Land Suitability Evaluation & Regional Potential Mapping

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

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

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FOREWORD

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

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

Manufahi District is one of the key areas in Timor-Leste with substantial potential in the agricultural sector. This area consists of four Sub-Districts, namely Alas, Fatuberliu, Same, and Turiscai. With geographical conditions that include approximately 25.32 % flat land, mainly along the southern coast, Manufahi District has considerable potential for the development of irrigated rice farming that can significantly support national food security in Timor-Leste.

In addition to the potential for rice fields, Manufahi District also has fertile soils comprising several types, such as Mollisols, which are dominant with an area reaching 50.56 %, followed by Entisols at 31.07 % and Vertisols at 5.47 %. These fertile and friable Mollisols strongly support the development of various food crops as well as horticultural and plantation commodities, which will directly increase agricultural production and the local economy.

In the current global context, the challenges of food security and climate change require all of us to take concrete steps in the sustainable management of land resources. This book appears at the right time to provide both scientific and practical guidance for land management in Manufahi District. We hope that this book will become a primary reference for planning sustainable agricultural development, in line with the achievement of the Sustainable Development Goals

(SDGs), particularly in addressing hunger (SDG 2), promoting inclusive economic growth (SDG 8), and conserving terrestrial ecosystems (SDG 15).

We extend our highest appreciation to the entire team of researchers, academics, and all parties who have worked hard in preparing this book. We hope that this work will bring tangible benefits for community welfare, economic growth, and environmental sustainability in Manufahi District and Timor-Leste as a whole.

Respectfully,

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EXECUTIVE SUMMARY

A. OVERVIEW OF THE STUDY AREA

This chapter presents an overview of Manufahi District as 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, based on an in-depth and comprehensive data-driven approach.

1. Demography: Foundation of Human Resource Potential

Manufahi District has a significant farmer population, particularly in Same Sub-District, where the high proportion of farmers supports the implementation of agricultural technology innovations, whereas areas such as Turiscai Sub-District require specific strategies to increase community engagement in land management.

2. Soil Types: Basis for Land Suitability Evaluation

The diversity of soil types in Manufahi District, such as Mollisols, Inceptisols, Vertisols, and Entisols, comprises fertile and potentially productive soils, indicating high productivity potential when properly managed. However, soils that are vulnerable to erosion, such as Entisols and Vertisols, require intensive conservation strategies to ensure sustained productivity.

3. Land Use: Dynamics of Ecosystems and Human Activities

Land use in Manufahi District consists of wetland (irrigated rice fields), dryland, protected forest, and agroforestry. Alas Sub-District has the largest proportion of wetland (14.28 %), making it an area with high potential for further development of rice fields through the implementation of irrigation systems. The sustainable development of forest land and agricultural intensification in this area requires integrated planning to support productivity and national food security.

4. Field Conditions: Constraints and Potential

Land degradation problems (erosion, landslides, and critical land), limited irrigation infrastructure, and suboptimal land management are the main constraints on land management. However, substantial potential, such as the development of industrial and horticultural crops, indicates opportunities that can be optimized through conservation-based approaches and community empowerment.

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

The invasive plant *Chromolaena odorata* in Manufahi District poses significant ecological challenges, but also has considerable potential as a source of organic fertilizer, traditional medicine, and bioenergy. Utilization-based strategies that involve communities and the private sector are key to managing this species sustainably.

B. RESEARCH METHODS

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

Research Procedures

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

   The physical and chemical soil parameters analyzed included:
   a.) Soil organic carbon (%) using the Walkley and Black method.
   b.) Total Nitrogen (%) kjeldahl method.
   c.) Soil texture using the pipette method.
   d.) Soil pH using a potentiometer *(H_2O 1:2.5)*.
   e.) Available Phosphorus and Available Potassium (ppm):
      - Bray-1 method for pH < 7 (with conversion to mg/100 g).
      - Olsen method for pH > 7 (with conversion to mg/100 g).
   f.) Salinity *dS/m* using a potentiometer *(H_2O 1:2.5)*.
   g.) Cation exchange capacity (CEC) (*cmol/(mg/100g)*) and base saturation (%) using *NH_4OAc 1N pH7*.
   h.) Total P (mg/100 g) using the 25 % HCl method.
   i.) Total K (mg/100 g) using the 25 % HCl method.

j.) Soil fertility status based on the PPT (1995) method.

k.) Erosion hazard based on field observations and the Universal Soil Loss Equation (USLE).

Stages of Land Suitability Classification

1. Actual Land Suitability

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

2. Land Improvement Recommendations

   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 reassessed after considering improvements in order to maximize land potential.

4. Zoning of Commodity Development Potential

   Zoning was determined by integrating the agro-ecological zones of Manufahi District, based on land suitability and specific agro-ecosystems.

C. CHARACTERISTICS OF AGRICULTURAL LAND AND FORESTS

1. Temperature

Air temperature is a key parameter in land suitability evaluation, with analysis based on the integration of field measurements and the SRTM Digital Elevation Model (DEM) using the *Braak* approach. Temperature distribution varies among Sub-Districts, reflecting complex topography and microclimates. Highland areas (< 18°C) have agronomic limitations but high erosion risk, whereas lowland areas (> 26°C) are vulnerable to high evapotranspiration and require adaptive water resource management. Optimal zones (24 to 26°C and > 26°C) dominate productive areas and are suitable for soil and water conservation.

2. Rainfall

Rainfall analysis based on CHIRPS data shows that the largest proportion of the area has an annual rainfall ranging from 1500 to 2000 mm/year, with different distributions in each Sub-District. Alas Sub-District is dominated by the 1500 to 2000 mm rainfall class, covering 69% of its total area. Fatuberliu Sub-District is also dominated by the 1500 to 2000 mm class, covering 71% of its total area. Same Sub-District is dominated by the > 2000 mm class, covering 57% of its area, while Turiscai Sub-District is dominated by the highest rainfall class, which covers more than 55% of its total area.

3. Dry Months

The distribution of dry-month periods reflects variation in water availability stability. The characteristics of dry months in Manufahi District vary across Sub-Districts, with most of the area dominated by 5 to 6 dry months. Alas Sub-District is dominated by 5 to 6 dry months, covering 54% of its area. In Fatuberliu Sub-District, 5 to 6 dry months cover 71%. In Same Sub-District, 5 to 6 dry months cover 48%. Turiscai Sub-District is dominated by 3 to 4 dry months, covering 55% of its total area.

4. Drainage

Drainage characteristics in Manufahi District show a similar dominance pattern. Alas Sub-District is dominated by well drained conditions over 69% of its total area. Fatuberliu Sub-District has well drained conditions over 71% of its area, and Same Sub-District is dominated by well drained conditions over 74% of its area. In Turiscai Sub-District, the entire area is classified as well drained.

5. Soil Texture

Manufahi District is dominated by moderately fine and fine soil textures, which support high water retention and soil fertility. Alas Sub-District has fine soil texture over 46% of its total area. Fatuberliu Sub-District has moderately fine texture over 41%. Same Sub-District has moderately fine texture over 35%, and Turiscai Sub-District has fine texture over 45%. Fine textures tend to increase water storage capacity and the availability of organic matter, whereas medium and coarse textures support better soil aeration.

6. Coarse Fragments

The distribution of coarse fragments in Manufahi District is dominated by contents < 5% (37%), indicating that most of the area has soils with low coarse fragment content, which tend to be more fertile and suitable for agriculture.

7. Surface Rock

The distribution of surface rock in Manufahi District is dominated by the 0 to 5% category (63%), followed by 5 to 10% (14%) and 10 to 20% (9%). This indicates that only a small proportion of the area has higher surface rock content, but still within manageable limits for agricultural activities. The 20 to 50% category (9%) indicates that some parts of the area have relatively high surface rock content, which may affect soil water infiltration and fertility. Meanwhile, the > 50% category covers only 5%, indicating that only a very small portion of the area is dominated by very high surface rock content, which is likely less suitable for intensive agriculture.

8. Rock Outcrops

The distribution of rock outcrops in Manufahi District is dominated by the 0 to 5% category (69%), indicating that most of the area has very limited exposed rock. The 5 to 10% category covers 14%, showing that a small part of the area has moderate rock exposure, but still within manageable limits for various land uses. The 10 to 20% category covers only 3%, indicating that the area with higher rock outcrop density is still quite limited, while the 20 to 50% category covers 14%.

D. SOIL FERTILITY STATUS

The results of the analysis show that Manufahi District has three fertility status classes, namely low (64.06%), followed by medium (21.88%) and high (14.06%). These categories were determined based on soil chemical parameters such as cation exchange capacity (CEC), base saturation (BS), soil organic carbon (C-organic), phosphorus (P), and potassium (K). The low soil fertility status is caused by several main factors, including low C-organic and potassium contents, as well as soil properties that favor nutrient leaching in areas with high rainfall. In addition, the timing of soil sampling during the dry season contributed to lower availability of organic matter, and to reduced water and nutrient retention in sandy-textured soils. Increasing environmental stress (climate, drought/ustic moisture regime) accelerates the degradation of soil chemical properties.

- Spatial Distribution of Soil Fertility

  Most of the area is dominated by soils with low fertility status. Some areas have medium fertility, whereas land with high fertility is very limited and scattered in small patches across various locations.

E. EROSION AND AGROFORESTRY-BASED CONSERVATION

1. Soil Erosion

Soil erosion plays an important role in land suitability evaluation and in the sustainability of land use. In Manufahi District, factors such as steep slopes, low vegetation cover, granular soil structure, and minimal conservation measures accelerate erosion rates. Manufahi District has very severe and light erosion levels that are almost comparable. Very severe and severe erosion together cover

49.43 %, nearly half of the district area. This condition makes it one of the areas with the highest erosion hazard.

The main factors causing erosion in this area include:

a.) Topography: Predominantly steep slopes.
b.) Soil type: Vertisols and Entisols, which are susceptible to erosion, particularly on slopes > 15 %.
c.) Rainfall: High rainfall intensity that causes severe to very severe erosion.
d.) Low 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.

