs, and buffalo. In Sub-District Fatumean, livestock development is suitable for beef cattle, dairy cattle, pigs, and buffalo but not for sheep due to temperature limitations. Sub-District Suai is suitable for sheep, beef cattle, and pigs, but not for dairy cattle and buffalo due to temperature limitations. Sub-District Tilomar is suitable for beef cattle and pigs but not for sheep, dairy cattle, and buffalo due to temperature limitations. For poultry, the ecological suitability of the land is categorized as very high and uniform, covering 100% of the analyzed area. This is due to the biological characteristics of poultry, which have a high ability to adapt to various environmental conditions, allowing them to be raised in almost all available land types.

In support of the livestock sector development program, it is necessary to identify and map areas that primarily function as livestock husbandry locations and forage crop cultivation sites. Covalima District has an average environmental temperature of approximately 24.90°C and annual rainfall of 1,848.35 mm/yr, providing an ecological potential conducive to supporting sustainable livestock operations. This condition also supports the continuous availability of forage throughout the year. Environmental temperature plays a central role in determining thermal comfort and livestock productivity. Extremely low temperatures can cause cold stress in livestock, which triggers an increase in body heat production and basal metabolic rate. If this condition persists without adequate feed support, the livestock's metabolic energy will be reduced, decreasing its ability to withstand extreme temperatures. This condition negatively impacts livestock growth, reduces productivity, and significantly increases the risk of disease outbreaks.

Conversely, extremely high environmental temperatures lead to decreased feed intake as livestock opt to increase water consumption. This reduction in nutrient intake directly impacts livestock performance. Therefore, optimal environmental management, particularly temperature and humidity regulation, is essential for sustainable livestock farming. This effort aims to create conditions that support the physiological balance of livestock, ensuring maximal productivity.

C. Social Economics of Livestock Framing in the Community

For the people of Covalima District, livestock plays a crucial and multifunctional role, far beyond merely being a source of food. Livestock is an integral part of the subsistence farming system and the developing civilization. It is still common to see people using livestock, such as cattle, buffalo, and horses, as draft animals for plowing rice fields and farmland. This use of animal power enables farmers to cultivate larger areas and significantly improve agricultural productivity. Moreover, in some cultures, livestock holds social, economic, or ritual significance. For example, in some traditions, livestock is used as dowries or offerings in cultural ceremonies. Additionally, the number of livestock owned by an individual often serves as a benchmark for wealth and social status in the community.

One of the endemic livestock species found in Timor-Leste is the Timor Buffalo (*karaw timor*). The Timor Buffalo holds an important place in the social life of Timor-Leste, particularly as an offering in death, birth, and wedding ceremonies. This buffalo is also involved in traditional transactions, such as land sales, and its manure is used as fertilizer for crops. In addition, it is a common practice among the local community to consume buffalo milk as a source of animal protein. As a result, Timor buffalo is highly valued and expensive.

Buffalo milk has been consumed by the community for generations and is one of the preferred types of milk, alongside cow and goat milk. Buffalo milk is thicker and has a distinctive smell compared to cow's milk. In the past, the community consumed Timor Buffalo milk directly without further processing, making it an essential part of the cultural identity.

Livestock farming is generally carried out using a traditional free-range grazing system, known as an extensive system. According to Williamson and Payne (1993), in the extensive management system, livestock are allowed to roam freely and graze on available natural forage. In this system, livestock are released in groups, usually with a mix of males and females. The key characteristic of extensive farming is that no housing is provided, and no supplemental feeding is given (Jamili, M. A., 2022). The advantages of the extensive system include low labor requirements, short working hours, and livestock's ability to find feed in pastures or former agricultural land. However, the challenges faced include difficulty controlling livestock feed consumption and susceptibility to diseases and mortality. Free-ranging and poorly supervised livestock also contribute to social issues, such as livestock theft and damage to farmers' crops.

The livestock business is still largely dependent on traditional local knowledge passed down through generations. The lack of large-scale livestock industries means that livestock production has not reached its optimal level, and many aspects still need improvement. Livestock distribution among the community remains relatively low due to limited capital and low breeding practices. This is because increasing livestock numbers requires significant financial investment and time. As a result, the community does not rely on livestock as a primary source of income, leading to a lack of livestock production in the area (Serey *et al*., 2014).

Interviews revealed that the community received assistance in the form of cattle and buffalo in 2014 from MAPPF. However, over time, due to poor supervision and a lack of education, these donations did not develop as initially intended. The community used the livestock to meet household needs or as part of dowries (*belis*). As a result, attention to the sustainability of livestock breeding has been neglected, which could hinder future development.

Other challenges in livestock farming are complex, spanning from pre-production to post-production stages, and require further infrastructure development. In terms of breeding, the community still practices natural mating without knowledge of artificial insemination, making sustainable breeding difficult. Additionally, there is a lack of understanding regarding good livestock management practices. The community has not been educated on proper feed management to enhance livestock productivity. Furthermore, in terms of marketing, farmers are only able to sell live animals, making it difficult to increase livestock product prices. Despite improved access from Dili, the capital, to other districts, inadequate road infrastructure remains a barrier to marketing livestock products to broader markets.

Considering the various challenges faced from pre-production to post-production, these issues must be addressed to lay the groundwork for a comprehensive livestock development master plan. Recommended improvements should begin with education on livestock breeding and the introduction of artificial insemination technology. In addition, livestock management education is essential to motivate the community to adopt a more economically oriented approach to livestock farming, moving beyond just a source of family savings. The government should not only focus on education but also provide financial support, such as credit loans, to facilitate livestock businesses. Enhancing the marketability of livestock products can also be achieved by educating farmers and opening new marketing channels, not limited to selling live animals.

X. FRESHWATER FISHERIES POTENTIAL

10.1 INTRODUCTION

Timor-Leste, an archipelagic country with a tropical climate, holds substantial potential for the development of the fisheries sector, not only in capture fisheries but also in the aquaculture subsector. As a strategic approach to address food security challenges and boost local economic growth, aquaculture development is a highly relevant option, particularly in areas with untapped land and water resources. Aquaculture includes not only freshwater fish farming in ponds but also systems for brackish water production, such as ponds and coastal areas that support the cultivation of brackish water species, such as shrimp and milkfish. One region with significant potential in this regard is Covalima District.

Covalima is located in the southern part of Timor Island, directly bordering the Timor Sea. Its strategic location, combining coastal areas, lowlands, and hills, gives the region a diverse ecosystem that is ideal for aquaculture development. Several rivers and permanent springs in the area can be utilized for freshwater farming, while the coastal and saline swamp areas offer great opportunities for brackish water aquaculture. This combination provides Covalima with a comparative advantage over other inland regions, especially in terms of commodity diversification and farming systems.

In the context of sustainable development, the development of aquaculture in Covalima not only aims to increase animal protein-based food production but also serves as a lever for local economic growth, job creation, and the protection of natural resources through productive land use. This aligns with the Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger), SDG 8 (Decent Work and Economic Growth), and SDGs 14 and 15, which focus on aquatic and terrestrial ecosystems.

However, the aquaculture potential in Covalima has not yet been fully optimized. Some of the challenges faced include limited supporting infrastructure, a lack of technical training, limited access to aquaculture technology, and land use that does not align with the specific characteristics of each area. The absence of comprehensive mapping on land suitability for aquaculture remains a significant barrier to the development of data-driven and field-based initiatives.

Therefore, land suitability evaluation becomes a critical step to ensure that the chosen locations truly support sustainable aquaculture operations. This assessment encompasses several important aspects, such as topography (slope gradient), which affects the ease of pond construction and potential erosion. Soil conditions are also crucial, including organic material content as an indicator of fertility, soil pH as a determinant of acid-base balance, and the clay content percentage, which affects the soil's ability to retain water.

Water quality is another key parameter in determining the feasibility of aquaculture. Factors such as temperature, salinity, total dissolved solids (TDS), pH, dissolved oxygen (DO), and ammonia levels significantly influence the health and growth of aquaculture organisms. Additionally, climate factors such as annual rainfall patterns and dry season duration determine water availability, flood risks, and the potential for drought, all of which impact pond management.

The evaluation is carried out through an integrated approach, combining laboratory analysis, field surveys, and climate studies. The land suitability assessment uses a weighted matrix to determine the viability of locations for aquaculture development. This approach aims to generate an accurate and practical land potential map that can serve as the basis for adaptive and sustainable aquaculture development planning in Covalima. The study focuses solely on freshwater aquaculture, particularly on cultivation activities carried out by communities in lowland and coastal areas.

By integrating both ecological and technical aspects, this study not only addresses the practical needs of aquaculture practitioners in Covalima District but also contributes significantly to achieving the Sustainable Development Goals (SDGs), especially in ensuring food security (SDG 2), decent work and responsible economic growth (SDG 8), and the preservation of terrestrial ecosystems (SDG 15). Furthermore, the findings of this study are expected to provide scientific support for the government in formulating strategic policies and long-term plans for integrated aquaculture sector development.

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**.

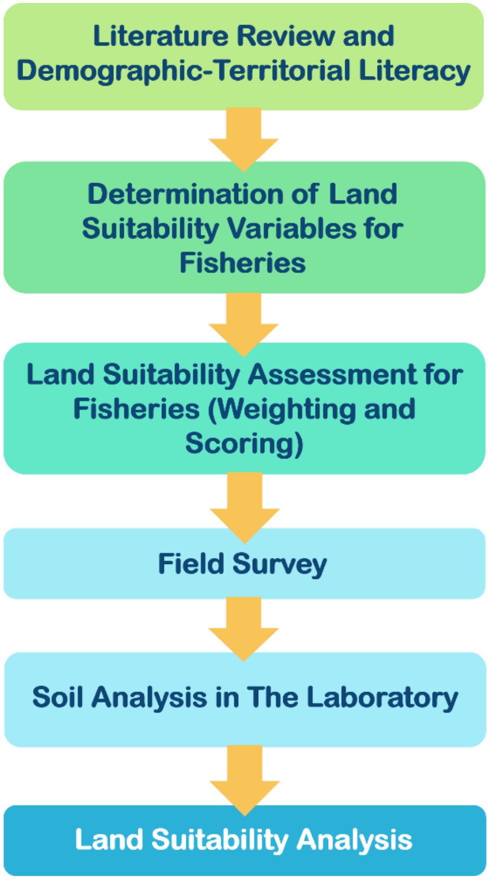


Figure 10.1 Flowchart of the research process for land suitability in the aquaculture sector

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 NH3 levels exceed 0.2 mg/L, the water becomes toxic for certain fish species (Sawyer & McCarty, 1978). Stickney (2000) noted that tilapia are relatively tolerant to high ammonia concentrations. Fish cannot tolerate excessive NH_3 levels as it disrupts oxygen binding by blood, potentially causing hypoxia or carps mortality.

d. Climate

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

D. Land Suitability Assessment for Aquaculture

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

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

Table 10.3 Land Suitability for Pond Aquaculture Parameters

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

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

Table 10.4 Land Suitability Scoring Calculation

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

E. Field Survey

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

Table 10.5 Field Survey Activities by Area in Covalima District

No.	Schedule	Sub-District	Village	Purpose (Ownership)
1	15 May 2025	Suai	Suai-Loro	Business (Individual)
2	15 May 2025	Suai	Suai-Loro	Business (Group)
3	15 May 2025	Maucatar	Matai	Business (Individual)
4	15 May 2025	Suai	Beco	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

In the context of the number of fishing households in Covalima District, Suai Sub-District stands out as the Sub-District with the highest number of fishing households, totaling 167 households (60.07%). In contrast, Fatumean Sub-District has the fewest fishing households, with only 3 households (1.08%). This may indicate limited local community involvement in fishing activities.

This distribution shows the differences in potential and challenges across each Sub-District in managing the fisheries sector. Suai Sub-District, with its dominant number of fishing households, presents a great opportunity for further development through improved fishing technology, training for fishermen, and market access. On the other hand, Fatumean Sub-District has initial potential that can be enhanced through empowerment programs and infrastructure support to encourage greater community participation in the fisheries sector. With a strategic approach, the fisheries potential in both Sub-Districts can be maximized to support the local economy sustainably. The graphs regarding the number of fishing households are presented in **Figures 10.2** and **10.3**.