Manufahi District has very bsevere erosion over 40.32% of its area, severe erosion over 9.11%, moderate erosion over 12.99%, and light erosion over 37.58%. Steep slopes and limited application of soil conservation techniques are the main causes of the high erosion levels in this area. In addition, low vegetation density accelerates the loss of topsoil due to surface runoff.

2. Agroforestry-Based Conservation

Agroforestry-based conservation is a primary and effective approach to addressing soil erosion in Manufahi 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:** Reducing surface runoff and maintaining soil moisture.
b.) **Enhancing soil fertility:** Through organic matter contributions from leaves and roots.
c.) **Managing water sustainably:** By retaining water in the soil profile through deep root systems.

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

a.) **Erosion mitigation**: Trees and crops act as natural barriers that protect soil from surface runoff.
b.) **Increased water infiltration:** Tree root systems enhance soil capacity 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 diverse yields.

3. Implementation of Agroforestry in Manufahi District

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

a.) **Alley cropping:** Planting crops between rows of trees on steep slopes to control erosion.

b.) **Live hedges:** Using erosion-tolerant plants such as vetiver to stabilize slopes.

c.) **Live stakes:** Using perennial species such as Leucaena to control erosion, combined with pepper and other climbing crops.

d.) **Multilayer planting:** Combining trees, shrubs, and ground cover crops to protect soil and reduce runoff.

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

4. Conservation Recommendations

a.) **Strengthening agroforestry practices** in erosion-prone zones, such as Same, Fatuberliu, and Turiscai Sub-Districts.

b.) **Implementing spatial data-based management** to identify priority locations for conservation interventions.

c.) **Enhancing farmer capacity** through training and adoption of modern agroforestry techniques.

d.) **Strengthening soil conservation policy** by integrating agroecological approaches into spatial planning.

F. EVALUATION OF AGRICULTURAL LAND SUITABILITY

1. Alas Sub-District

a.) Food crops that can be developed include irrigated rice fields, upland rice, corn, sorghum, sweet potato, iles-iles, soybean, mung beans, cowpea, and peanut.

b.) Horticultural vegetable crops such as eggplant, beet, Tomato Vegetable, shallot, chili, Bell Pepper, cabbage, Green Beans, Long Beans, cucumber, Bitter Melon, broccoli, and asparagus can be developed on land classified as S2 (moderately suitable) to S3 (marginally suitable). In addition, horticultural fruit crops such as snakefruit, durian, rambutan, and avocado show strong potential in Villages such as Dotic Village, Mahaquidan Village, and Taitudac Village.

c.) Industrial crops such as Robusta Coffee, cacao, sugarcane, and melinjo are considered moderately suitable (S2).

d.) The development of forestry species such as Albizia, Acacia, Leucaena, and Melaleuca is assessed as fairly good.

2. Fatuberliu Sub-District

a.) The development of food crops such as irrigated rice, upland rice, corn, peanut, sweet potato, and taro is considered moderately suitable for the existing land conditions.

b.) Horticultural crops including eggplant, beet, chili, Tomato Vegetable, Bell Pepper, Green Beans, cabbage, Petsai, spinach, cucumber, papaya, watermelon, cantaloupe, melon, mango, pineapple, and banana have good development potential.

c.) Industrial crops such as Robusta Coffee, coconut, and tobacco have moderately suitable land conditions.

d.) Spice crops such as ginger, Aromatic Ginger, and Jatropha are considered highly suitable.

3. Same Sub-District

a.) Same Sub-District has strong potential for several food crops, including irrigated rice, upland rice, corn, sorghum, cassava, sweet potato, taro, iles-iles, soybean, mung beans, cowpea, and peanut, which are generally classified as moderately suitable (S2).

b.) In the industrial crop sector, Robusta Coffee is moderately suitable (S2) in Holarua Village, and coconut is also suitable for development in Betano Village and Babulu Village.

c.) Horticultural vegetable crops such as kailan, Tomato Vegetable, shallot, Green Beans, Long Beans, lettuce, Petsai, caisim, chili, eggplant, and Bitter Melon have strong potential with land classified as moderately suitable (S2). Fruit crops such as starfruit, soursop, custard apple, sapodilla, longan, strawberry, persimmon, banana, orange, avocado, Passion Fruit, durian, rambutan, and snakefruit also show promising potential.

d.) Spice crops such as pepper, candlenut, vanilla, Lemongrass, Vetiver Root, ginger, turmeric, galangal, and Aromatic Ginger have fairly good potential.

4. **Turiscai Sub-District**

a.) Turiscai Sub-District has significant potential for the development of Arabica Coffee and Quinine.

b.) Food crops such as corn, sorghum, wheat, iles-iles, hui, cowpea, mung beans, and chickpea also have land classified as moderately suitable (S2).

c.) In the horticultural sector, vegetable crops such as kailan, cabbage, Green Beans, Long Beans, broccoli, asparagus, radish, lettuce, caisim, Petsai, and spinach show good development potential. Fruit crops such as papaya, apple, mango, breadfruit, snakefruit, and banana are also moderately suitable for cultivation.

d.) Spice crops such as candlenut, cardamom, and Jatropha are not recommended.

e.) Forestry species such as Agathis, Altingia, Albizia, and Eucalyptus are considered less suitable for development.

G. LIVESTOCK POTENTIAL IN MANUFAHI DISTRICT

This study aimed to evaluate the potential and land suitability for livestock development in Manufahi District, Timor-Leste, to support food security, nutritional supply, and community economic improvement. The analysis was conducted using a Geographic Information Systems (GIS) approach, field observations, and socio-economic evaluation to assess the availability of forage feed, the ecological suitability of five main livestock types (sheep, beef cattle, dairy cattle, pigs, and buffalo), and local farming systems. Several key locations served as focal points for the evaluation, namely:

1. **Alas Sub-District**, the main problems include limited soil quality (low pH, limited nutrients) and an extensive management system that is relatively inefficient. Potential forages include Elephantgrass and Setaria. Proposed solutions include organic and NPK fertilization, liming, and the development of locally based supplementary feeds.
2. **Fatuberliu Sub-District,** constraints include low HPT productivity and limited market access. Potential forages include legumes such as Calliandra and turi. Recommended solutions include increasing the diversity of forage species (grass-legume mixtures), improved grazing land management, and enhanced support for market access.

3. **Same Sub-District,** the main problems are free-range management, high risk of theft, and limited reproductive management. Potential forages include stylo, Indigofera, and turi. Solutions that can be implemented include the development of communal housing, technical training in artificial insemination (AI), and improved livestock health monitoring.
4. **Turiscai Sub-District,** this area is highly potential for beef cattle, dairy cattle, pigs, and buffalo, but faces water limitations during the dry season. Potential forages include combinations of Elephantgrass, Setaria, and legumes. Solutions that can be implemented include constructing storage tanks, developing water distribution systems, and applying semi-intensive management systems.

H. FRESHWATER FISHERIES POTENTIAL IN MANUFAHI DISTRICT

There are three main sites that serve as focal points for aquaculture development:

1. Balai Centru Clacuc (Fatuberliu Village), the main problems at this site are low water quality (pH 6.4), limited aeration, and high mortality in catfish. In addition, water discharge is unstable throughout the dry season. Proposed solutions include the application of simple aeration (paddlewheels or manual blowers), the addition of dolomitic lime to stabilize pH, optimization of permanent water sources through storage systems, and community-based training on water quality management.
2. Sentra Fini Ikan, Alas Sub-District (Uma Berloic Village), the main problems at this site are low water quality (pH 6.3 to 6.5), fluctuating temperatures in highland areas, and limited local feed resources. Proposed solutions include improving water quality through simple filtration and liming, selecting commodities that are more adaptive to the temperature regime, such as carp and tilapia, developing alternative feed production units based on local materials (rice bran, Azolla, agricultural residues), and implementing extension programs and routine water quality monitoring.
3. Turiscai Sub-District, this site faces major limitations in terms of low water availability during the dry season and restricted infrastructure accessibility. Possible solutions include re-mapping water sources, constructing storage

reservoirs and simple distribution systems, and upgrading basic infrastructure.

I. ZONING OF AGRICULTURAL COMMODITY DEVELOPMENT IN MANUFAHI DISTRICT

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

1. Irrigated Rice Fields (21.22% of total area)
    a.) **Area:** These zones are located at low elevations (0 to 100 m above sea level) with slope gradients of 0 to 8%.
    b.) **Main areas:** Alas Sub-District has the largest area, covering 10.07 % of the total District area, followed by Fatuberliu Sub-District with 6.95 % and Same Sub-District with only 4.20 % of the total area of Manufahi District.
    c.) **Strategy:** Develop additional irrigation infrastructure, such as piped conveyance and pumping systems, in areas with relatively low rainfall.
2. Rainfed Rice Fields (0.02 % of total area)
    a.) **Area:** 0.25 km². Rainfed rice fields are located at elevations above 500 m above sea level, with a rainy season lasting 6 to 7 months per year.
    b.) **Main areas:** Turiscai Sub-District, covering 0.02 % of the total area of Manufahi District.
    c.) **Strategy:** Recommended strategies include the construction of small reservoirs, the use of drought-tolerant rice varieties, and improved water management to increase yields.
3. Dryland Agriculture (27.14 % of total area)
    a.) **Area:** 359.11 km². These zones are located at elevations of 100 to 500 m above sea level with slope gradients of 8 to 25%.
    b.) **Main areas:** Same Sub-District has the largest dryland agriculture area, covering 11.69% of the total District area. Alas Sub-District ranks second with 10.48%, followed by Fatuberliu Sub-District with 3.65%,

while Turiscai Sub-District has the smallest dryland agriculture area at 1.31% of the total area of Manufahi District.

c.) **Main commodities:** Corn, cassava, and peanut (food crops); vegetables, fruit, and ornamental flowers (horticulture); and coffee, cacao, and spices (industrial crops).

d.) **Strategy:** Apply strip cropping and crop rotation to maintain soil stability and sustain land fertility over the long term.