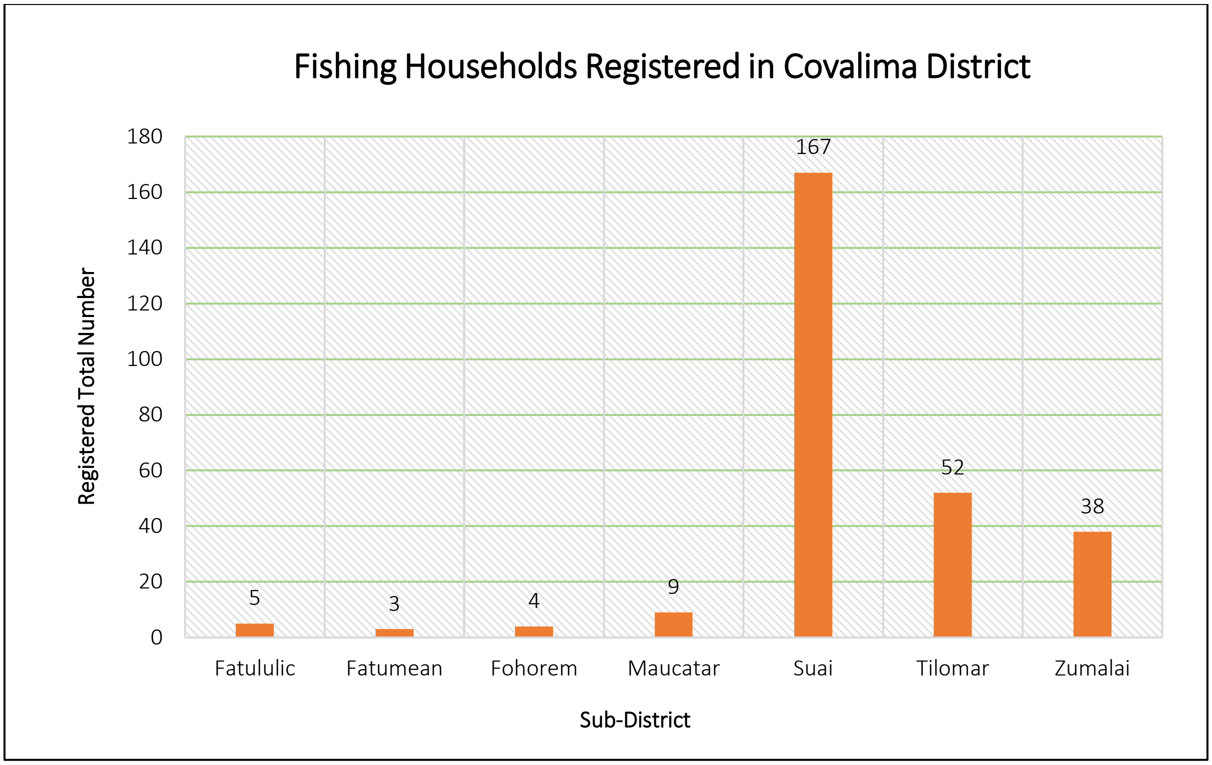


Figure 10.2 Fishing Households in Covalima District
(Source: Timor-Leste Agriculture Census, 2019)

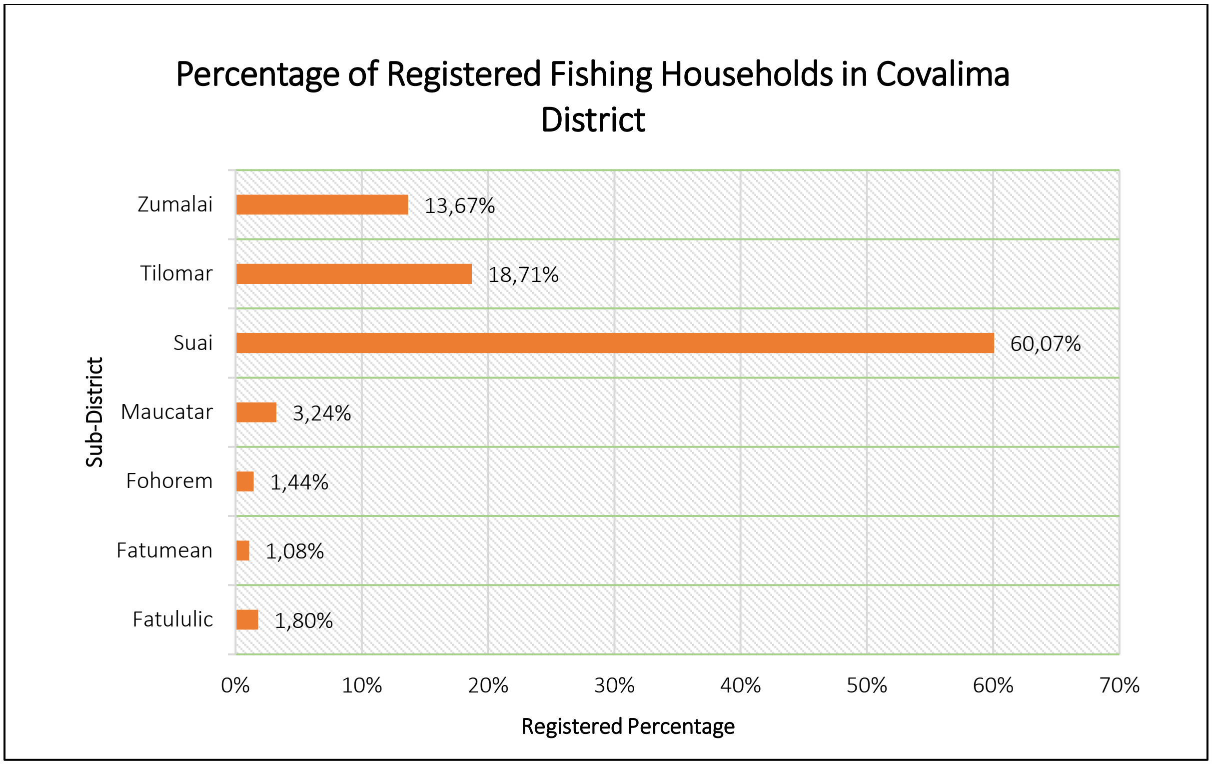


Figure 10.3 Percentage of Fishing Households in Covalima District
(Source: Timor-Leste Agriculture Census, 2019)

2. Households Involved in Fishing Activities

Households involved in fishing activities are categorized into three types: consumption and social obligations, consumption and occasional sales, and direct sales. Sulai Sub-District recorded the highest number of households involved in fishing activities, both for consumption and direct sales.

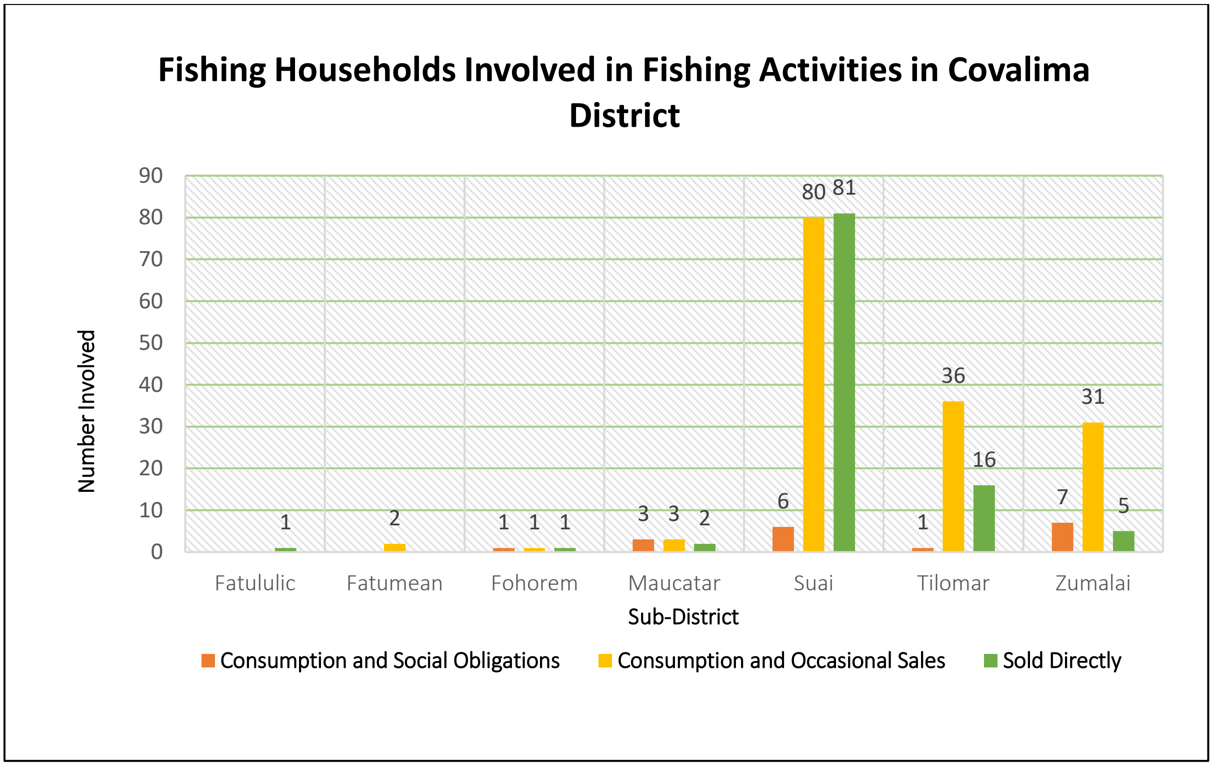


Figure 10.4 Number of Households Involved in Fishing Activities
(Source: Timor-Leste Agriculture Census, 2019)

A total of 80 households participate in fishing for consumption, making up 52% of the total number of households, while 81 households or 76% of the total are involved in fishing for direct sales. Conversely, Fohorem Sub-District has the smallest contribution in this category, with only 1 household or 1% of the total number of households, reflecting a significant difference in the scale of fishing activities between these areas. Meanwhile, Zumalai Sub-District has the highest number of households involved in fishing for consumption and social obligations, with 7 households or 39%, followed by Suai Sub-District with 3 households or 33%. This suggests that Covalima is beginning to develop a variety of fishing activities, although not all Sub-Districts are equally involved. The number of households involved in fishing activities is presented in **Figures 10.4** and **10.5.**

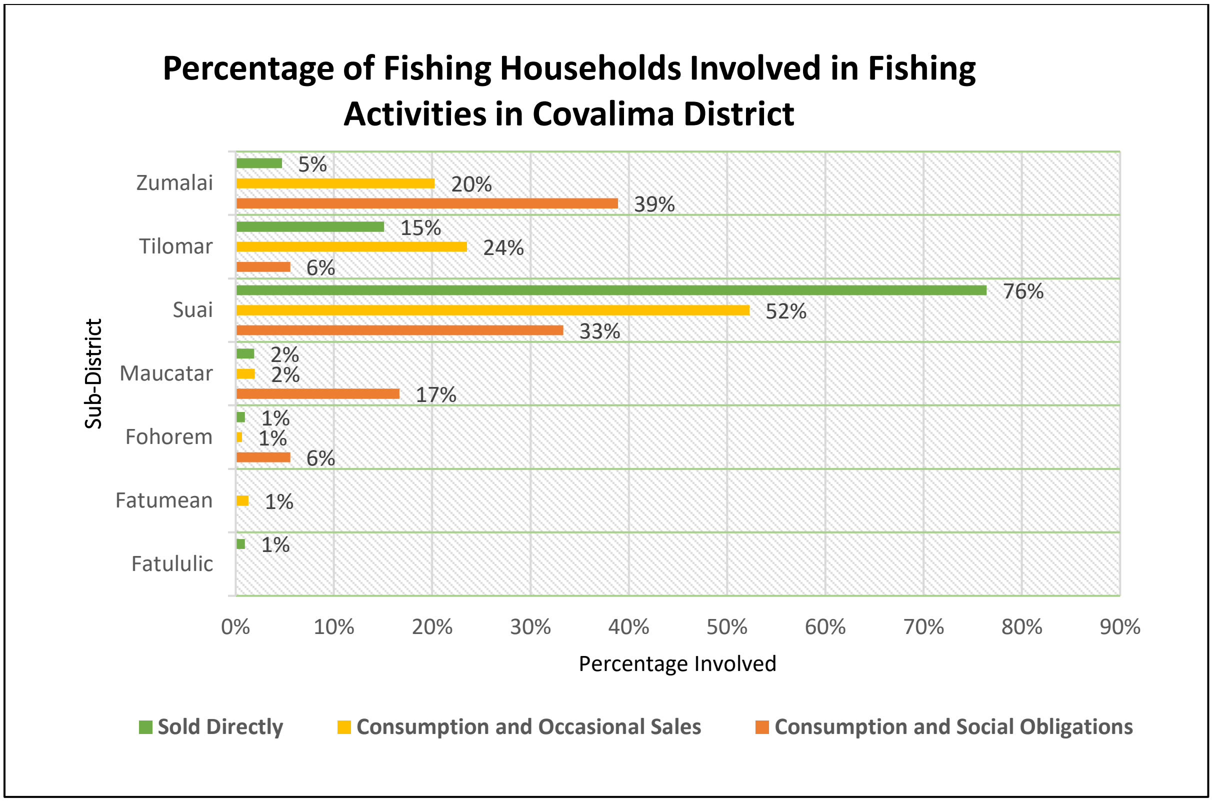


Figure 10.5 Number of Households Involved in Fishing Activities
(Source: Timor-Leste Agriculture Census, 2019)

B. Aquaculture

Aquaculture in Covalima District has great potential to support the livelihoods of local communities, particularly through the sustainable management of both marine and land resources. This area is known for its marine biodiversity, which can be utilized for fish farming and other forms of aquaculture. Aquaculture production in the region includes both freshwater fish farming and other marine products, although the scale remains relatively small.

According to data from the da Focesta (2022), aquaculture fish production consumed in Covalima District, it shows that the aquaculture sector in Covalima has not yet made a direct contribution to local fish consumption levels in the given period. Development strategies could include training for fish farmers, improving market access, and investing in innovative aquaculture technologies to support the growth of the aquaculture sector in this region.

1. Proportion of Land for Aquaculture

The distribution of land for aquaculture in Covalima District shows significant differences across each Sub-District. Zumalai Sub-District dominates with the largest area of aquaculture land, covering 5.37 hectares (36.58%). In contrast, Fatumean Sub-District has only about 0.80 hectares of aquaculture land or 5.44%, indicating a relatively limited potential or development of aquaculture compared to Zumalai Sub-District. Meanwhile, Maucatar Sub-District has less than 1 hectare of aquaculture land. The proportions of land for aquaculture are presented in **Figures 10.6** and **10.7.**

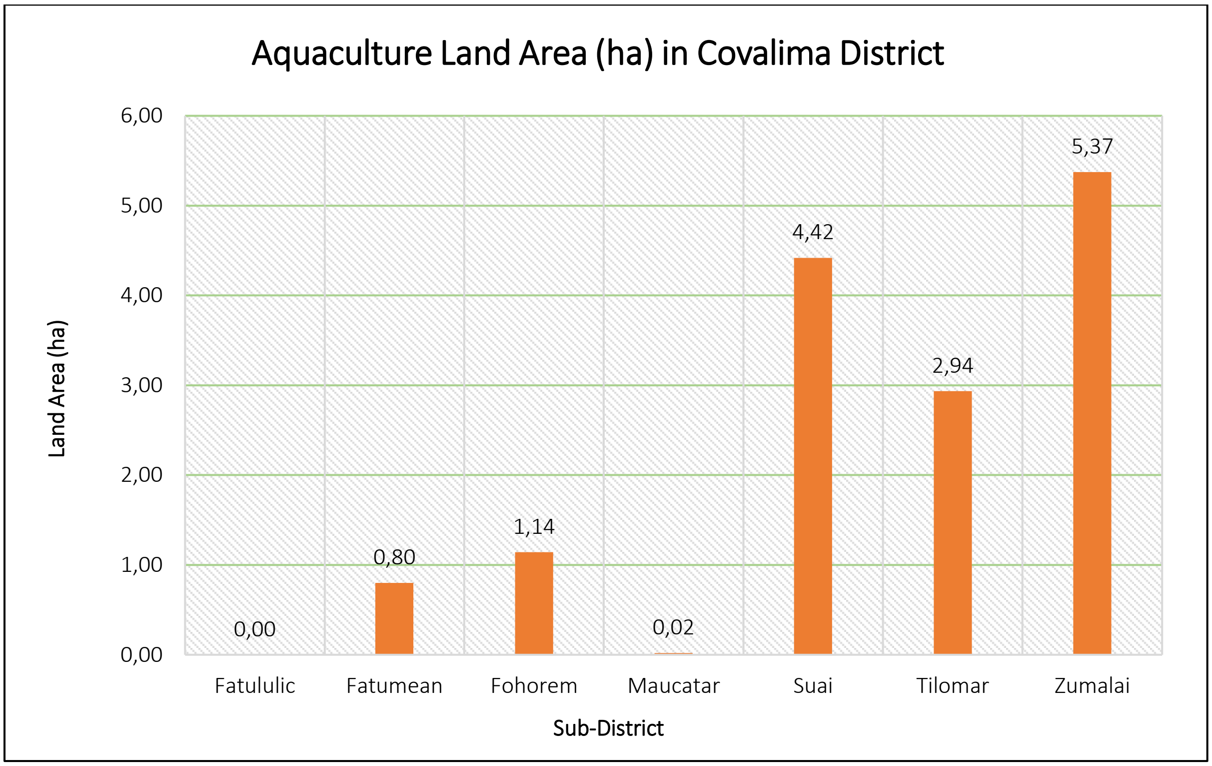


Figure 10.6 Aquaculture Land Area in Covalima District
(Source: Timor-Leste Agriculture Census, 2019)

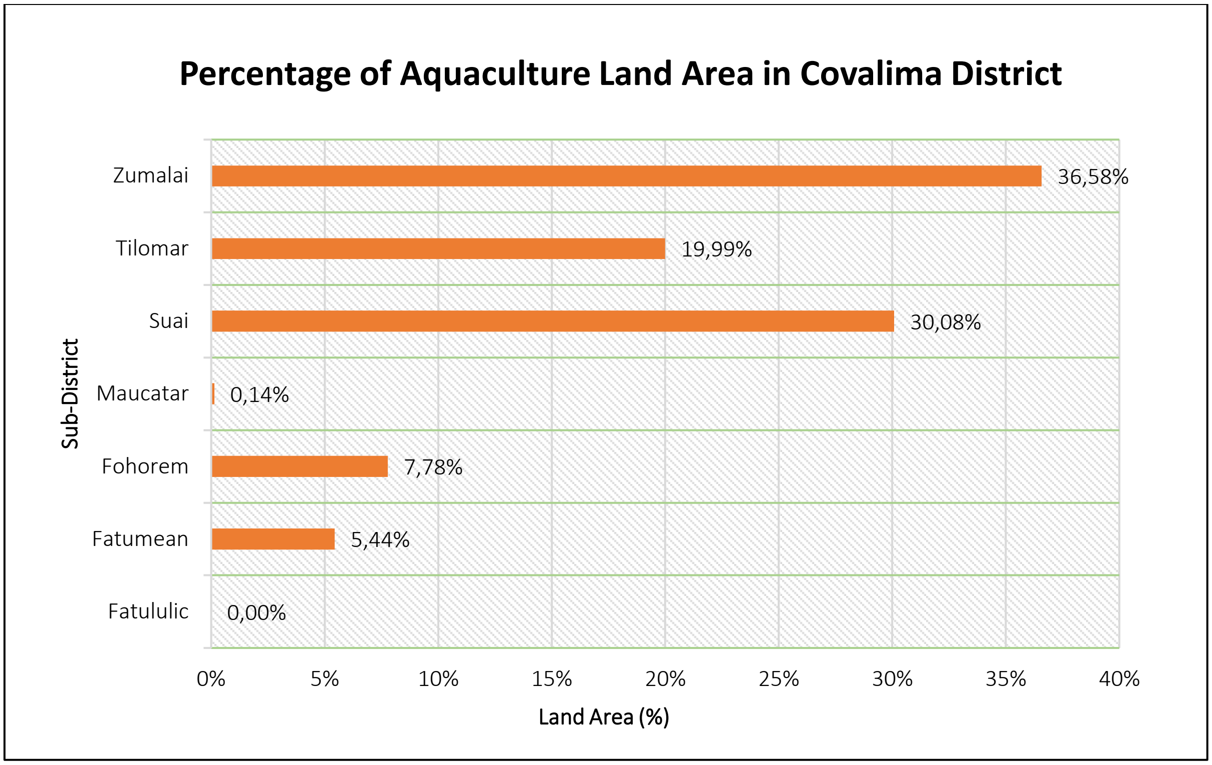


Figure 10.7 Percentage of Aquaculture Land in Covalima District
(Source: Timor-Leste Agriculture Census, 2019)

2. Aquaculture Households

Households involved in aquaculture play a key role in driving local fisheries sector growth while supporting food security and the local economy. Each household involved in aquaculture reflects the sustainability of aquaculture practices and their adaptation to economic opportunities based on water resources.

The number of households involved in aquaculture in Covalima District shows significant variation. Fohorem Sub-District has the largest number of households involved in aquaculture, with 43 households (34.96%), while Maucatar Sub-District has only 4 households (3.52%) engaged in aquaculture.

A strategic approach is required to increase community participation in Sub-Districts with lower involvement in aquaculture. Through strengthening local capacity and optimizing aquaculture potential in each Sub-District, Covalima District can increase the contribution of this sector to local economic growth. The number of households involved in aquaculture in Covalima District is shown in **Figures 10.8** and **10.9.**

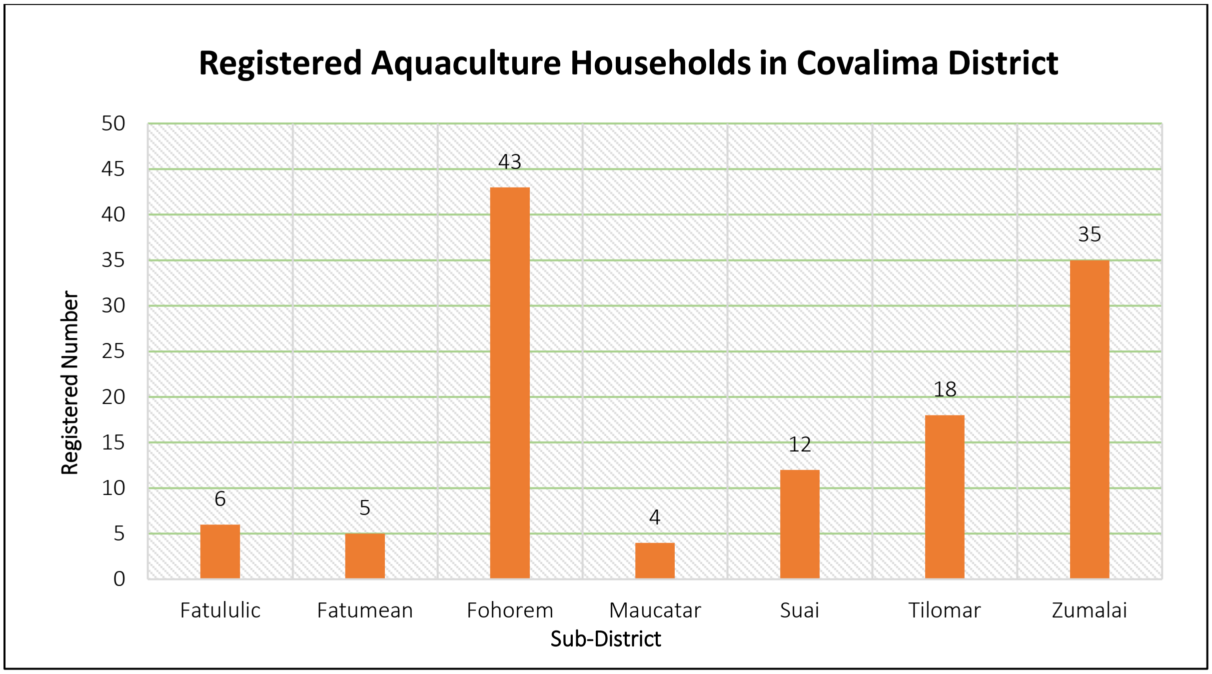


Figure 10.8 Aquaculture Households in Covalima District
(Source: Timor-Leste Agriculture Census, 2019)

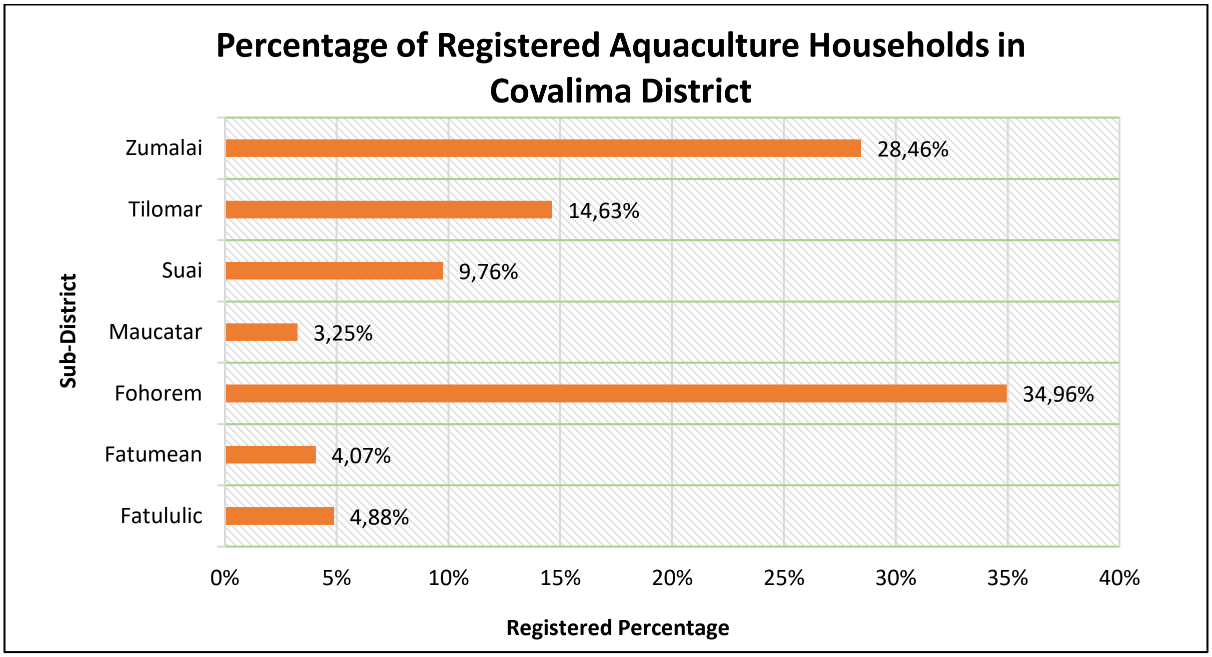


Figure 10.9 Percentage of Aquaculture Households in Covalima District
(Source: Timor-Leste Agriculture Census, 2019)

3. Aquaculture Systems

The aquaculture systems in Covalima District show diverse distribution patterns across its Sub-Districts, with a dominance of pond-based aquaculture systems spread throughout the region. Fohorem Sub-District has the highest number of ponds, totaling 82 units or about 48%. Additionally, pond-based systems and fish cages are found in Suai Sub-District, although in small numbers, with 3 units (100%). Furthermore, aquaculture based on seedling production is found in Tilomar Sub-District with 2 units (100%), showing the diversity of aquaculture methods practiced in Covalima District, albeit on a small scale. The graph depicting the facilities used for aquaculture in Covalima District is presented in **Figures 10.10** and **10.11.**