J. FORESTRY POTENTIAL IN MANUFAHI DISTRICT

Agroforestry (25.70% of total area)

a.) **Area:** 340.00 km² at elevations from 100 m up to more than 500 m above sea level with slope gradients of 25 to 45%.

b.) **Proportion:** 30 to 40% agricultural crops (coffee, cacao, and peanut) and 60 to 70% forest tree species (mahogany and Agathis).

c.) **Strategy:** Integrate small-scale livestock production to diversify household income.

Protected and Conservation Forest Area (25.37% of total area)

a.) **Area:** 335.68 km² at elevations above 500 m above sea level with slope gradients > 45%.

b.) **Purpose:** Soil and water conservation and biodiversity preservation.

c.) **Strategy:** Reforestation and ecosystem restoration to reduce land degradation.

K. RESEARCH RECOMMENDATIONS

1. Zoning Management

a.) **Irrigated and rainfed rice fields:** Optimize land in Alas, Fatuberliu, Same, and Turiscai Sub-Districts to serve as national rice production centers through irrigation development and the use of drought-tolerant rice varieties.

b.) **Agroforestry and forestry:** Focus on coffee, cacao, horticultural crops, and high-value tree species in agroforestry zones, such as Teak, Mahogany, and Albizia, while maintaining protected forests for ecosystem conservation and climate change mitigation.

2. Strategies to Increase Productivity

a.) **Improvement of land limiting factors:** Apply technologies such as liming on acid soils, the use of fertilizers containing sulfur on alkaline soils (high pH), addition of organic matter, improved drainage, and site-specific fertilization to address soil fertility constraints.

b.) **Utilization of invasive weeds:** Use *Chromolaena odorata* as organic fertilizer, biochar, or pharmaceutical raw material to support sustainable land management.

3. Soil and Water Conservation

a.) **Erosion mitigation:** Implement terracing, ground cover vegetation, mulching with litter, and check dam technologies to protect land from erosion on steep slopes.

b.) **Rainwater harvesting:** Construct small reservoirs, infiltration wells, and drainage systems in agricultural areas to support water availability throughout the year.

4. Community Empowerment

a.) **Training and education:** Provide training on soil conservation and soil fertility, agroforestry, and weed utilization technologies for farmers in collaboration with universities.

b.) **Farmer commitment:** Strengthen farmer commitment through activities aimed at increasing land productivity.

c.) **Multisector partnerships:** Involve government, academia, and the private sector to support research and technology development.

5. Policies and Incentives

a.) **Economic incentives**: Provide subsidies and microcredit for farmers who adopt environmentally friendly technologies.

b.) **Zoning regulations:** Establish land use regulations consistent with zoning to ensure the sustainability of natural resources.

6. Monitoring and Evaluation

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

b.) **Local participation:** Involve communities in evaluation and planning to ensure program sustainability.

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I. INTRODUCTION

New Context: ASEAN, the SDGs, and the Backbone of the Economy

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

In this new era, Timor-Leste is required to strengthen its economic foundation. The agricultural sector, as the backbone of the economy, plays a central role. The challenge of achieving food self-sufficiency and optimizing the use of natural resources has become a priority.

This issue of food security is closely linked to the Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger), SDG 6 (Clean Water and Sanitation), and SDG 13 (Climate Action). Productive and efficient land use is therefore essential, and Manufahi District has substantial potential to contribute.

Regional Focus: Assets of Flat and Fertile Land

Manufahi District is one of the areas with the greatest potential to support national food security. This district, which comprises Same, Fatuberliu, Alas, and Turiscai Sub-Districts, is endowed with highly favorable geographic characte`

Its main asset is topography. Approximately **55.73 % of the total area** has gentle to moderate slopes (0 to 15 %). This is a major advantage that makes Manufahi District highly suitable for the development of intensive and irrigation-based agriculture.

Technical Basis: The Golden Asset of Mollisol Soils

This ideal topographic potential is reinforced by high-quality soils. The "golden asset" of Manufahi District is the dominance of **Mollisols (50.56 %).** These soils are widely recognized as fertile, with high organic matter content, making them highly suitable for the production of food crops, horticulture, and plantation crops.

This potential is complemented by:

1) **Entisols (31.07 %),** whose potential can be realized through the use of organic fertilizers and irrigation;

2) **Vertisols (5.47 %),** which have high water retention capacity and offer opportunities for commodities that require stable moisture conditions, such as rice.

Geological conditions (metamorphic rocks such as phyllite and schist) also contribute to soil fertility through weathering processes.

Opportunities for Integrated Sector Development (Four Pillars)

With the combined assets of flat land and fertile soils, Manufahi District has a unique opportunity to develop four development pillars in an integrated manner:

1. **Agricultural Sector (including Plantations):** This is the core potential. Flat land and Mollisols are ideal for intensive agriculture with food crops (rice and horticultural crops) as well as high-value plantation crops such as coffee and cacao, which can form part of the national export strategy.
2. **Forestry Sector:** In areas with steeper slopes, the forestry sector plays a vital role. The implementation of conservation-based agroforestry systems is essential to maintain ecosystem stability, reduce erosion risk, and ensure land sustainability.
3. **Livestock Sector:** Extensive land and natural grazing systems can support the development of cattle, goats, and poultry. This can be integrated with agriculture, where crop residues are used as feed and manure is returned to the soil as fertilizer.
4. **Freshwater Fisheries Sector:** In line with the focus on water management (SDG 6) and irrigation development, there is also potential for freshwater aquaculture. Such systems can be integrated with agriculture (for example rice–fish systems) to diversify food sources and increase farmer income.

Management Challenges and the Purpose of This Evaluation

Despite its substantial potential, Manufahi District still faces several challenges, such as land degradation due to erosion in sloping areas and limited agricultural infrastructure and market access.

Therefore, the research underpinning this book aims to evaluate land suitability and map the potential for regional development in Manufahi District. The focus covers four pillars: **the agricultural sector (including plantations), forestry, livestock, and freshwater fisheries** as integrated supporting sectors.

This book is expected to provide strategic recommendations for government, academics, and other stakeholders to design sustainable development policies that support national food security and strengthen inclusive economic growth in Timor-Leste.

History and Administrative Evolution of Manufahi District

Historically, before the Portuguese established their authority in Manufahi, the area was under the traditional rule of kings and queens who led society through a strong customary system. The Manufahi Kingdom, located on the southern coast of Timor-Leste, began to exercise power in the 17th century and for centuries served as a center of political and cultural influence in the region. The period of the kingdom's prominence occurred between the late 19th and early 20th centuries, when Manufahi was recognized as a wealthy and influential kingdom with extensive networks of relations with surrounding areas. Social life at that time was characterized by strong customary traditions, leadership systems based on lineage, and social practices that reinforced the collective identity of the Manufahi people.

On 20 April 1859, Governor António Coelho Guerreiro established 14 districts as part of Portuguese administrative policy. Under this arrangement, Manufahi was designated as the District of Dotic and included within the Alas region, which comprised Manufahi, Alas, Raemean, Cammnassa, and Suai. This designation marked the beginning of the integration of the Manufahi area into the Portuguese colonial administrative system, although traditional authorities continued to exert influence in community life. During the Indonesian occupation, Manufahi was designated as a standalone District, with a more formal governmental structure in accordance with Indonesian administrative policies. After Timor-Leste achieved independence, Manufahi was subsequently recognized as one of the Districts, reflecting not only its long historical significance but also the continuity between traditional authority and modern governance systems. The District remains known for its rich cultural heritage, strong customary traditions, and its role in the historical struggle of the people of Timor-Leste.

II. GENERAL OVERVIEW OF THE AREA

2.1 DEMOGRAPHY

Manufahi District consists of 4 Sub-Districts: Same, Fatuberliu, Alas, and Turiscai. Manufahi District is bordered by: to the north, Aileu District; to the east, Manatuto District; to the west, Ainaro District; and to the south, the Indian Ocean. Geographically, the study area is located at a latitude of 9.0145° S and a longitude of 125.8280° E. The administrative map of Manufahi District is presented in **Figure 2.1.**