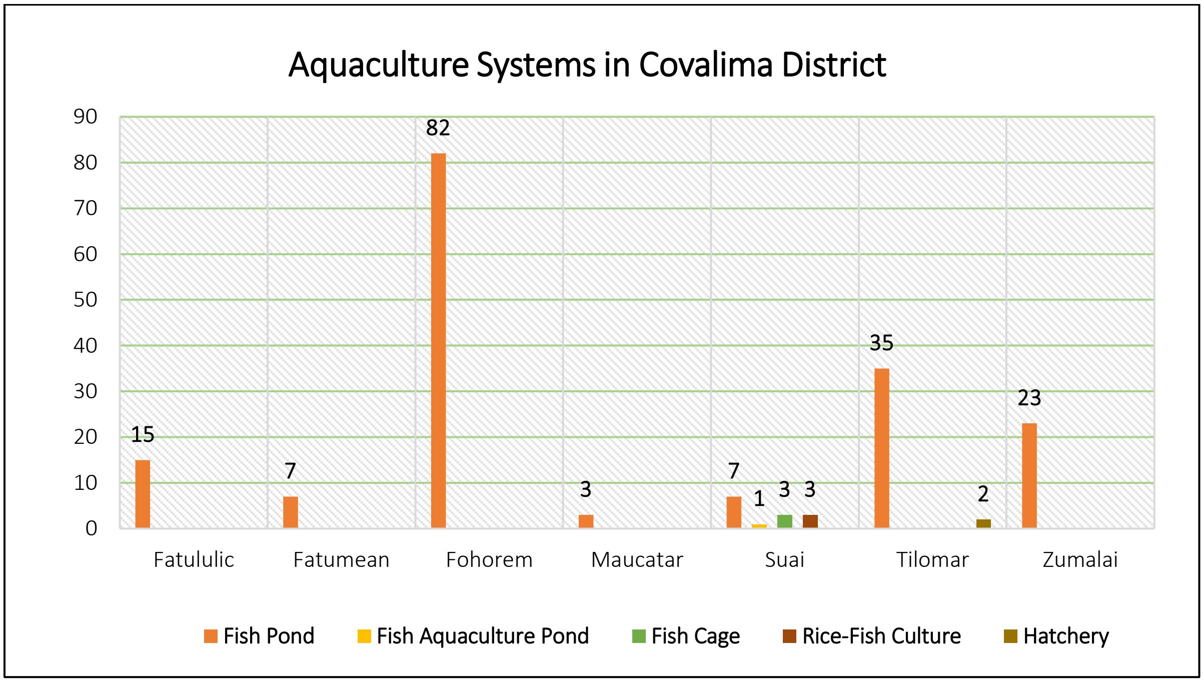


Figure 10.10 Aquaculture Systems in Covalima District
(Source: Timor-Leste Agriculture Census, 2019)

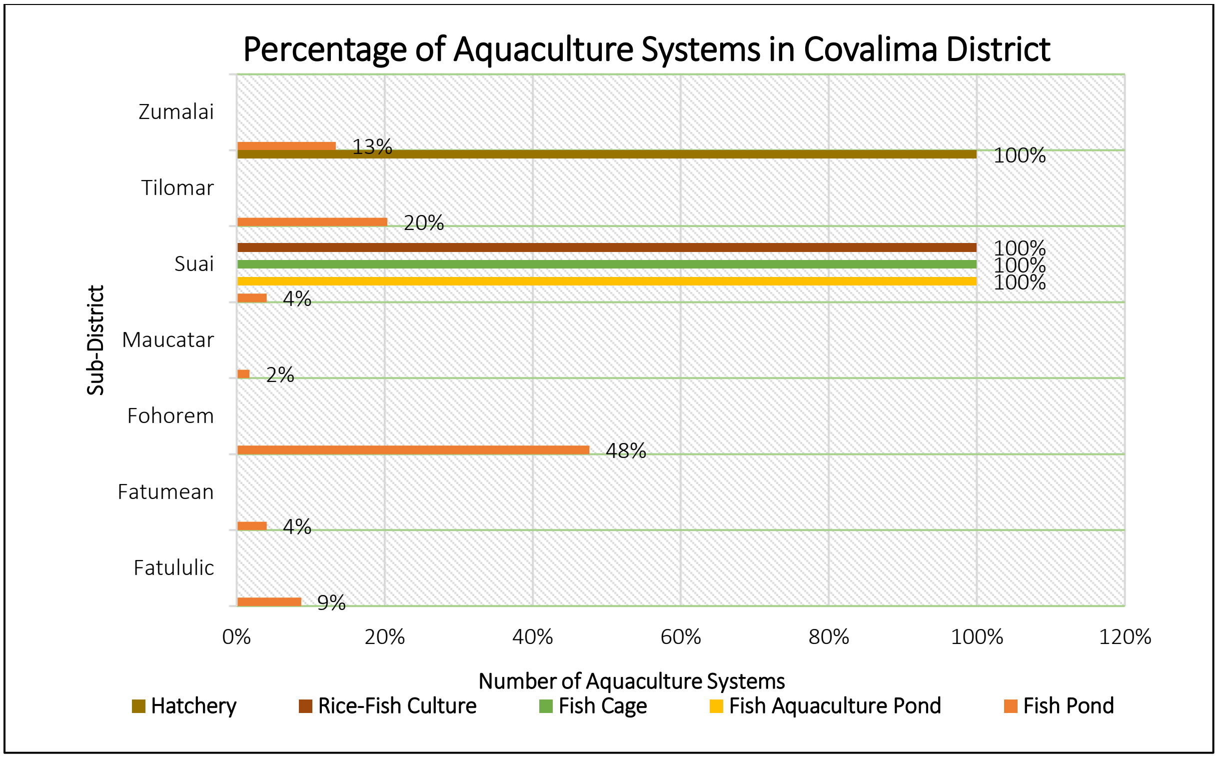


Figure 10.11 Percentage of Aquaculture Systems in Covalima District
(Source: Timor-Leste Agriculture Census, 2019)

C. Field Observation Results

Covalima District has various fishing systems and potentials, ranging from private ponds to mangrove areas planned for integrated development. In Suai Loro Village, there are privately owned aquaculture ponds with two types of ponds: concrete and earth ponds, focused on tilapia farming. The pond owner, who holds a bachelor's degree in animal science from UNTL, faced production challenges at the early stage, such as mass fish mortality, likely due to a lack of aeration. As a solution, a simple aeration system using a water pump was implemented. Currently, the farmer plans to expand the pond to two hectares but still requires technical assistance from the government, particularly in management and feed technology to achieve greater independence. Agricultural commodities such as corn, mung beans, moringa leaves, rice bran, and cassava available in the region have the potential to be used as raw materials for feed to improve production sustainability.

Figure 10.12 Aquaculture Pond in Suai Loro Village
(Source: Researcher Documentation, 2025)

Still in Suai Loro Village, there is a lagoon that was previously a rice field. However, after a natural disaster caused seawater to enter the rice fields, this area has now transformed into a natural pond that has the potential to be developed into a milkfish pond, covering approximately three hectares. During high tide, water flows into the lagoon through a small river, trapping adult and juvenile milkfish naturally. The owner plans to utilize the juvenile milkfish for initial production, but more structured management of the broodstock is necessary for production stability, including the provision of better facilities to support the aquaculture system.

Figure 10.13 Lagoon in Suai Loro Village
(Source: Researcher Documentation, 2025)

In Matai Village, a 7x5 meter concrete pond is privately owned but has never been used for aquaculture. A plan to expand the pond was considered, but there were concerns from the local community regarding the quality of the water source from the borehole. According to local beliefs, the groundwater in this area is suspected to contain oil, which has led the community to hesitate in starting aquaculture activities without certainty about the effects on the fish.

Figure 10.14 Aquaculture Pond in Matai Village
(Source: Researcher Documentation, 2025)

Meanwhile, the area in Beco Village is a government-owned mangrove zone covering 300 hectares. This area is planned as part of an integrated development project, including sectors such as agriculture, livestock, fisheries, and forestry. Mangrove vegetation and lontar trees dominate this area, with water sources coming from small rivers and seawater that enters during high tide. One of the main challenges in developing aquaculture in this location is the limited supply of freshwater, as the water flow is insufficient to support larger-scale production.

Overall, the fisheries in Covalima District have significant potential for further development, particularly through the improvement of aeration systems, optimization of local feed resources, and stabilization of water source quality. With adequate technical support and infrastructure, these observation sites can contribute more to the sustainability of fisheries production in the region.

Figure 10.15 Planned Aquaculture Development Area in Beco Village
(Source: Researcher Documentation, 2025)

10.4 COMPREHENSIVE LAND SUITABILITY ANALYSIS FOR AQUACULTURE

A. Aquaculture Land Suitability in Covalima District

Land suitability refers to the degree to which a region is suitable for a particular purpose, in this case, for aquaculture development. This concept emphasizes assessing whether the land has the physical, chemical, and climatic characteristics that support optimal and sustainable aquaculture commodity growth. Land suitability evaluations are typically performed under two conditions: actual (current) and potential (after improvements).

The actual land suitability assessment is derived from field survey data and reflects the land's capacity in its natural state, without additional interventions. This evaluation does not consider possible improvements or management strategies that could address the constraints or limiting factors inherent in each land unit. The assessment of the actual suitability class starts by evaluating the land quality based on limiting factors, followed by scoring, ultimately yielding a final evaluation value. This result provides a realistic picture of the challenges the land faces.

In contrast, potential land suitability refers to the degree to which land would be suitable after improvements are made. For instance, land that is considered marginally suitable (S3) under current conditions can be upgraded to moderately suitable (S2) or highly suitable (S1) after improvements such as water quality regulation or topographical modification. This assessment considers possible improvements to the limiting factors, with the expectation that land suitability can be enhanced.

With the aid of technology, land that has a low natural suitability class (actual) can be upgraded to a higher suitability class (potential). However, not all land characteristics can be improved with current technology, or some may require intensive management. In land use planning for aquaculture, potential suitability is prioritized, as this assessment reflects the land's maximum capacity after improvements. Therefore, the potential suitability analysis serves as the foundation for designing effective, sustainable, and optimal land use.

B. Results of Aquaculture Land Suitability Evaluation

Land suitability analysis is an essential step in designing strategies for utilizing land resources to support sustainable aquaculture development. This evaluation is conducted through an integrated approach that utilizes topographic data, field observations, and physical and chemical soil and water analysis in laboratories. This approach allows for the identification of the land's potential and bio-physical limitations in supporting various aquaculture commodities.

The obtained data are then analyzed based on the growth requirements of each aquaculture commodity, both in actual and potential conditions, such as topographical modifications, water quality management, or the implementation of adaptive aquaculture techniques. This analysis provides comprehensive information for setting development priorities, identifying limiting factors, and formulating appropriate technical solutions. This scientific approach forms the basis for the land suitability evaluation in Covalima District.

The analysis results offer strategic guidance to improve land productivity while also preserving the sustainability of water resources in each area. The field and laboratory data used as the basis for the evaluation are presented in relevant supporting documents. The distribution map of land for aquaculture is presented in Figure 10.16.

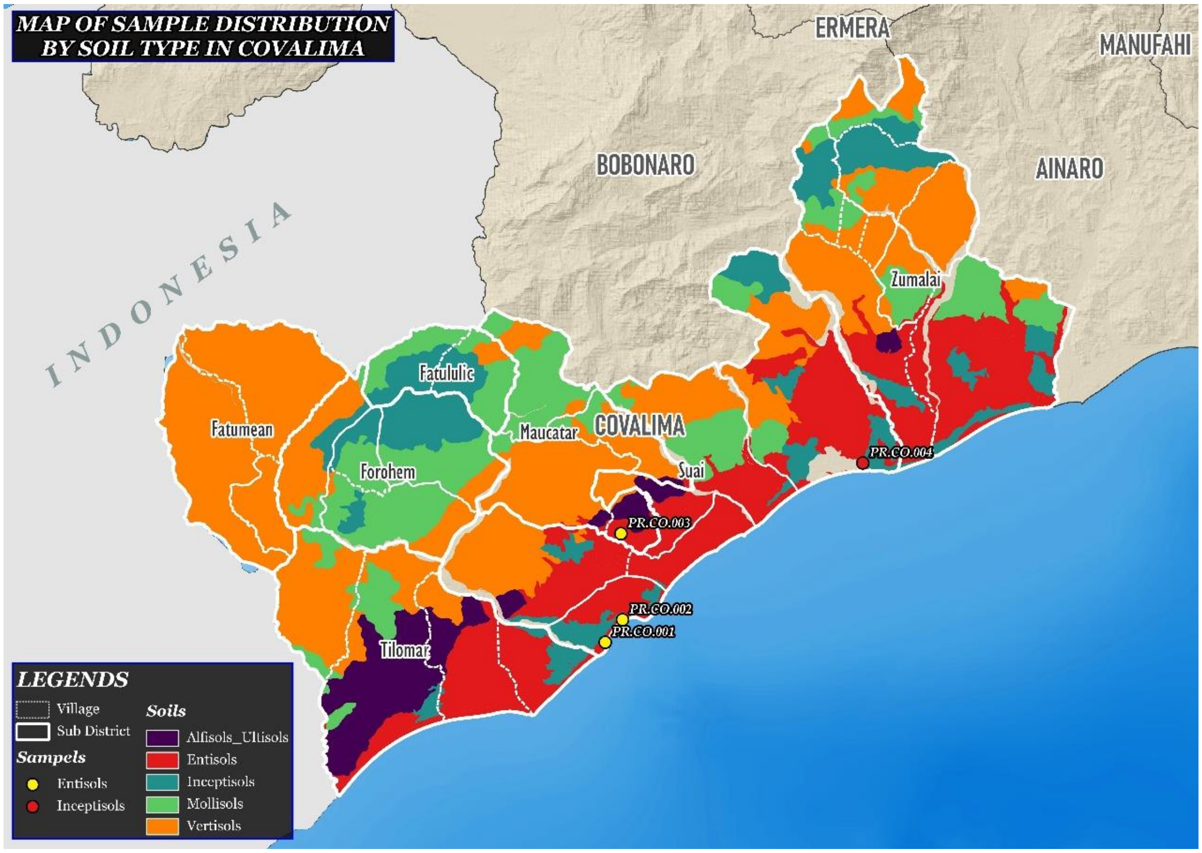


Figure 10.16 Map of Soil Distribution on Aquaculture Land in Covalima District

a. Land Suitability Evaluation in Maucatar Sub-District

The land suitability evaluation for aquaculture development in Maucatar Sub-District, Timor-Leste, reveals several ecological constraints that affect the feasibility of various commodities. According to data from **Table 10.9**, freshwater commodities such as gourami (*Osphronemus gouramy*), catfish (*Clarias batrachus*), carp (*Cyprinus carpio*), and tilapia (*Oreochromis niloticus*) generally face limitations due to high rainfall, long dry periods, and fairly steep slopes. Slope gradient becomes the main limiting factor with an S2 rating, meaning conventional pond construction is difficult without site modification. However, technical solutions such as terracing or stepped ponds can mitigate these issues, increasing the actual suitability rating to S1.

While some factors can be improved through corrective efforts listed in **Table 10.11**, climatic constraints such as extreme rainfall and long dry seasons remain significant barriers because they are natural conditions that cannot be directly modified. Therefore, even with improvements in topography or water quality, the land suitability rating for climate-related parameters remains S2 or S3.

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

Commodity	Current Land Suitability Limiting Factors	Current Final Evaluation	Potential Land Suitability Limiting Factors	Potential Final Evaluation
Gourami (*Ospronemus gouramy*)	S3: High rainfall, dry season S2: pH, slope	3.49	S3: High rainfall, dry season	3.68
Catfish (*Clarias batrachus*)	S3: High rainfall, dry season S2: Slope	3.56	S3: High rainfall, dry season	3.68
Carp (*Cyprinus carpio*)	S3: High rainfall, dry season S2: High temperature, DO, slope	3.36	S3: High rainfall, dry season	3.68
Tilapia (*Oreochromis niloticus*)	S3: High rainfall, dry season S2: pH, DO, slope	3.34	S3: High rainfall, dry season	3.68
Milkfish (*Chanos chanos*)	S3: Low salinity, dry season S2: pH, slope, rainfall	3.35	S3: High rainfall, dry season	3.68
Mangrove crab (*Scylla serrata*)	N: Low salinity, dry season S2: pH, DO, slope, rainfall	3.35	S3: High rainfall, dry season	3.68
Vannamei (*Litopenaeus vannamei*)	S3: Low salinity, high rainfall, dry season S2: pH, DO, slope	3.26	S3: High rainfall, dry season	3.68

Meanwhile, for brackish water commodities such as milkfish (*Chanos chanos*), mangrove crab (*Scylla serrata*), and vannamei shrimp (*Litopenaeus vannamei*), the challenges are much greater. This is due to the geographical conditions of Maucatar, which lacks direct access to the coast and is mostly located in highland areas, leading to very low natural salinity levels. This factor becomes a critical constraint, with an S3 classification for milkfish and vannamei shrimp, and N (not suitable) for mangrove crab. Increasing salinity through seawater mixing requires expensive logistics and infrastructure, making it economically inefficient due to the distance from the sea. Additionally, slope and climate factors also remain limiting for these three commodities.

Based on these results, aquaculture development in Maucatar Sub-District is better focused on freshwater commodities that are more adaptable to local environmental conditions. By implementing aquaculture technologies suitable for the topographical characteristics, such as stepped or terraced ponds, and integrated water quality management, fisheries activities in this region can be carried out more optimally and sustainably.

b. Land Suitability Evaluation in Suai Sub-District

The land suitability evaluation for fisheries development in Suai Sub-District, Timor-Leste, indicates that this region has considerable potential. The presence of coastal and brackish water areas is a crucial asset for the development of marine and brackish water commodities, as shown in **Table 10.10**. However, several limiting factors are still present, particularly related to water quality, topographical conditions, and climate factors. Freshwater commodities such as gourami (*Osphronemus gouramy*), catfish (*Clarias batrachus*), carp (*Cyprinus carpio*), and tilapia (*Oreochromis niloticus*) generally face challenges with slope gradients, long dry seasons, and high rainfall.

Slope gradient is the primary limiting factor at many locations, making conventional pond construction less effective. However, the application of terracing techniques or stepped pond construction could be a solution to manage the topography and improve the actual land suitability for better outcomes.

For brackish water commodities such as milkfish (*Chanos chanos*), mangrove crab (*Scylla serrata*), and vannamei shrimp (*Litopenaeus vannamei*), the presence of brackish water in this region presents a promising opportunity for development. However, several challenges still need to be addressed, particularly concerning salinity variation, relatively high water temperatures, and TDS values that sometimes exceed optimal thresholds. These challenges can be mitigated by water quality management, such as adjusting salinity through the mixing of seawater and freshwater according to commodity requirements. For example, in areas with low salinity, adding seawater can improve the actual conditions, making them closer to potential suitability, especially for milkfish and vannamei shrimp.

In addition to salinity, TDS values in this region range from S3 to S1. Improvements that can be implemented include conventional or modern pond filtration systems, using Reverse Osmosis (RO) filtration systems. However, applying this technology requires larger investment and operational costs. Therefore, the choice of TDS management methods should align with the local farmers' economic conditions to ensure efficient and sustainable water quality improvements.

On the other hand, climatic factors such as long dry seasons and high rainfall remain permanent constraints, as they are difficult to modify technically. Therefore, the aquaculture development strategy in Suai Sub-District should be aligned with local characteristics, either by selecting adaptive commodities or applying resource-efficient farming technologies that effectively manage water. With this approach, aquaculture activities in this region have the potential to develop sustainably and contribute significantly to local food security.

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

Commodity	Current Land Suitability Limiting Factors	Current Final Evaluation	Potential Land Suitability Limiting Factors	Potential Final Evaluation
Gourami (*Ospronemus gouramy*)	N: High salinity, TDS, slope S3: Dry season, rainfall S2: pH	2.74	S3: Dry season, rainfall, slope S3: Salinity	3.24
Catfish (*Clarias batrachus*)	N: TDS, slope S3: Dry season, rainfall S2: High temperature, high salinity	2.96	S3: Dry season, rainfall, slope	3.44
Carp (*Cyprinus carpio*)	N: TDS, slope S3: Dry season, rainfall, high temperature S2: High salinity	2.94	S3: Dry season, rainfall, slope	3.44
Tilapia (*Oreochromis niloticus*)	N: TDS, slope S3: Dry season, rainfall S2: High temperature	3.06	S3: Dry season, rainfall, slope	3.44
Milkfish (*Chanos chanos*)	N: TDS, slope S3: High temperature, low salinity, dry season S2: Rainfall	2.87	S3: Dry season, slope S2: Rainfall	3.62
Mangrove crab (*Scylla serrata*)	N: Low salinity, TDS S3: Slope, dry season S2: High temperature	3	S3: Dry season S2: Rainfall, slope	3.62
Vannamei (*Litopenaeus vannamei*)	N: Slope S3: Low salinity, TDS, dry season, rainfall S2: High temperature	2.93	S3: Dry season, rainfall, slope	3.44

C. Aquaculture Land Improvement Efforts

The results of the actual land suitability evaluation in Covalima District show that there are various limiting factors, causing much of the area to be categorized as not suitable or only marginally suitable for aquaculture. To improve these land suitability classes, corrective actions or improvements to address the limiting factors are required, as much as possible. Land improvement efforts in aquaculture include any technical interventions aimed at improving the bio-physical conditions of the land and the quality of the aquatic environment to better meet the optimal needs of cultivated commodities. These improvements can include modifications to aquaculture habitats (e.g., physically improving pond conditions), water quality manipulation, and the provision of supporting infrastructure.

Based on **Table 10.11**, there are different types of improvement efforts with varying levels of management difficulty. The levels of management difficulty are categorized into three: low, medium, and high. These levels are further assessed to improve the actual land quality into its potential state, as shown in **Table 10.12**.

Table 10.11 Recommended Improvement Measures for Limiting Parameters

No	Parameter	Improvement Measures	Management Difficulty Level
1	High Temperature	- Planting shade trees - Using hapa/paranet netting as a roof - Creating indoor ponds	- Low - Medium - High
2	High Salinity	- Mixing with freshwater	- Medium
3	Low Salinity	- Mixing with seawater conventionally - Using a seawater pump system	- Medium - High
4	Water pH	- Periodic water exchange - Using zeolite	- Medium - High
5	TDS	- Using simple filtration methods - Using modern filtration methods (RO filter machine)	- Medium - High
6	Slope	- Using tiered pond systems	- High
7	Rainfall	- Cannot be improved	
8	Dry Season	- Cannot be improved	

Description :

- *Low management difficulty: Management can be carried out by the farmers with relatively low costs.*
- *Medium management difficulty: Management can be carried out by intermediate-level farmers, requiring moderate capital and intermediate aquaculture techniques.*
- *High management difficulty: Management can only be done with relatively high capital, typically carried out by the government or large or 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)*

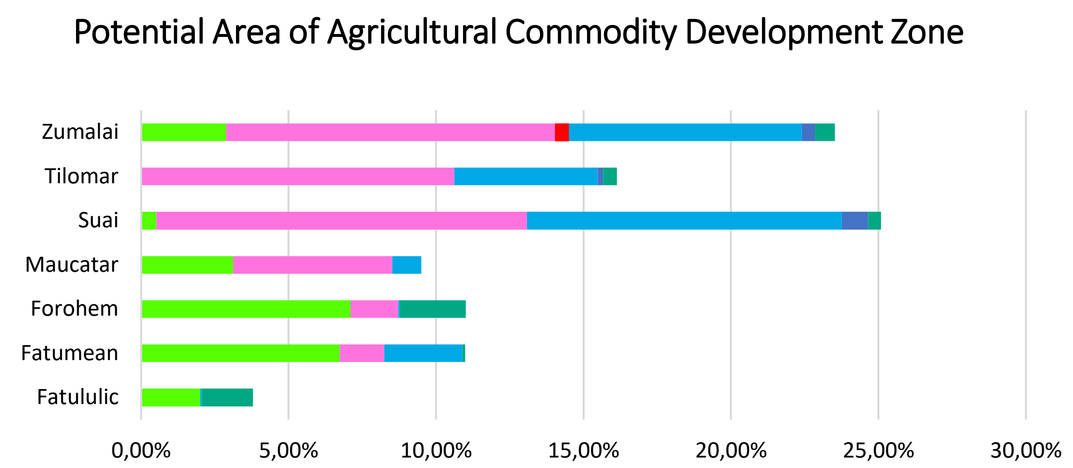
+++ *Improvement will increase the suitability class by three levels (N to S1)*

XI. ZONING FOR AGRICULTURE COMMODITY DEVELOPMENT

11.1 AGRICULTURE COMMODITY DEVELOPMENT ZONING

Covalima District has significant land resource potential to support the development of agriculture, forestry, and livestock sectors. In an effort to maximize this potential, land suitability evaluation was conducted using a comprehensive scientific approach, including field observations, laboratory testing of soil samples, and matching crop growth requirements with agroclimate maps of the area. The results of this evaluation produced a systematic, science-based zoning to identify the potential for developing various strategic commodities, such as rice, maize, horticulture, industrial crops, and forestry areas. This zoning is expected to support the efficient and sustainable management of land resources, contributing to national food security and improving community welfare.

Covalima District has land development potential divided into several main categories: irrigated rice fields covering 285.64 km² (23.75%), agroforestry areas covering 318.55 km² (26.49%), grazing land covering 5.74 km² (0.48%), protected forests covering 56.45 km² (4.69%), mixed gardens covering 517.87 km² (43.06%), and mangroves covering 18.29 km² (1.52%). The area of agricultural commodity development potential per Sub-District is presented in **Figure 11.1**, and its spatial distribution is shown in **Figure 11.2**. This zoning reflects the diversity of land utilization potential to support agriculture, forestry, and livestock sectors sustainably, contributing to food security, environmental protection, and the improvement of community welfare.