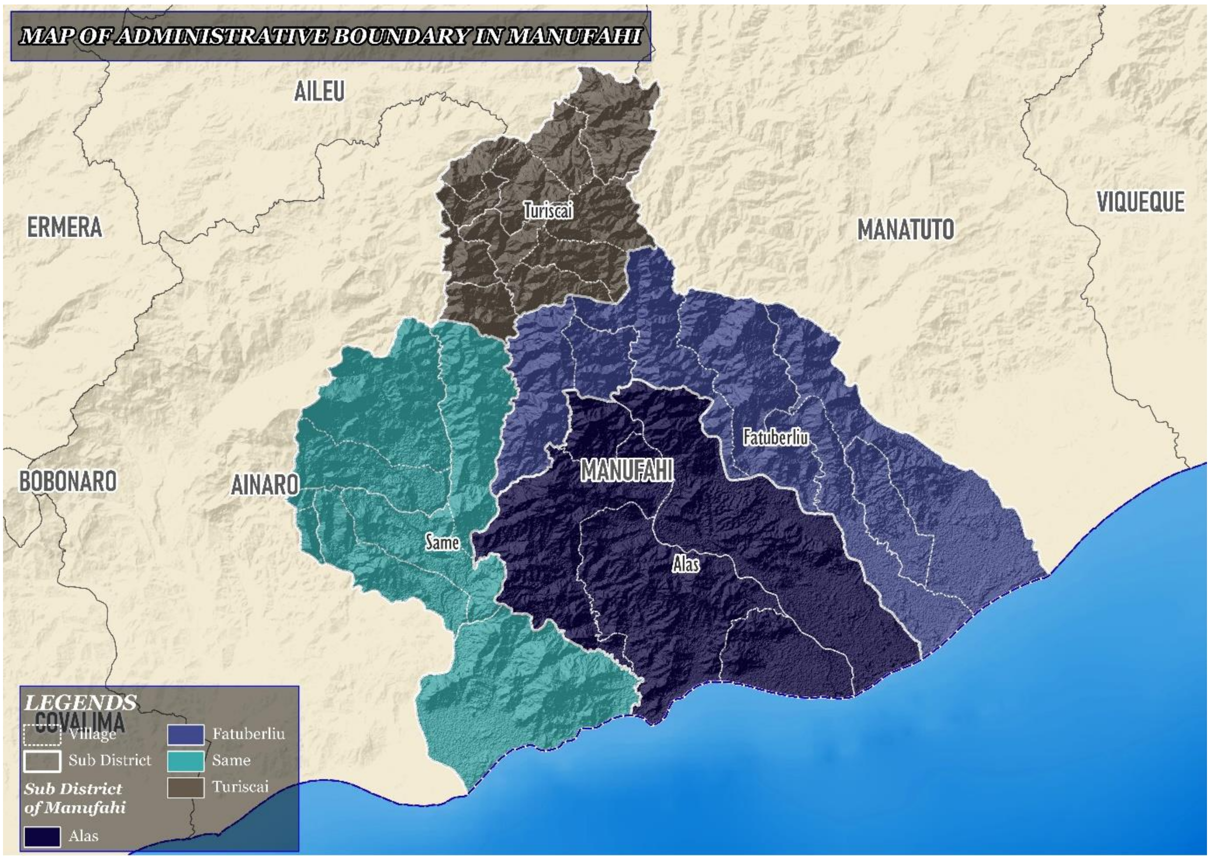


Figure 2.1 Administrative Area in Manufahi District.

The population in the study area is 74,319 (Autoridade Munisipiu Manufahi, 2025). The high population figures contribute to the success of the agricultural sector in terms of economic development and food sustainability. However, a smaller population does not necessarily indicate that the development of the agricultural sector is not progressing well (**Table 2.1**).

Table 2.1 Area of Manufahi District

Sub-District	Area (ha)
Alas	40.527,94
Fatuberliu	37.435,83
Same	35.380,58
Turiscai	18.766,14

In the effort towards food security, mapping the potential of regions based on demographics becomes a crucial component in land suitability evaluation. The high population in areas such as Same and Alas reflects the availability of labor ready to adopt agricultural innovations and land management technologies. However, this success requires the integration of appropriate management strategies, including the use of location-specific technologies and the provision of agricultural infrastructure.

This approach is not only relevant to support the national food security goals but also to optimize natural resources in alignment with the Sustainable Development Goals (SDGs), particularly Goal 2 (Zero Hunger) and Goal 15 (Life on Land). For example, areas with high erosion levels, such as those found in some mountainous regions, require sustainable soil conservation interventions, while alluvial areas can be utilized for the development of irrigated rice fields to support food productivity.

In the context of mapping regional potential, demographic data is also relevant for determining priorities in agricultural commodity development. Areas with populations predominantly engaged in farming can be focused on developing local flagship commodities, such as corn, cassava, or legumes, which are suited to the local agroecosystem conditions. Research by FAO (2020) emphasizes that mapping regional potential based on demographic and ecological data can improve natural resource management efficiency by up to 30% and support local economic development.

With a deep understanding of demographic aspects, this study aims to provide data-driven recommendations that support sustainable land management. Demographic data serves as a guide in developing inclusive land management strategies, considering the needs and capacities of local communities in each Sub-District. Developing the agricultural sector based on local potential not only supports food security but also strengthens local economic capacity, reduces poverty, and improves the well-being of rural communities.

Thus, optimizing natural resource management is expected to not only meet current food needs but also ensure its sustainability for future generations.

2.2 SOIL TYPE

The soil types found in Manufahi District show significant variation, reflecting the complexity of terrestrial ecosystems that form the foundation for land suitability evaluation. Mapping these soil types provides a deep understanding of the land characteristics needed to support optimal and sustainable natural resource management. Each district has a dominant soil type that has implications for specific, data-driven management strategies.

The soil types found in Manufahi District include: Mollisols (Hapludolls, Calciudolls); Inceptisols (Dystropepts, Eutropepts, Tropaquepts, Humitropepts); Entisols (Tropopsamments, Udifluvents, Troporthents); Vertisols (Chromusterts); and Alfisols (Haplustalfs). Potentially, the soils in Manufahi District are dominated by mature, highly productive soils such as Mollisols, Inceptisols, Vertisols, and Entisols. The presence of these mature soils offers significant opportunities for sustainable and productive agricultural development in Manufahi District.

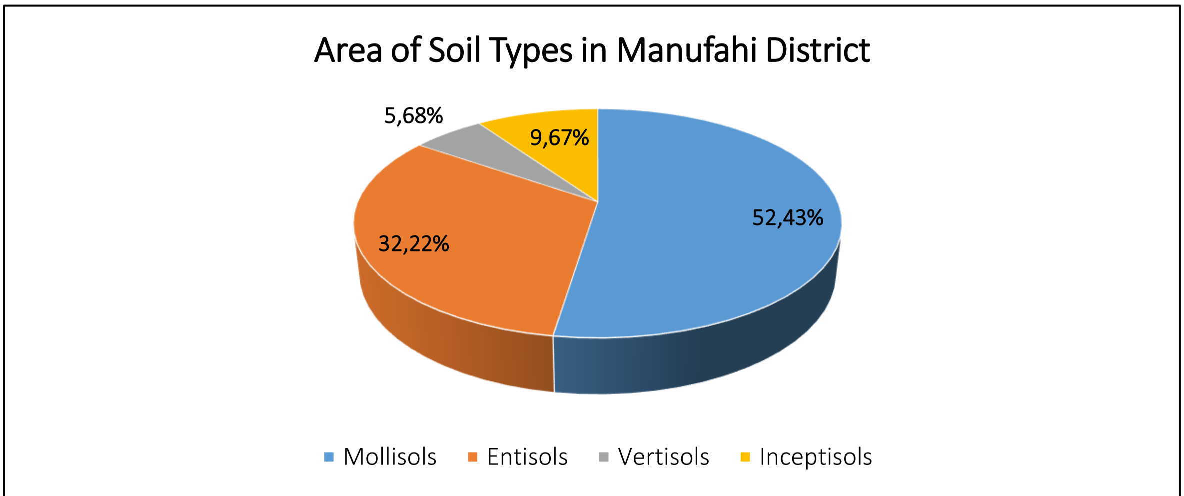


Figure 2.2 Area of the Region Based on Soil Types

Mollisols, which cover 53.43% of the total area, are known for their high fertility, supporting intensive management to enhance land productivity.

Inceptisols, covering 18.6%, offer flexibility in management and are often used in areas with varying management needs (FAO, 2018). Entisols, covering 32.22%, are found in areas with low soil development, such as steep slopes, and therefore require conservation interventions to reduce erosion risks (Rossiter, 1996). The area of each soil type in each Sub-District and overall is presented in **Figure 2.2**, while the distribution map is shown in **Figure 2.3**.

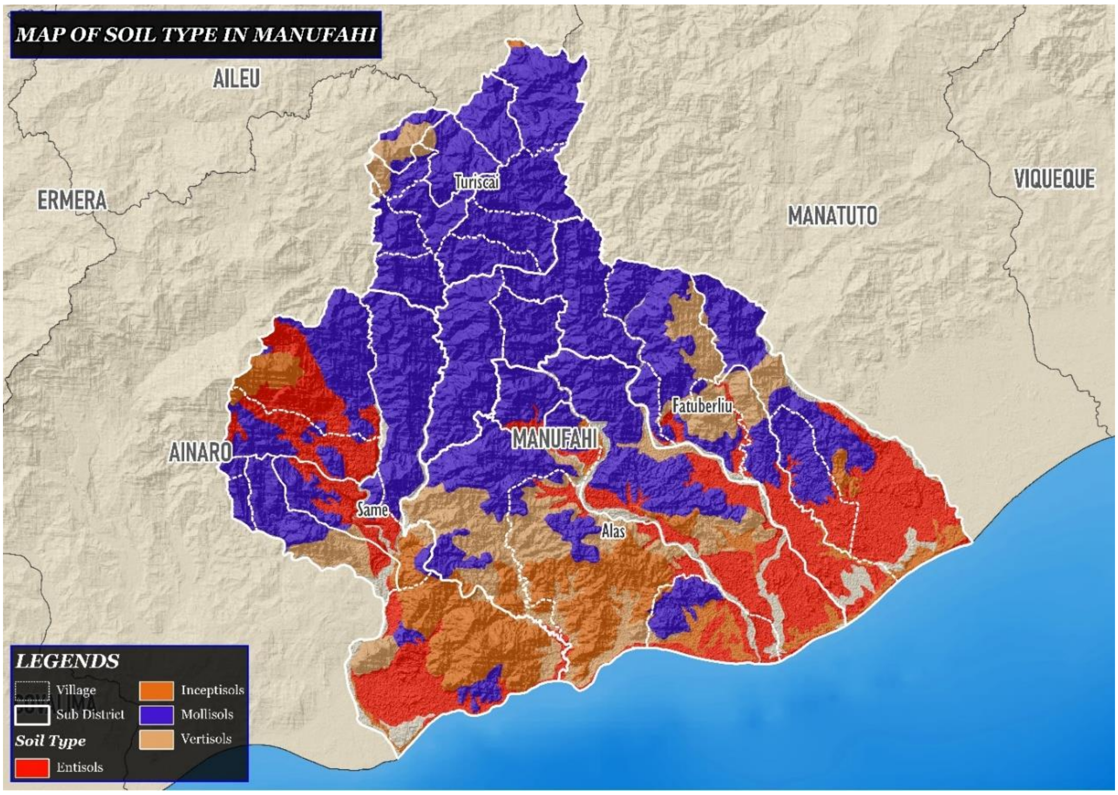


Figure 2.3 Soil Types Map in Manufahi District

2.3 LAND USE

Land use in Manufahi District includes various land types, each designated for specific purposes, providing a foundation for the development of agricultural commodities as well as high-value economic commodities. The Sub-District of Alas has 23.90% of its area allocated for agriculture, making it the largest land use zone in the district. In contrast, river areas only account for a small portion, approximately 0.76%. Forest land use in this sub-district occupies around 6.02%, making it the smallest forest area compared to other sub-districts. The distribution of land use indicates that agricultural development should be carried out sustainably, leveraging the extensive agricultural area, while also emphasizing the importance of maintaining and utilizing forest areas properly. Data on land area based on land use type is presented in **Figure 2.4.**

Fatuberliu Sub-District has 9.92% of its area allocated for agriculture, followed by commercial agriculture, which occupies approximately 1.42%. The forest area in this sub-district covers 16.32% of the total land area, while river areas make up 0.66%. However, data on settlement areas is not available. The land use distribution indicates the potential for agricultural development by optimizing it for intensive use, while also implementing sustainable forest management practices.