	Fatululic	Fatumean	Forohem	Maucatar	Suai	Tilomar	Zumalai
Agroforestry	2,00%	6,74%	7,10%	3,12%	0,51%	0,00%	2,87%
Dryland Farming	0,00%	1,50%	1,62%	5,39%	12,57%	10,61%	11,16%
Grazing Area	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,48%
Irrigated Rice Fields	0,05%	2,65%	0,05%	0,99%	10,68%	4,86%	7,90%
Mangrove Forest	0,00%	0,00%	0,00%	0,00%	0,89%	0,19%	0,44%
Protected Forest	1,74%	0,10%	2,23%	0,00%	0,43%	0,46%	0,67%

Figure 11.1 Area of Agricultural and Forestry Commodity Development per Sub-District

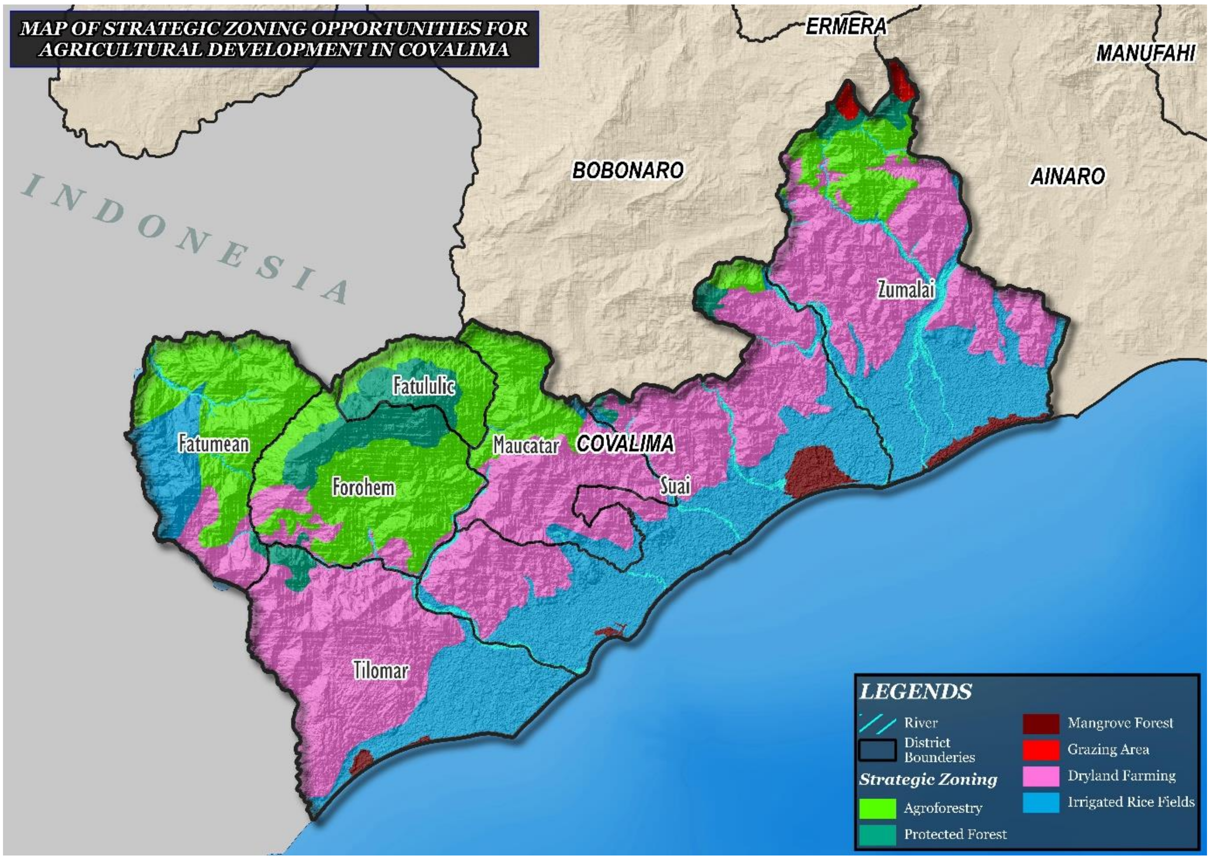


Figure 11.2 Map of Agricultural and Forestry Commodity Development Potential in Covalima District

A. Irrigated Rice Fields

The irrigated rice field zoning covers an area of 286.64 km², or 23.75% of the total area of Covalima District, and is located in regions with an elevation of less than 100 meters above sea level and a slope gradient of 0-8%. This topography supports an efficient irrigation system that enhances agricultural productivity. This area falls within agroclimate zone F, which experiences a wet season lasting 7 to 8 months per year. This condition is crucial for supporting sustainable cropping patterns. The largest distribution of irrigated rice fields is found in Suai Sub-district, with 10%, followed by Zumalai Sub-district, with 8%.

B. Dryland Agriculture (Mixed gardens and Dryland Fields)

Dryland agriculture is the largest sector, covering an area of 517.87 km², or 43.06% of the total area of Covalima District, located at an elevation of 100 to 500 meters above sea level and with a slope gradient of 8-25%. This reflects both the challenges and potential for agricultural systems relying on rainfall as the primary source of natural irrigation. The area lies within agroclimate zone E, which has a wet season lasting 8 months. This condition supports cropping patterns adapted to rainfall, promoting the production of food crops and other agricultural commodities that are resistant to dryland conditions. The largest distribution of dryland agriculture is found in Suai Sub-District, with 13%, followed by Sub-Districts Tilomar and Zumalai, each with 11%. The extensive area of dryland agriculture underscores the importance of this sector in food security, the local economy, and community welfare, although it still faces challenges in managing water resources and soil fertility.

C. Grazing Area

The grazing area covers 5.74 km², or 0.48% of the total area of Covalima District, located in regions with an elevation of 100 to 500 meters above sea level and a slope gradient of 8-25%. This reflects both the challenges and potential for an agricultural system dependent on rainfall as the primary source of natural irrigation. The area is within agroclimate zone E, which experiences a wet season lasting 8 months. This condition enables cropping patterns that adapt to rainfall, supporting the production of food crops and other agricultural commodities that can withstand dryland conditions. The largest grazing area distribution is found in Sub-District Zumalai, covering 0.48%. While this area is relatively small compred to other land use sectors, it still plays a crucial role in supporting the local livestock system, both on a small scale and as part of the broader agricultural economy

Table 11.1 Recommendations for the Development of Commodities for Food Crops, Industry, Horticulture, Spices and Medicinal Plants, and Forestry in Covalima District

NO	SUB-DISTRICT	FOOD CROPS	DRYLAND AGRICULTURE (PLANTATIONS & HORTICULTURE)	FORESTRY	GRAZING
1	Fatululic	DRY LAND FOOD **S3:** Corn, Cassava, Sweet Potatoes	INDUSTRY **S3:** Arabica Coffee FRUITS **S3:** Papaya, Durian, Duku, Jackfruit, Mangosteen VEGETABLE **S3:** Eggplant, Biet, Vegetable Tomatoes, Red Chili, Paprika, Cabbage FLOWER **S3:** Rose, ylang-ylang, Tuberose, Hairgrass, Gladiol, Daisies SPICES&MEDICINAL **S3:** Pepper, Candlenut, Vanilla, Lemongrass, Sweet root, Ginger, Aromatic ginger, Tumeric, Galangal, Cadarmom, Jatropha	**S2:** Teak, Mahogany **S3:** Agathis, Altingia, Sengon, Acacia, Leucaena, Eucalyptus, Gelam	
2	Fatumean	DRY LAND FOOD **S2:** Corn, Green beans, Cowpeas **S3:** Sorghum, Wheat, Soy bean, Peanuts, Cassava, Sweet Potatoes, Taro	INDUSTRY **S3:** Coconut, Oil palm, Arabica Coffee, Cocoa, Clove, Tobacco, Sugarcane, Melinjo, Kapok, Quinine FRUITS **S2:** Papaya, Durian, Duku, Jackfruit, Breadfruit, Mangosteen, Pineapple, Persimmon, Kepayang, **S3:** Apple, Mango, Rambutan, Guava, Water melon, Cantaloupe, Melon, Soursop, Custard		

			apple, Snake fruit, Sapodilla, Longan, Strawberry, Carica, Banana, Orange, Avocado, Passion fruit, Grape VEGETABLE **S2:** Lettuce, Petsai, Caisim, Spinach **S3:** Eggplant, Biet, Vegetable Tomatoes, Red Chili, Paprika, Cabbage, Beans, Long beans, Snow peas, Cucumber, Bitter melon, Shallot FLOWER **S2:** Rose, Tuberose, Hairgrass, Gladiol, Daisies **S3:** Kenanga, Sunflower SPICES&MEDICINAL **S3:** Pepper, Candlenut, Vanilla, Lemongrass, Sweet root, Ginger, Aromatic ginger, Tumeric, Galangal, Cadarmom, Jatropha		
3	Forohem	DRY LAND FOOD **S3:** Corn, Cassava, Sweet Potatoes	INDUSTRY **S3:** Arabica Coffee FRUITS **S3:** Papaya, Durian, Duku, Jackfruit, Mangosteen VEGETABLE **S3:** Eggplant, Biet, Vegetable Tomatoes, Red Chili, Paprika, Cabbage FLOWER **S3:** Rose, Kenanga, Tuberose, Hairgrass, Gladiol, Daisies SPICES&MEDICINAL **S3:** Aromatic ginger, Ginger, Tumeric	**S3:** Agathis, Leucaena, Eucalyptus	

4	Maucatar	DRY LAND FOOD **S3:** Corn, Cassava, Sweet Potatoes	INDUSTRY **S3:** Arabica Coffee FRUITS **S3:** Papaya, Durian, Avocado, Jackfruit, Mangosteen VEGETABLE **S3:** Eggplant, Biet, Vegetable Tomatoes, Red Chili, Paprika, Cabbage FLOWER **S3:** Rose, Kenanga, Tuberose, Hairgrass, Gladiol, Daisies SPICES&MEDICINAL **S3:** Aromatic ginger, Ginger, Tumeric	**S2:** Teak, Mahogany **S3:** Agathis, Altingia, Sengon, Acacia, Leucaena, Eucalyptus, Gelam	
5	Suai	WETLAND FOOD **S2**: Irrigated rice fields DRY LAND FOOD **S2:** Upland rice, Corn, Sorghum, Peanuts, Cowpeas, Cassava **S3:** Soy bean, Mung beans, Chickpeas, Sweet Potatoes, Taro, Iles-Iles, Hui	INDUSTRY **S2:** Rubber, Coconut, Oil Palm, Robusta Coffee, Tobacco **S3:** Cocoa, Clove, Sugarcane, Cashew, Melinjo, Cotton, Kapok, Quinine FRUITS **S2:** Papaya, Apple, Mango, Rambutan, Guava, Belimbing, Durian, Water melon, Cantaloupe, Melon, Duku, Jackfruit, Soursop, Custard apple, Breadfruit, Snake fruit, Sapodilla, Longan, Mangosteen, Pineapple, Strawberry, Kepayang, Banana, Orange, Avocado, Grape **S3:** Carica, Persimmon, Passion fruit VEGETABLE **S2:** Petsai, Spinach, Mustard,	**S2:** Teak, Mahogany **S3:** Agathis, Sengon, Acacia, Leucaena, Eucalyptus, Gelam	

			S3: Lettuce, Eggplant, Biet, Vegetable Tomatoes, Red Chili, Paprika, Cabbage, Beans, Long beans, Cucumber, Bitter melon **FLOWER** **S2:** Rose, Kenanga, Tuberose, Hairgrass, Gladiol, Daisies, Sunflower **SPICES & MEDICINE** **S1:** Jatropha **S2:** Pepper, Pala, Candlenut, Vanilla, Lemongrass, Sweet root, Aromatic ginger, Tumeric, Galangal, Cadarmom **S3:** Ginger		
6	Tilomar	**WETLAND FOOD** **S2**: Irrigated rice fields **DRY LAND FOOD** **S2:** Upland rice, Corn, Sorghum, Soy bean, Peanuts, Green beans, Cowpeas, Cassava, Sweet Potatoes **S3:** Chickpeas, Taro, Iles-Iles, Hui	**INDUSTRY** **S2:** Rubber, Coconut, Robusta Coffee, Cocoa, Clove, Tobacco **S3:** Oilm palm, Sugarcane, Melinjo, Cotton, Kapok, Quinine **FRUITS** **S2:** Apple, Mango, Rambutan, Guava, Belimbing, Durian, Water melon, Cantaloupe, Melon,longan, Jackfruit, Soursop, Custard apple, Breadfruit, Sapodilla, Longan, Mangosteen, Pineapple, Strawberry, Persimmon, Kepayang, Banana, Orange, Avocado, Grape **S3:** Papaya, Carica, Passion fruit **VEGETABLE** **S2:** Petsai, Caisim, Spinach, Eggplant, Biet, Vegetable Tomatoes, Red Chili, Paprika,	**S3:** Teak, Mahogany, Agathis, albizia, Acacia, Leucaena, Eucalyptus, Gelam	

			Cabbage, Beans, Long beans, Cucumber, Bitter melon **S3:** Lettuce **FLOWER** **S2:** Rose, ylang-ylang, Tuberose, Hairgrass, Gladiol, Daisies, Sunflower **SPICES&MEDICINAL** **S2:** Candlenut, Vanilla, Aromatic ginger, Tumeric, Galangal, Cadarmom, Jatropha **S3:** Pepper, Lemongrass, Vetiver root, Ginger,		
7	Zumalai	**WETLAND FOOD** **S2**: Irrigated rice fields **DRY LAND FOOD** **S2:** Upland rice, Corn **S3:** Sorghum, Soy bean, Peanuts, Green beans, Cowpeas, Chickpeas, Cassava, Sweet Potatoes, Taro	**INDUSTRY** **S2:** Tobacco **S3:** Karet, Coconut, Coconut Mustardt, Kopi Robusta, Cocoa, Clove, Sugarcane, Cotton, Quinine **FRUITS** **S2:** Papaya, Mango, Rambutan, Guava, Belimbing, Durian, Water melon, Cantaloupe, Melon, longan, Jackfruit, Soursop, Custard apple, Breadfruit, Snake fruit, Sapodilla, Longan, Mangosteen, Pineapple, Strawberry, Persimmon, kepayang, Banana, Orange, Avocado, Passion fruit, Grape **S3:** Apple, Carica **VEGETABLE** **S3:** Lettuce, Spinach, Mustard, Petsai, Eggplant, Biet, Vegetable Tomatoes, Red	**S3:** Teak, Mahogany, Agathis, albizia, Acacia, Leucaena, Eucalyptus, Gelam	**S3:** Grazing

			Chili, Paprika, Cabbage, Beans, Long beans, Cucumber, Bitter melon FLOWER S3: Rose, ylang-ylang, Tuberose, Hairgrass, Gladiol, Daisies, Sunflower SPICES&MEDICINAL S3: Pepper, Pala, Candlenut, Vanilla, Lemongrass, Sweet root, Ginger, Aromatic ginger, Tumeric, Galangal, Cadarmom, Jatropha		

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

11.2 FOOD CROP DEVELOPMENT POTENTIAL ZONE

According to the 2021 Crop and Food Security Assessment Mission (CFSAM) report, agricultural production in Covalima District reflects the dynamics of a farming system dependent on various key commodities, including maize, rice (paddy), and root crops. Data indicates that the area used for maize cultivation is 4,200 hectares, with an average yield of 2.2 tons per hectare, resulting in a total maize production of 9,200 tons during the main planting season. Additionally, there is an additional production of 800 tons, bringing the total maize production for the entire season to 11,000 tons.

Similarly, the rice sector also contributes significantly to overall food production. The area of paddy fields used during the main planting season is 2,200 hectares, with a paddy yield of 3.5 tons per hectare. After milling, this yields 2.1 tons of rice per hectare. Therefore, the total rice production during the main planting season reaches 4,620 tons, plus an additional 350 tons from the second planting season, resulting in a total rice production of 4,970 tons.

In addition to maize and rice, root crops also play a vital role in the food security system of Covalima. With a production of 7,500 tons, root crops make a substantial contribution to meeting the food needs of the community, particularly as an alternative carbohydrate source. When all these commodities are converted to a Single Cereal Equivalent (SCE), agricultural production in Covalima District reaches 17,370 tons. This figure reflects the cumulative production from various crops converted to a standardized unit equivalent to cereals, allowing clearer comparisons in the context of food security and land productivity. SCE is a data conversion method used to equate the production of various agricultural commodities to a standard unit. This conversion is necessary because each commodity, such as maize, rice, and root crops, has different nutritional content and calorie values. By equating the production results based on energy or calorie content comparable to cereals like rice or wheat, analysis and comparison of productivity across commodities become easier and more accurate. This approach allows for a more comprehensive evaluation of food security and agricultural production efficiency.

Research focused on Covalima District has resulted in zoning for food crop development that aligns with local agroclimatic characteristics. The region holds significant potential to support national food security and reduce dependency on imports by optimizing local food production. Based on agroclimatic zoning, Suai

Sub-district has been identified as an area with high land suitability for irrigated paddy cultivation, as well as for other food crop commodities such as maize, sorghum, groundnuts, millet, and cassava. Each Sub-district in Covalima District has different agroecological characteristics, requiring a specific management approach to optimize productivity and ensure the sustainability of the farming system in the region.

The food crop sector plays a key role in strengthening food security in Covalima, particularly in Suai Sub-district, which has large areas of land available for agricultural development. A primary strategy in this effort is optimizing irrigated rice fields, which cover 286.64 km² or 23.75% of the total area. With agroclimatic conditions supporting agricultural intensification, this area has great potential to increase rice production. However, to ensure sustainable water resource utilization, strengthening supporting infrastructure, including the construction of reservoirs and piped irrigation systems, is needed to optimize water distribution for agriculture.

In addition to irrigated rice fields, mixed gardens also play a significant role in supporting food production in Covalima. The area of mixed gardens covers 517.87 km² or about 43.06% of the total area, making it one of the dominant land use types. The mixed garden system adopts agroforestry principles, integrating various types of plants, including forestry, agricultural, and plantation crops, into one ecosystem. This approach not only enhances biodiversity but also provides economic benefits to farmers through diversified products. Zumalai and Tilomar Sub-districts are the main centers for mixed garden development, with agroclimatic conditions that support the growth of various plant species. To maintain soil fertility and improve long-term productivity, the application of conservation techniques such as strip cropping and crop rotation is a strategic step that can be implemented.

With an integrated management strategy, Covalima District has a great potential to contribute to achieving national food self-sufficiency. The development of irrigated rice fields, combined with diversification through mixed gardens, serves as a key pillar in strengthening the agricultural sector. Through the synergy between the government, local communities, and the application of innovative agricultural technologies, Covalima can enhance food security while promoting sustainable farmer welfare.

Figure 11.3 Potential for Food Crop Development in Covalima District
(Source: Research Documentation 2024)

XII. RECOMMENDATION

12.1 LAND MANAGEMENT RECOMMENDATIONS

These recommendations were formulated based on a scientific study that conducted an in-depth analysis of the potential of Covalima District for the development of food and horticultural commodities, plantation crops, forestry, and grazing areas. The zoning of the area produced through the land suitability evaluation serves as the main basis for formulating land management strategies aimed at supporting food security, economic sustainability, and environmental conservation. Based on the analysis, the total zoned area is divided into six main categories, namely irrigated rice fields covering 23.75% of the total area, agroforestry covering 26.49% of the total area, grazing areas covering 0.48 % of the total area, protected forest covering 4.69 % of the total area, mixed garden covering 43.06% of the total area, and mangrove covering 1.52% of the total area. This distribution reflects the diversity of the area's biophysical potential and the importance of specific approaches to the management of each zone.

Food crop zones play a significant role in strengthening food security at the national level. Areas such as Suai Sub-District and Zumalai Sub-District, which have been identified as food production centers, are expected to contribute as the main rice granaries of Covalima District. Through efforts to optimize irrigation systems, land management oriented toward improving soil fertility, and the application of sustainable agricultural technologies, the potential of these food crop zones can be optimized. This also reflects the diversity of the area's biophysical potential and the need for specific approaches in the management of each zone.

The agroforestry and protected forest zones, with a combined share of 31.1% of the total area, are important areas for economic diversification through the development of high-value commodities. Areas such as Fatululic Sub-District, Fatumean Sub-District, Forohem Sub-District, Suai Sub-District, and Tilomar Sub-District have high potential for industrial crops such as Robusta coffee, Arabica coffee, cacao, and coconut, as well as horticultural fruit and vegetable crops such as banana, avocado, and red chili. Agroforestry systems integrated with horticultural crops not only increase land productivity but also play a role in soil and water conservation, reduce erosion risk, and support adaptation to climate change.

The forestry zone includes protected forest areas that aim to conserve ecosystems, with a focus on biodiversity protection, water resource management, and climate change mitigation. The development of protected forest areas across all Sub-Districts is recommended to reduce greenhouse gas emissions, increase carbon stocks, and maintain ecosystem balance. In addition, production forests planted with teak, mahogany, and Albizia are also proposed to provide economic benefits while involving local communities in sustainable forest management.

This strategy makes a direct contribution to achieving the SDGs, particularly those related to food security, climate change mitigation, and the conservation of water resources. By combining scientific approaches with zoning-based management, these recommendations are expected to address agrarian challenges in Covalima District while promoting sustainable development that balances economic and ecological aspects.

Improving the productivity and sustainability of the agricultural sector requires remedial measures for each existing limiting factor. Constraints such as shallow soil depth, inadequate drainage, erosion risk, and the presence of surface rock require specific solutions so that land potential can be optimized. The proposed improvements for each limiting factor are formulated as an implementation basis for enhancing land suitability in support of agricultural and forestry commodity development, as summarized in **Table 12.1.**

Table 12.1 Recommendations for Improvement Measures for Each Limiting Factor

No	Land Quality/Characteristics	Type of Improvement Measure	Management Level
1.	**Temperature (tc)** - Mean annual temperature	No improvement possible. Replacement with suitable commodities/varieties.	Not improveable
2.	**Water availability (wa)** - Rainfall/year - Rainfall during the growing period	Irrigation/construction of small reservoirs/drip irrigation. Planting Pattern/Planting Calendar Management	Moderate, high

3.	**Rooting medium (rc)** - Drainage - Texture - Effective depth - Coarse Fragments	 Improvement of the drainage system, such as construction of drainage channels and ridges/raised beds. No direct improvement possible; constraints can be mitigated by adding organic matter. Generally not improvable, except in soft and thin hardpan layers that can be broken up during land preparation. Depends on the amount and distribution in the soil profile. If the amount is less than 35 %, it is referred to as an obstructing layer (root-impeding) and can be addressed by adding organic matter and applying minimum tillage. If the amount is more than 90 %, it is referred to as a restricting layer (root-restricting) and is difficult to improve.	 Moderate, high High Moderate, high High
4.	**Nutrient retention (nr)** - CEC - Base Saturation - pH - C-organic	 Addition of organic matter. Liming and addition of organic matter. Liming when soil pH is low, whereas for high pH sulfur or ammonium sulfate (ZA) can be applied. Addition of organic matter/organic fertilizer and returning crop residues to the soil.	 Moderate, high Moderate, high Moderate, high Moderate, high
5.	**Nutrient Availability (na)** - Total-N - Available - P - Available - K	 N fertilization (urea and ammonium sulfate/ZA). P fertilization (SP-36 and TSP). K fertilization (KCl). Compound fertilizer (NPK).	 Low, Moderate, High Low, Moderate, High Low, Moderate, High
6.	**Erosion Hazard (eh)** - Slope (%) - Erosion Hazard	 Erosion control, terracing, contour planting, planting of cover crops, application of mulch/crop residues, implementation of agroforestry.	 Moderate, high

7.	**Flood Hazard (fh)** - Height - Duration	Construction of flood protection dikes, construction of drainage channels to accelerate water removal, construction of infiltration wells.	High
8.	**Land Preparation (lp)** - Surface Rock (%) - Rock Outcrops (%)	If the amount is small, rocks are removed; if the amount is high or very high, apply no-tillage (TOT), construct planting holes, and add organic matter.	Moderate, high
9.	**Improvement of technical cultivation practices**	Plot establishment, pruning, and maintenance/care.	Moderate, high

Explanation:

- *Low management level: Management can be carried out by farmers with relatively low costs.*
- *Moderate management level: Management can be carried out by intermediate-level farmers and requires medium capital*
- *Intermediate-level agricultural techniques.*
- *High management level: Management can only be carried out with relatively large capital and is generally implemented by the government or large or medium-scale companies.*

12.2 GLOBAL RECOMMENDATIONS

These recommendations aim to provide data-based strategic guidance for policymakers in Covalima District. The main focus of this approach is the management of the conservation sector and the sustainable utilization of weeds. By combining innovative solutions and integrated management strategies, this approach is expected not only to address complex ecological challenges, but also to foster food security, environmental sustainability, and community well-being in a holistic manner.

One of the major ecological constraints faced in the area is the spread of the invasive weed *Chromolaena odorata* (*C. odorata*), which is known for its remarkable regenerative capacity. Eradication efforts using conventional methods are often ineffective, require high costs, and have the potential to accelerate ecosystem degradation. Therefore, an innovative approach based on sustainable utilization is prioritized in these recommendations. This strategy seeks to transform existing challenges into opportunities by harnessing the economic, social, and ecological potential of *C. odorata*.

In the context of Covalima District, which is dominated by marginal land, this approach is highly relevant for supporting sustainable development. Through a combination of soil conservation practices, agroforestry, and creative weed management, these recommendations offer integrated solutions to maximize the use of available natural resources. The expected long-term outcome is a positive impact that benefits the environment while also making a tangible contribution to local community welfare.

This approach highlights the importance of maintaining a balance between conservation and the innovative use of resources, which is a key element in realizing the vision of sustainable development.

A. New Paradigm: Utilization of *Chromolaena odorata*

The eradication-based approaches that have so far been applied to control weeds often encounter various constraints that result in failure during implementation. One of the main factors is the ability of weeds to regenerate rapidly through their roots and remaining stems. In addition, very abundant seed production makes weed control a major challenge, as their presence is difficult to eliminate completely. The use of herbicides as one method of control also poses risks to ecosystem health. On the other hand, destructive approaches such as slash-and-burn practices, which are still frequently applied, tend to worsen land conditions and accelerate ecosystem degradation.

Given the inherent weaknesses of eradication-based approaches, a paradigm shift in weed management is required. This new approach should focus on the sustainable utilization of weeds. In this way, weeds are not viewed solely as a problem, but also as a resource that can provide economic, environmental, and social benefits if managed appropriately. This approach is expected to support the sustainability of the agricultural sector while minimizing negative impacts on the ecosystem.

B. Soil and Water Conservation

The soil and water conservation recommendations were designed with consideration for efficiency and ease of implementation to support the sustainability of the agricultural sector. Agroforestry is proposed as one of the long-term solutions that integrates conservation efforts with economic value. Systems such as agrisilviculture, which combines food crops with timber trees; silvopastoral systems, which combine trees and pasture for livestock feed; and agrosilvopastoral systems, which integrate crops, trees, and livestock on the same land, are recommended forms of agroforestry.

In addition, simple technologies such as biopore infiltration holes and drainage channels can enhance water infiltration and prevent waterlogging, particularly on horticultural land and stony areas. These systems also play a role in increasing groundwater reserves, which are important for agricultural sustainability.

The use of technologies such as check dams also has an important role in reducing erosion in waterways. There are three types of check dams that can be applied, namely brushwood structures made from wood or branches for small channels, loose stone structures that use rocks in stony areas, and gabions, which are wire baskets filled with stones and are effective for larger water flows.

Furthermore, policies and regulations are key elements in the success of conservation efforts, particularly on land with slope gradients greater than 45 %. Government is expected to regulate conservation measures through formal policies, while customary law can also be optimized to support implementation at the community level. With this integrated approach, soil and water conservation practices are expected to be effectively implemented to support agricultural sustainability in the area.

C. Addition of Organic Matter and Fertilization

Most areas in Covalima District have low organic matter content, which directly affects soil fertility, the capacity of soil to store water, and the activity of microorganisms that play an important role in soil ecosystems. To address this challenge, several strategic measures are recommended as solutions.

First, local organic materials such as farmyard manure, compost, and biochar can be used to improve soil structure, support detoxification processes, and increase biological activity that strengthens soil resilience. This approach is highly effective in improving land quality to support the cultivation of priority commodities such as upland rice, sorghum, chili, and tomato.

Second, organic residues can be applied as mulch on the soil surface. This technique helps maintain soil moisture, enhances the soil's water-holding capacity, and prevents erosion, making it highly suitable for flat land as well as land with drought risk, including areas located on slopes.