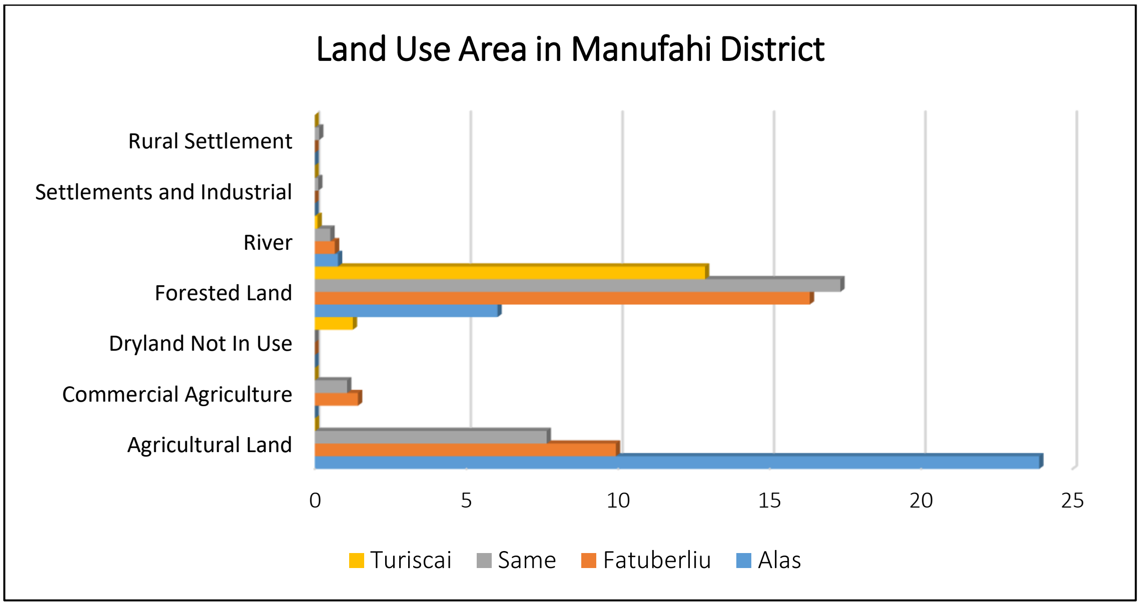


Figure 2.4 Land Use Area Chart in Manufahi District.

Same Sub-District has distinct characteristics, with 7.64% of its area allocated for agriculture and approximately 1.06% for commercial agriculture. The forest area in this sub-district is the largest compared to other sub-districts, covering 17.33% of the total land area. River areas occupy only 0.51%, and settlement areas are small, around 0.25%. The potential for agricultural development should be pursued intensively, with effective management practices, while sustainable conservation measures must be applied to the forest areas due to their high development potential.

Meanwhile, Turiscai Sub-District has unique differences from other sub-districts, with agricultural land use covering only 0.01%, followed by dryland areas at 1.25%. The forest area in this region has one of the highest development potentials, covering 12.86% of the total area, with river areas around 0.09%. The high potential for forest area development in this region must be carried out with high efficiency and sustainability.

The diversity of land use in Manufahi District presents significant opportunities for the development of agriculture and forestry by utilizing the available land allocation areas. However, achieving optimal development requires adherence to sustainability principles, utilizing resources as efficiently as possible, and implementing effective conservation practices. Moreover, this development should be initiated by the Ministry of Agriculture, Fisheries, Livestock, and Forestry of Timor-Leste to ensure it is well-organized, integrated, and aligned with the desired improvements in agricultural outcomes. The land use map of Manufahi District is presented in **Figure 2.5.**

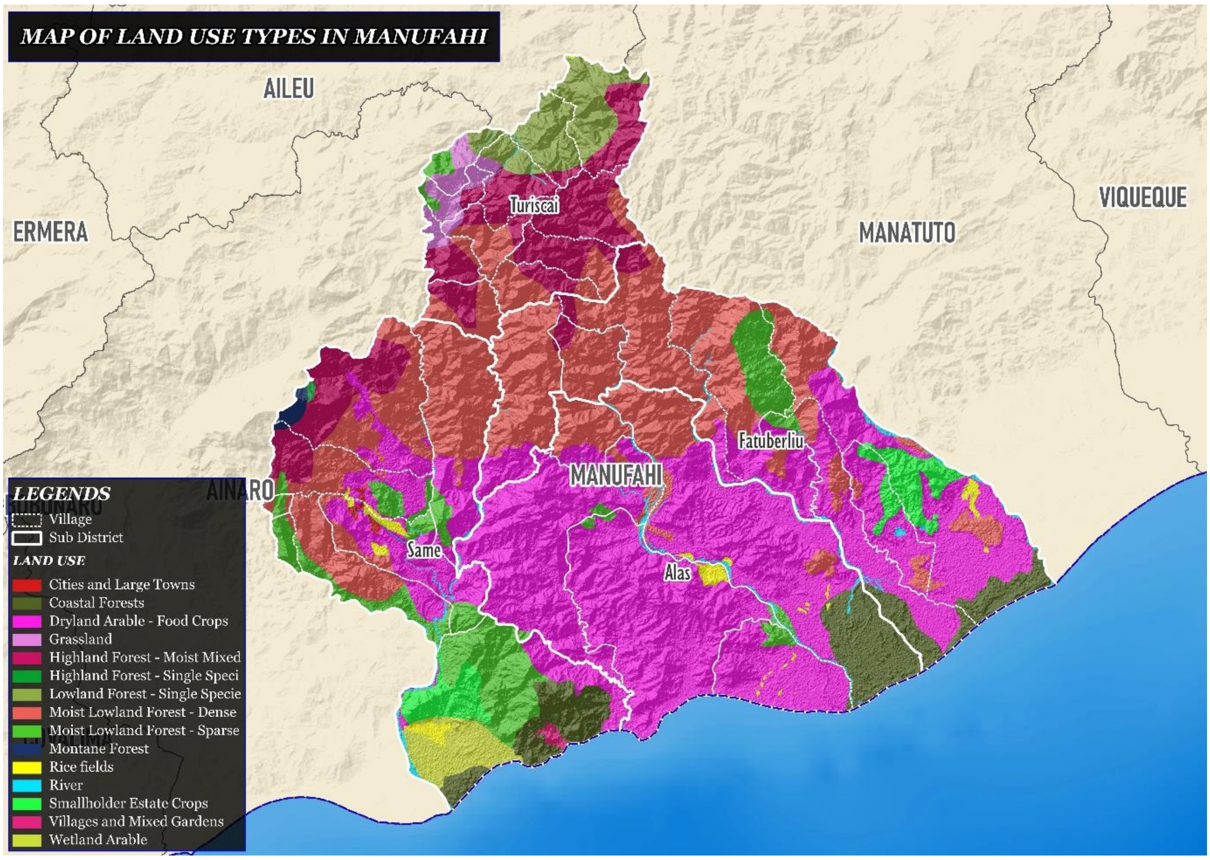


Figure 2.5 Land Use Map in Manufahi District

2.4 EXISTING FIELD CONDITIONS

The distribution of landforms in Manufahi District includes: alluvial and colluvial landforms, karst, denudational hills, denudational mountains, and marine areas. Based on field observations, there are many idle lands (land that is not utilized) with significant potential to be developed into productive land. This potential is supported by the availability of sufficient water, including rainfall, rivers, and the possibility of utilizing shallow wells and reservoirs.

In general, vegetation growth in this region shows relatively good fertility. However, there is a lack of adequate technical practices, such as proper planting distance, plant type combinations, and plant care practices such as pruning, weeding, and fertilization (organic, inorganic, or biological). The shortcomings in the implementation of these techniques are evident in all types of current land use.

Figure 2.6 Rice Fields in Manufahi District
(Source: Researcher Documentation, 2024)

In addition, Manufahi District has several flagship commodities, one of which is coffee, widely found in Turiscai Sub-District (**Figure 2.7**). The coffee industry is very important for the local economy, as it provides a significant contribution with high market value. In the forest areas, the dominant industrial trees are teak and eucalyptus (**Figure 2.8**). These two types of trees play a crucial role in the timber industry and also contribute greatly to the sustainability of the local ecosystem. Meanwhile, in mixed garden areas, Manufahi District relies on various crop commodities such as coconut, areca nut, and sago (**Figure 2.9**). These commodities not only support the local economy but also provide food and processed products with high economic value for the local community.

Figure 2.7 Coffee Plants
(Source: Researcher Documentation, 2024)

Figure 2.8 Eucalyptus Plants
(Source: Researcher Documentation, 2024)

Figure 2.9 Sago Plants
(Source: Researcher Documentation, 2024)

Field observations found that former rice fields now planted with cassava and bananas have the potential to be restored as rice fields (**Figure 2.10**). Restoring this land could significantly increase food crop production. In Alas Sub-

District, there are extensive areas with potential to be developed for livestock grazing. Manure from this area can be used as organic fertilizer, providing additional benefits for agriculture in the region.