Third, the application of site-specific fertilization is also recommended to increase the content of key nutrients such as nitrogen, phosphorus, and potassium. This can be implemented through the application of macro-nutrient fertilizers at specific doses, namely 200 kg NPK ha^{-1}, 175 kg urea ha^{-1}, 40 kg SP-36 ha^{-1}, and 100 kg KCl ha^{-1}. These fertilizers are designed to meet nutrient requirements in soils used for rice cultivation in irrigated fields, in accordance with the local soil fertility characteristics.

Through this combination of strategies, the problem of low organic matter content in soils of Covalima District is expected to be addressed, so that land potential can be sustainably optimized to support the agricultural sector.

D. Drainage Management and Shallow Soil Depth

Poor drainage conditions and shallow soil depth are the main challenges in stony and sloping areas. These problems require appropriate technical approaches to improve productivity and the sustainability of land management. One proposed solution is the improvement of drainage channels through the application of ridge or raised bed systems, which are designed to prevent waterlogging and support efficient water management, particularly on horticultural land. This system can increase the efficiency of water use, reduce excessive water loss, and improve soil aeration, thereby making land quality more optimal.

In addition, technologies such as biopore infiltration holes, rorak pits, and infiltration wells are also recommended as solutions for stony soils. These techniques not only help increase water infiltration but also function as storage sites for organic materials, such as crop residues or other organic fertilizers, which can improve overall drainage quality. Biopores are also effective in increasing water storage capacity during the dry season, making them an appropriate option to support the sustainability of the agricultural sector.

Another recommended measure is the construction of planting holes with greater depth, which allows plants to develop stronger root systems. This technique is highly beneficial for industrial crops such as coconut and forest trees, which are often planted on land with shallow effective soil depth. Through the implementation of these measures, stony and sloping land can be managed in a more productive and sustainable manner.

E. Alternative Crop Development on Stony Land

Poor drainage conditions and shallow soil depth are the main challenges in stony and sloping areas. These problems require appropriate technical approaches to improve productivity and the sustainability of land management. One proposed solution is the improvement of drainage channels through the application of ridge or raised bed systems, which are designed to prevent waterlogging and support efficient water management, particularly on horticultural land. This system can increase the efficiency of water use, reduce excessive water loss, and improve soil aeration, thereby making land quality more optimal.

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Another recommended measure is the construction of planting holes with greater depth, which allows plants to develop stronger root systems. This technique is highly beneficial for industrial crops such as coconut and forest trees, which are often planted on land with shallow effective soil depth. Through the

implementation of these measures, stony and sloping land can be managed in a more productive and sustainable manner.

F. Implementation Strategies

The implementation strategies designed based on the regional zoning system aim to optimize land management in Covalima District. The zoning scheme, which includes irrigated rice fields (23.75 %), dryland agriculture/mixed garden (43.06%), agroforestry (26.49%), grazing areas (0.48%), and protected/conservation forest (4.69 %), serves as the main basis for designing management strategies oriented toward food security, economic sustainability, and environmental conservation. With this zoning-based approach, the following measures are relevant:

1. Optimization of Productionin the Food Zone

The optimization of production in the food zone, particularly in irrigated rice fields, plays an important role in strengthening national food security. The focused management strategy consists of two main measures:

a) **Improvement of Irrigation Infrastructure** The expansion of irrigation networks in Fatumean Sub-District and Forohem Sub-District is important. These areas have the potential to become significant rice production centers in Covalima District. To support the intensification of cropping patterns, priority actions include the development of micro-irrigation systems and the construction of small reservoirs to ensure a stable water supply.

b) **Diversification of Food Commodities** Beyond the main focus on rice production, this food zone also has potential to be used for the cultivation of other food crops such as corn, soybean, and cassava. The diversification of commodities not only enriches food sources but also enhances food security through diversified agricultural outputs.

This approach was designed to optimize the potential of the food zone in order to support sustainable and inclusive agricultural development. The strategy positions food security as the main priority while also creating broader socio-economic impacts.

2. Utilization of Agroforestry and Protected Forest Potential

This strategy was designed to optimize the potential of agroforestry and protected forest zones, which together cover 31.18 % of the total area. With an integrative approach, the strategy focuses not only on ecosystem conservation but also on promoting sustainable economic diversification. Its main components are as follows:

a) Development of Agroforestry Systems:
  - **Industrial crops:** Focus on high-value crops such as Robusta coffee, Arabica coffee, cacao, and coconut in Fatululic Sub-District, Fatumean Sub-District, Forohem Sub-District, Maucatar Sub-District, Suai Sub-District, Tilomar Sub-District, and Zumalai Sub-District.
  - **Horticulture:** Integration of fruit crops (avocado, mango, and banana) and vegetable crops (tomato, chili) with forest trees on sloping land to support soil conservation.

b) Management of Protected Forest:
  - Prioritize protected forest for biodiversity conservation, climate change mitigation, and land resource management.
  - **Production forest:** Plant teak, mahogany, and Albizia to generate additional economic value while involving local communities in sustainable forest management.

c) **Utilization of Weed Biomass:** The utilization of *Chromolaena odorata* biomass for organic fertilizer or bioenergy can reduce pressure on forest ecosystems.

3. Development of Infrastructure and Technology

a) Development of supporting infrastructure:
  - **Small reservoirs and rainwater storage reservoirs:** Constructed in dryland zones to increase water availability during the dry season.
  - **Drainage channels:** Help control runoff in sloping areas, particularly in agroforestry zones.

b) **Use of GIS and remote sensing technology:** Utilization of GIS and remote sensing for mapping land potential and monitoring land cover.

4. Community Capacity Building

a) **Training and education:** Training in soil conservation, water management, and commodity diversification for farmers in various zones.

b) **Empowerment of women and communities**: Training in agroforestry and biomass management to promote social inclusion and increase household income.

5. Weed Management Strategy: Utilization of *Chromolaena odorata*

a) Biomassa Utilization:
   - Processing *C. odorata* biomass into organic fertilizer to improve soil fertility.
   - Production of biochar and briquettes as bioenergy for local needs..

b) **Development of herbal products:** The potential of *C. odorata* as a raw material for traditional medicine can be further explored through collaboration between government and the pharmaceutical sector.

c) **Multi-stakeholder collaboration:** Government, academics, and the private sector need to work together in research and technological development for weed utilization.

6. Integrated Spatial Zoning

The spatial zoning approach enables more effective land use:

a) **Protected and conservation forest:** Areas with slope gradients greater than 45 % for ecosystem conservation.

b) **Agroforestry zones:** Areas with slope gradients of 15 to 45 % for timber and horticultural crops.

c) **Intensive agricultural zones**: Flat areas or areas with slope gradients less than 15 % for cultivation of major food crops.

7. Policies and Incentives

a) **Economic incentives:** Subsidies, microcredit, and bonuses for agroforestry- and conservation-based enterprises.

b) **Zoning regulations:** Spatial planning established in accordance with the zoning results.

8. Monitoring and Evaluation

a) **Data-based monitoring:** Use of GIS to evaluate the effectiveness of strategies.

b) **Participatory evaluation:** Involvement of communities, stakeholders, and government to maintain the relevance of the strategies.

Through the integration of scientific approaches, modern technology, and active community participation, these strategies form a foundation for addressing conservation challenges while advancing sustainable local economic development in Covalima District.

12.3 LIVESTOCK SECTOR

Based on geospatial and land analysis, the areas of Lactos, Calobor, and Fohorem have significant potential to be developed as centers for beef cattle production, both for breeding and fattening. High land suitability for the production of quality forage feed commodities, such as elephantgrass, Setaria, and legumes, is a key factor in ensuring a sustainable supply of nutrients. Supportive micro-ecological conditions, including temperature and rainfall, minimize heat stress in livestock, thereby increasing feed conversion efficiency and daily weight gain. Thus, the integration of agroclimatology and resource availability makes these areas strategic locations for the development of an efficient and sustainable beef cattle industry. The utilization of this potential can drive local economic growth and strengthen animal-based food security at the regional level.

12.4 FISHERIES SECTOR

The study showed that Covalima District has significant potential for aquaculture development, particularly in Maucatar Sub-District and Suai Sub-District, for both freshwater fish and brackish water commodities. Actual and potential land suitability values indicate a high level of feasibility, especially in Maucatar Sub-District, which has values greater than 3.3 for most species. However, several technical and environmental constraints still hinder the optimization of aquaculture, such as limitations in water quality (salinity, TDS), low rainfall during the dry season, and steep slope gradients in several locations.

Field observations also indicated strong community enthusiasm for developing aquaculture enterprises, with emerging self-initiated efforts such as private ponds, simple aeration systems, and the use of local resources for feed. However, technical support and infrastructure are still urgently needed to ensure production sustainability.

1. Site-Specific Technical Recommendations

There are various site-specific constraints in Covalima District. In Suai Sub-District, in Suai Loro Village, fish mortality occurred at the early stages of culture due to inadequate aeration, and milkfish broodstock are still managed naturally and not yet in a structured manner. In Matai Village, ponds are not used because local communities are concerned that groundwater is contaminated with oil. Meanwhile, in Maucatar Sub-District, participation in aquaculture is still low (3.52

%), and the use of local feed resources is not yet optimal. In Beco Village, 300 ha of mangrove forest have not been fully utilized, and a shortage of freshwater limits the development of large-scale aquaculture.

Improving aeration and pond infrastructure is an important measure to increase productivity, supported by technical assistance and the provision of simple aeration systems and basic infrastructure improvements for community ponds. Implementation can begin at active sites, such as ponds in Suai Loro Village. To reduce dependence on commercial feed, the optimization of local feed resources can be carried out through the formulation and training of feed production based on local commodities such as moringa leaves, corn, tubers, and rice bran, particularly developed in Maucatar Sub-District. In addition, groundwater quality testing in Matai Village needs to be conducted in the laboratory; if harmful substances are found, biofilter technology and reservoirs can be applied before the water is used for aquaculture.

Management of milkfish broodstock can also be improved, particularly by utilizing former rice-field lagoons in Suai Loro for the development of semi-intensive milkfish ponds, through the construction of water channels and partition systems for fish size grading. Equally important, mangrove areas in Beco Village can be managed under integrated mangrove-aquaculture (IMA) or silvofishery schemes, with an emphasis on the culture of mangrove crab and milkfish without damaging native vegetation.

2. Designation of Pilot Project

Pilot projects are recommended at two main locations.

a) **The first location is in Suai Loro Village (Suai Sub-District),** focusing on the culture of tilapia and milkfish in ponds or lagoons. The main partners at this site are pond owners with an educational background in animal husbandry. The reasons for selecting this location include the active involvement of partners, their interest in business expansion, suitability values greater than three, and the availability of local feed resources.
b) **The second location is in Beco Village (Maucatar Sub-District),** with silvofishery activities for mangrove crab. Partners at this site include government institutions and local fisher groups. Site selection is based on the availability of 300 ha of mangrove and the need for a sustainable coastal utilization model.

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

a) Government should allocate resources for extension programs and intensive technical training for aquaculture farmers in Covalima, particularly related to aeration and water quality management, on-farm feed formulation, and semi-intensive and integrated (silvofishery) culture techniques.

b) Government should promote the formation of pilot groups in priority locations to serve as learning centers and hubs for aquaculture innovation.

c) The development of ponds, water biofilters, clean water supply networks, and water quality monitoring systems should be supported through central government programs and development partners.

d) Spatial zoning adjustments are needed to accommodate the use of potential areas such as Beco Village so that there is no overlap with plans from other sectors.

e) A monitoring system involving universities, the Fisheries Service, and local communities is needed to ensure that all interventions are well targeted and sustainable.

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Covalima Municipality

Covalima Municipality is a strategic area within the southern national rice granary corridor of Timor-Leste, extending from Manufahi Municipality through Covalima Municipality, Ainaro Municipality, and Hatu Udo Administrative Post. Spatially, land use is dominated by dryland agriculture (43.06%), followed by irrigated rice fields (23.75%) and agroforestry systems (26.49%). Protected forest areas (4.69%) play a critical role in maintaining regional ecological balance, while grazing areas are relatively limited, covering only 0.48% of the area. Coastal ecosystems are supported by mangrove forests, with the largest distribution in Suai Administrative Post (0.89%), followed by Zumalai Administrative Post (0.44%) and Tilomar Administrative Post (0.19%).

Based on land suitability evaluation, potential wetland food crop commodities include irrigated rice, while dryland food crops comprise upland rice and corn. The horticultural sector shows promising prospects for fruit commodities such as jackfruit and durian, as well as economically valuable vegetables including snow pea and broccoli. For industrial and biopharmaceutical crops, Covalima Municipality has potential for the development of Robusta coffee and sugarcane, along with spice and medicinal crops such as pepper and cardamom. The forestry sector supports the development of mahogany and agathis, while grazing systems are suitable for forage crops such as elephantgrass and legumes.

In the livestock sector, Covalima Municipality has strong potential for the development of cattle and goat production. Three villages Lactos Village, Calobor Village, and Fohorem Villageare recommended as centers for beef cattle production based on breeding and fattening systems. The fisheries sector is developing in both coastal and inland waters, particularly in Suai Administrative Post (Suai Luro Village) and Maucatar Administrative Post (Beco Village), with leading commodities including tilapia, milkfish, and mud crab.

Regional development in Covalima Municipality is directed toward multisector integration based on integrated farming systems and aquaculture intensification. As a strategic measure, Beco Village, Matai Village, Suai Loro Village, Casabauc Village, and Fohoren Village are recommended as pilot project sites for sustainable integrated agricultural development, aimed at strengthening national food security, particularly in support of Timor-Leste's integration into ASEAN.