Figure 2.10 Former Rice Fields Now Planted with Cassava and Bananas (Source: Researcher Documentation, 2024)

Several challenges are faced in the area. Access to potential lands is often difficult due to the extreme terrain, making it challenging for farmers and developers. Additionally, agricultural and forest lands in areas with steep slopes are highly susceptible to soil erosion (**Figure 2.11**). Erosion poses a serious challenge to land management in Manufahi District and requires effective solutions to maintain soil sustainability and agricultural production in the future.

The erosion hazard in this area is classified as moderate to severe, as indicated by the thin topsoil layer and the occurrence of land slides. This high level of erosion risk is caused by the lack of conservation efforts by farmers. The absence of mechanical conservation techniques such as terracing and vegetative methods like planting cover crops worsens soil conditions, increasing the risk of erosion and land degradation.

Figure 2.11 Erosion Occurring in the Field
(Source: Researcher Documentation, 2024)

In general, the land management practices implemented by farmers are still very limited. Some indicators of this situation include:

1) The absence of adequate production inputs, such as quality seeds, leading to low crop yields.
2) Low fertilizer usage, both organic and inorganic, which affects crop quality and production.
3) Insufficient application of proper cultivation techniques, including planting distance, effective planting methods, and poorly organized plant arrangements.
4) Minimal attention to plant care, pruning, and orchard cleanliness, all of which contribute to suboptimal production outcomes.

The lack of efforts to improve these practices highlights the need for additional training and support for farmers to better manage their land and increase agricultural productivity.

2.5 *Chromolaena odorata*

Chromolaena odorata (**Figure 2.12**), commonly known as Siam weed, is a flowering weed from the Asteraceae family that thrives in tropical and subtropical regions. Its spread, particularly in developing countries like Timor-Leste, has a significant impact on the environment and the local economy.

Figure 2.12 *C. odorata* in Manufahi District
(Source: Researcher Documentation, 2024)

This plant has distinctive morphological characteristics, such as a hairy cylindrical stem, simple serrated leaves, and compound flowers that are bluish when young and turn brown as they mature (**Figure 2.13**). Chemically, *C. odorata* contains active compounds such as flavonoids, tannins, alkaloids, saponins, and essential oils (Jamatia *et al.,* 2024). These compounds offer significant potential as raw materials for traditional medicines used to treat conditions such as diabetes, burns, hypertension, and skin infections (Jamatia *et al.,* 2024).

Figure 2.13 Leaf Structure and Flowers of *Chromolaena odorata*
(Source: https://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:57443-2/images)

III. RESEARCH METHODS

This study was conducted in Manufahi District, Timor-Leste, with the primary objective of evaluating land suitability for the development of sustainable agricultural sectors. The region has significant potential for food production and horticultural commodities, supported by varying soil characteristics and a climate conducive to plant growth. Data collection was carried out through field surveys, laboratory analysis, and the use of Geographic Information System (GIS) technology. The study took place from July to August 2024, encompassing field observations, soil sampling, interviews with farmers, and mapping of the region using geospatial technology. All stages were carried out systematically to obtain accurate information as a basis for planning optimal and sustainable land management.

3.1 RESEARCH DESIGN

A. Methodologi Approach

This study employs both quantitative and qualitative approaches. The quantitative approach is used to obtain numerical data, which is then analyzed statistically, while the qualitative approach aims to understand the insights and experiences of farmers regarding agricultural land management in the study area (Trigunasih, 2016). The research methods applied include field surveys and laboratory analysis, including soil sampling and interviews with farming communities.

B. Determination of Sampling Points

The sample points are determined using the Homogeneous Land Unit approach, which is obtained through overlaying thematic maps, including Land Use Map, Soil Type Map, Geological Map, and Slope Map. The analysis and delineation of land units were conducted using the QGIS 3.10 software (Trigunasih *et al.,* 2023). Soil samples were collected randomly and compositely using soil drilling techniques. Each land unit is represented by one composite soil sample, collected at depths of 0-30 cm for annual crops and 30-60 cm for perennial crops. Each soil sample was collected in a quantity of 1 kg for further laboratory analysis.

C. Soil Morphological Observations

During the soil sampling process, observations and documentation of field soil characteristics were carried out to understand the physical conditions of the soil in more detail. Parameters observed include soil color, texture, structure, consistency, and drainage system. For more detailed analysis, ring samples were used for core soil sampling to measure bulk density (BD) and soil porosity, which are important indicators in determining soil fertility and water retention capacity (Sukarman *et al.,* 2017).

D. Interviews and Questionnaires

In addition to field observations, interviews and questionnaire surveys were conducted with farming communities to gather further information on agricultural practices in the study area. The respondent selection technique used was purposive sampling or judgmental sampling, which considers the experience and expertise of farmers in land management (Sekaran & Bougie, 2013). The data collected includes planting patterns, agricultural challenges, and the land management systems implemented in the study area.

E. Land Suitability Evaluation

The results of the field surveys, climate data, and laboratory analysis were then compiled and evaluated using an agroecological land suitability assessment system based on the criteria of Ritung *et al*. (2011). The classification method applied follows the FAO (1976) system with a matching approach, which matches the land characteristics with the growing requirements of the analyzed crops. The agricultural commodities evaluated in this study include food crops, horticulture, and high-economic-potential plantation commodities.

3.2 RESEARCH PROCEDURE

A. Literature Review

The initial stage of the research begins with a literature review to gather relevant secondary data to support the analysis. The data collected includes administrative maps of the study area, geographical conditions, agricultural land area, and agricultural commodity production data. Climate data analyzed includes temperature, rainfall, dry months, and humidity. Additionally, previous studies related to land suitability evaluation are reviewed to strengthen the scientific foundation of this research.

B. Land Unit Analysis

Land unit analysis aims to determine land units as a basis for planning field observations. The homogeneous land units obtained are used as references for soil sampling and the preparation of land suitability maps. The analysis process includes:

a. Interpretation of Digital Elevation Model (DEM) maps to analyze landforms and slope gradients.
b. Satellite imagery analysis to verify actual land use patterns, particularly in areas that have undergone land conversion, such as rice fields, settlements, and plantations.
c. Utilization of supporting data, such as slope maps, geological maps, and soil type maps, to reinforce land unit delineation.
d. Overlaying various thematic maps to generate homogeneous land units that will serve as the basis for soil sampling.

C. Field Survey

The field survey is conducted to verify the suitability of homogeneous land units with actual field conditions. If discrepancies are found between the map analysis and field conditions, the delineation is revised to match the actual situation. Sample points are determined based on the analysis results and current field conditions.

In addition, interviews with local farmers are conducted to gather additional information about agricultural practices and the challenges faced in land management. Observations also include environmental factors that affect agricultural productivity, such as soil drainage, effective depth, erosion risk, flood risk, and surface rock content (Ritung *et al.,* 2011).

Soil sampling is carried out using the drilling method to a depth of 0-30 cm for annual crops and 30-60 cm for perennial crops. The collected soil samples are then further analyzed in the laboratory to determine the physical and chemical properties of the soil that may influence land productivity. Climate data, such as temperature, rainfall, and humidity, are obtained from local climate observation stations and presented in a data table format. The results of the land suitability evaluation and characteristics of each land unit are shown in **Table 3.1**, while the land suitability distribution map is presented in **Figure 3.1**.

Table 3. 1 Relationship of Parameters, Data Acquisition, and Data Sources

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

D. Laboratory Soil Analysis

The parameters used to determine soil properties or characteristics from samples analyzed in the laboratory were:

a. Soil Organic Carbon (SOC) by Walkley dan Black method (%).
b. Total N by the Kjeldahl method (%).
c. Soil texture by the pipette method.
d. Soil pH by the potentiometric method (H_2O 1:2,5).
e. Available P (ppm) and Available K (ppm) by the Bray^{-1} method when soil pH was below 7 and by the Olsen method when soil pH was above 7, with unit conversion (mg/100 g)
f. Salinity (dS/m) by the potentiometric method (H_2O 1:2,5).

g. CEC (cmol) dan BS (%) using NH_4OAc 1N 7 pH as the extractant.
h. Total P (mg /100 g) using the 25 % HCl method.
i. Total K (mg/100 g) using the 25 % HCl method.
j. Determination of soil fertility status based on the PPT (1995) method.
k. Erosion hazard using the Universal Soil Loss Equation (USLE).

E. Land Suitability Analysis

Field observations and laboratory results were tabulated into agroecosystem land characteristics/qualities. Agroecosystem land suitability was then analyzed by matching land characteristics/qualities to the growth requirements of bamboo, teak, mahogany, pine, coffee, cacao, and coconut, to obtain land suitability classes based on the criteria of Ritung *et al*. (2011). Classification of land suitability was carried out to the land unit level.

Land suitability classes were defined as actual and potential suitability. Actual suitability for each homogeneous land unit was determined by matching land characteristics/qualities with crop requirements without improving limiting factors. Potential suitability was determined by considering inputs and management measures for each land unit, assuming efforts to ameliorate the limiting factors.

F. Agricultural Commodity Development Planning

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

G. Land-Use Recommendations

Land-use recommendations were made at the land unit level, based on the highest land suitability ratings followed by lower classes, treatment of limiting factors, and improvement measures for each homogeneous land unit in the Sub-Districts of Manufahi District. Preparation of digital maps using a geographic information system facilitated information display. The information included agroecosystem land suitability, land-use recommendations, and agricultural commodity zoning. Land suitability maps were prepared based on homogeneous land units and the results of agroecosystem land suitability classification.

The classified land suitability for each evaluated crop group was mapped. Crop-specific land suitability was presented in agricultural commodity zoning maps, while land-use planning was presented in land-use recommendation maps.

The research flowchart is presented in **Figure 3.1**.

H. Data Analysis Using Geographic Information System Technology

The land suitability information system consisted of spatial data (land unit maps) and attribute data (land suitability classes). Combining these components produced an information system using QGIS 3.10. The outputs comprised land suitability classes for food crops, horticultural crops, industrial crops, forestry species, spices and medicinal plants, forage feed, and grazing, based on the evaluation results. The land suitability maps, together with databases and land resource information, were compiled using land suitability data and criteria, in line with evolving uses such as varieties, cultivation technology, and land management.

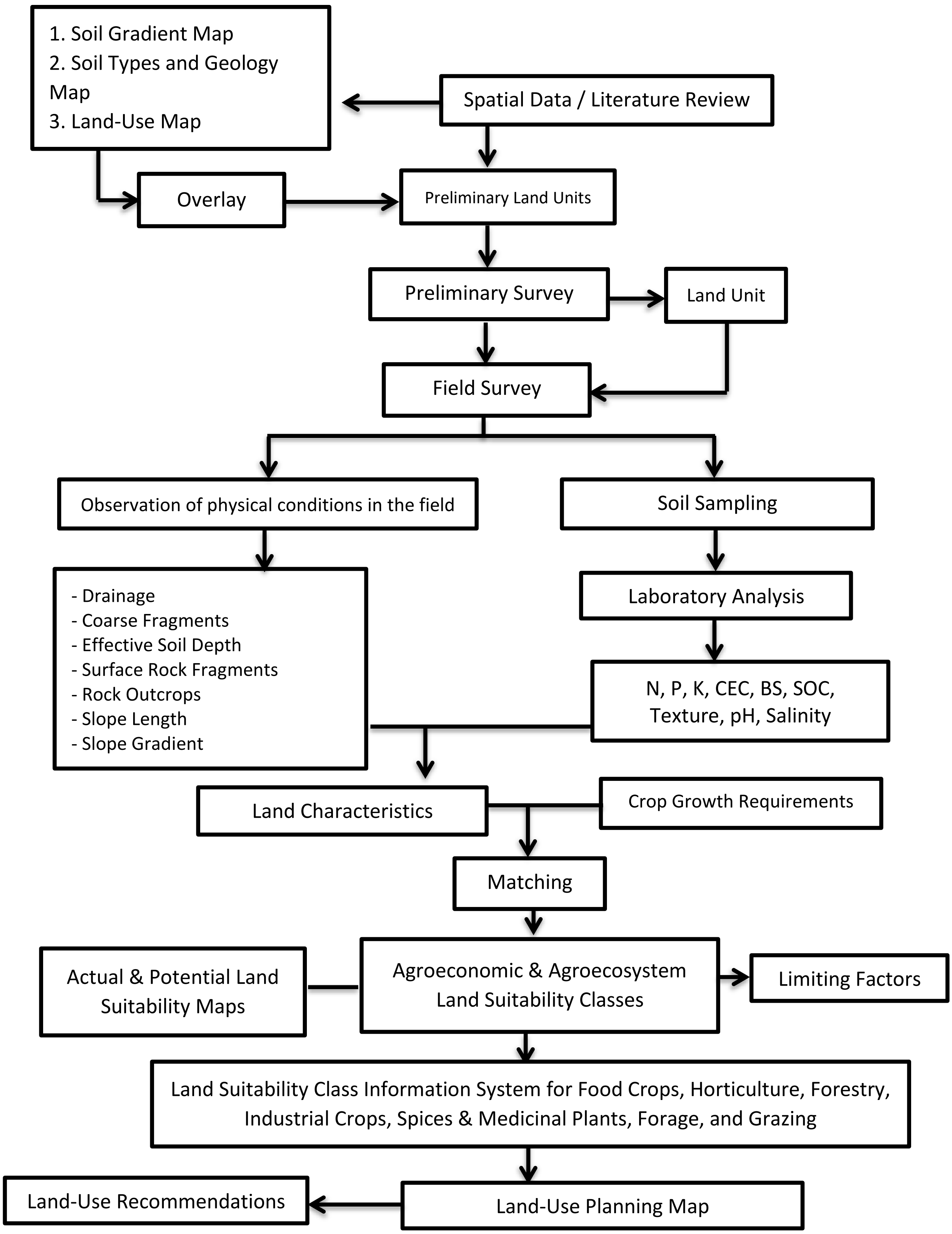


Figure 3.1 Research Process Flowchart

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

3.3 GEOGRAPHIC INFORMATION SYSTEM TECHNOLOGY

A Geographic Information System (GIS) is a system containing spatially referenced data that can be analyzed and transformed into information for specific purposes. GIS is defined as a system that can:

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

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

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

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

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

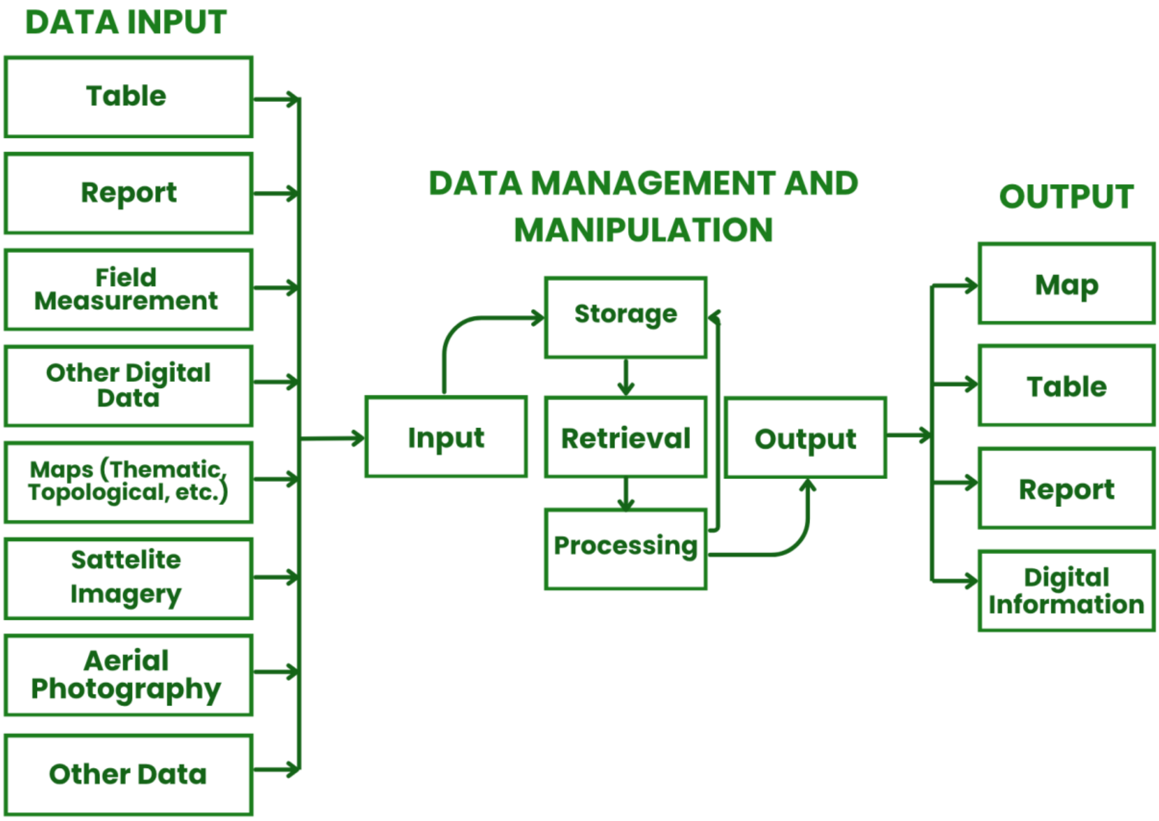


Figure 3.2 Components Constituting GIS
(Source: Prahasta, 2005)

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

1. Cartographic Capabilities

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

2. Data Management Capabilities

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

3. Analytical Capabilities

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

4. Integration of GIS and Multimedia

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

A. GIS Processed and Components

GIS essentially performs six processes (Prahasta, 2005):

1. Data Input

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

2. Data Transformation

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

3. Editing

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

4. Data Management

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

5. Query and Analysis

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

a) Proximity Analysis

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

b) Overlay Analysis

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

6. Visualization

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

B. GIS Components

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

1. **Hardware**

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

2. **Software**

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

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

3. **Data**

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

4. **Human**

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

5. **Methods**

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

C. Data Processing in GIS

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

1. **Base Map Digitizing**

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

2. Import Data

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

3. Geometric Correction of Imagery

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

4. Digital Image Processing

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

5. Satellite Image Classification

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

6. Updating Spatial Information

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

7. Field Survey

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

8. Reinterpretation and Editing

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

9. Edge Matching

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

10. Digital Cartography and Map Production

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

11. Database Development and Modeling

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

IV. LAND CHARACTERISTIC

4.1 TEMPERATURE

Air temperature is one of the key factors in land suitability evaluation as it greatly influences the sustainability of natural resource management and the potential for regional development. In this study, the distribution of temperature was analyzed by integrating field measurement data and geospatial data based on the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) using the Braak formula approach. This analysis provides a comprehensive view of temperature variability reflecting the complexity of topography, elevation, and microclimates in Timor-Leste. The air temperature analysis results in Manufahi District show that the area is dominated by warm to hot temperatures (**Figure 4.1**). The temperature category of 24–26°C has the largest percentage, 39%, indicating that most of the area experiences relatively high temperatures, but still within the range that supports agricultural activities.

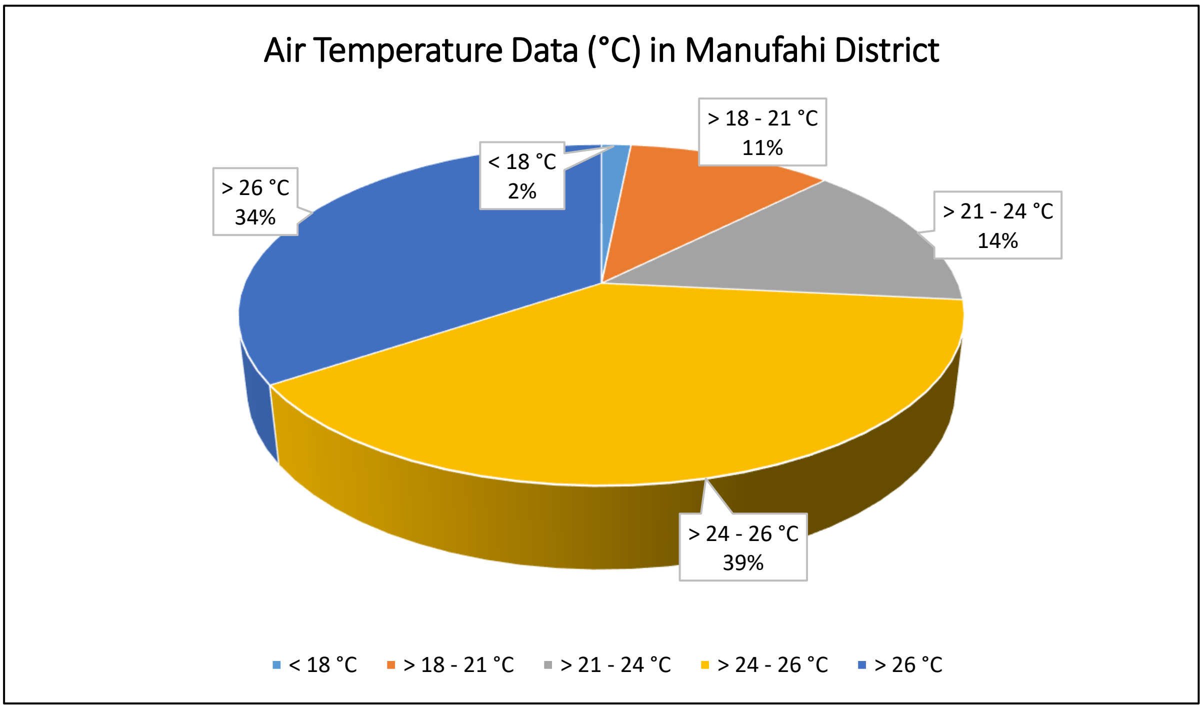


Figure 4 1 Air Temperature Data (°C) in Manufahi District

The temperature category >26°C covers 34%, showing that nearly one-third of the area has a quite hot temperature, which could affect evaporation rates and water requirements in agricultural systems. The temperature category of 21–24°C covers only 14%, showing that areas with moderate temperatures are more limited compared to the higher temperatures. The lower temperature categories, such as 18–21°C, cover 11%, while temperatures <18°C are found in only 2% of the area, indicating that cool conditions are rare in Manufahi District.

This temperature distribution significantly impacts the agricultural sector. Areas with dominant temperatures of 24–26°C and >26°C are more suitable for tropical crops like irrigated rice, corn, peanut, and plantation crops such as coconut and robusta coffee. However, high temperatures also increase the risk of drought and require efficient irrigation systems. Areas with cooler temperatures (<21°C) could be used for horticultural crops that require lower temperatures, although the percentage is relatively small. Therefore, water management strategies, the selection of heat-tolerant crop varieties, and soil conservation are essential to improve agricultural productivity in Manufahi District.

4.2 RAINFALL

Land characteristics in Manufahi District based on field observations, including rainfall, dry months, drainage, soil texture, slope gradient, and erosion hazard, show varied rainfall patterns across the region. In Same Sub-District, the most dominant rainfall category is 1500–2000 mm, covering 69% of the total area. Fatuberliu Sub-District shows the most dominant rainfall in the 1500–2000 mm range, covering 71%. In Same Sub-District, the most dominant rainfall category is >2000 mm, covering 57%, and Turiscai Sub-District shows the most dominant rainfall in the >2000 mm category, covering 55% of the total area (**Figure 4.2**). The differences in rainfall characteristics across the sub-districts affect water availability, and each region must maximize this resource for better agricultural development.

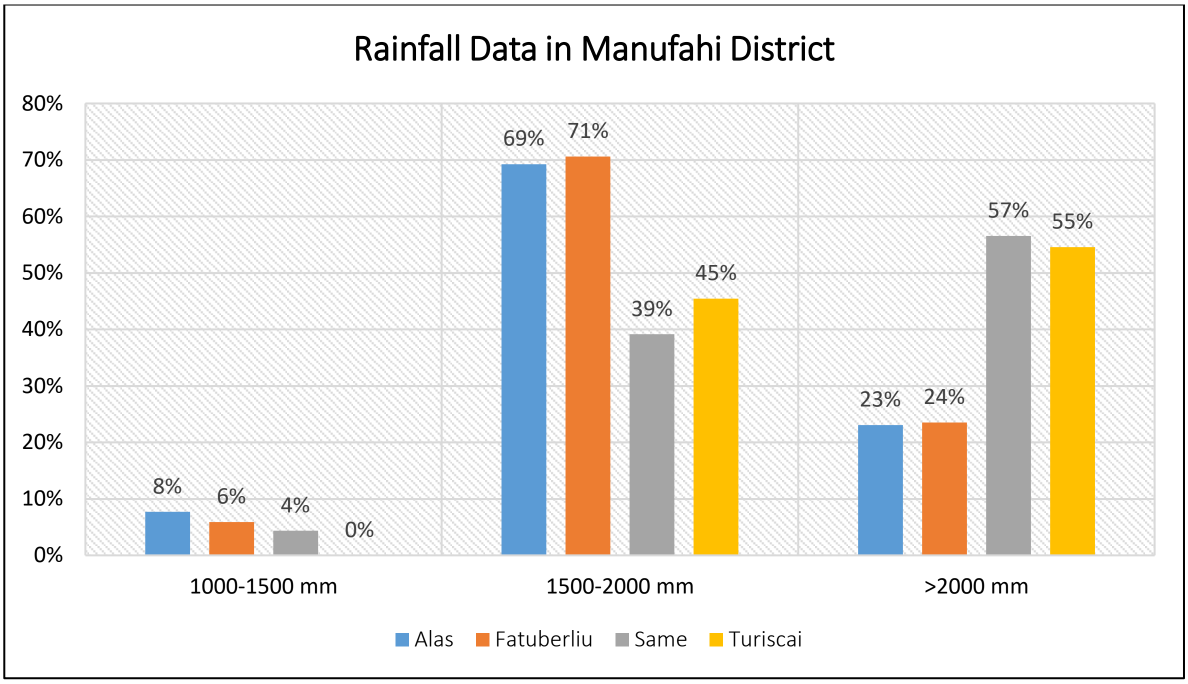


Figure 4.2 Rainfall Data in Manufahi District

4.3 DRY MONTHS

Land characteristics based on dry months also show variation and differences across sub-districts. Same Sub-District has the most dominant dry months in the 5–6 month range, covering 54%. Fatuberliu Sub-District shows the most dominant dry months in the 5–6 month range, covering 71%, while Same Sub-District also shows 5–6 months as the most dominant, covering 48%. Turiscai Sub-District is distinct from the others, as it has the most dominant dry months in the 3–4 month range, covering 55% of the total area (**Figure 4.3**). This dry month distribution indicates that most sub-districts in Manufahi District experience dominant dry periods of 5–6 months, which will affect water availability. However, Turiscai Sub-District has a relatively shorter dry period compared to others.

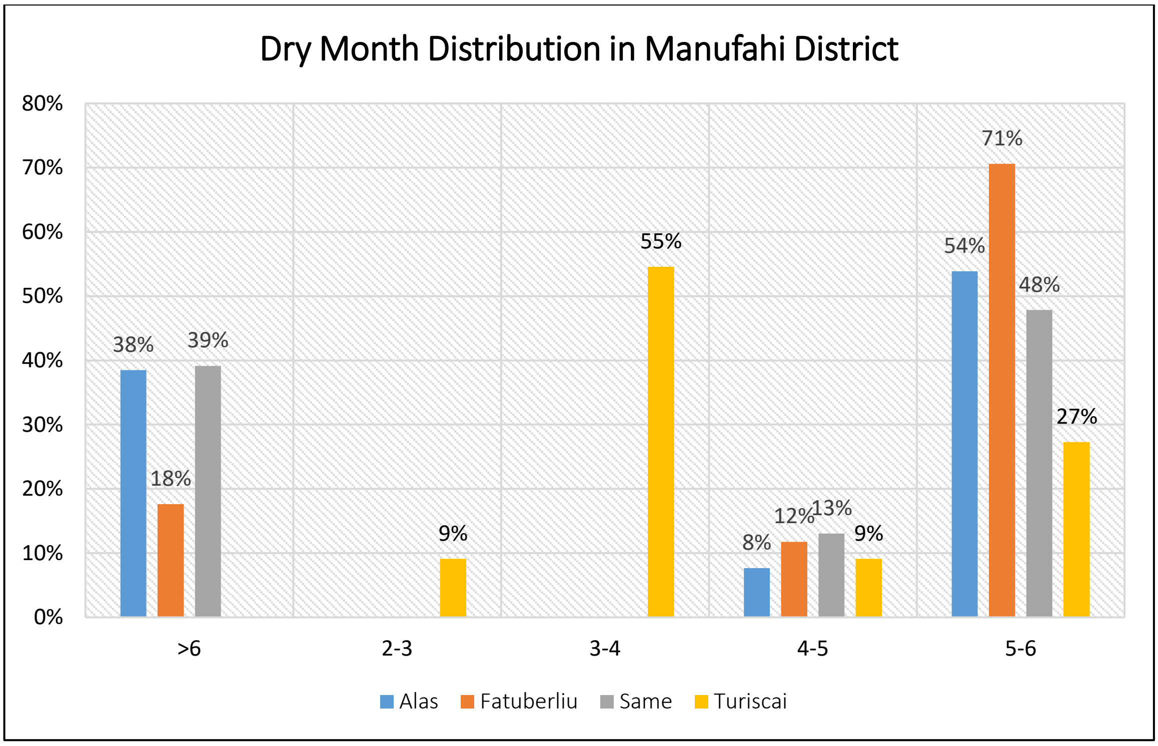


Figure 4.3. Dry Month Distribution in Manufahi District

4.4 DRAINAGE

The drainage characteristics in Manufahi District show a similar dominant pattern across sub-districts. Same Sub-District has the most dominant drainage classified as "good," covering 69% of its total area. Fatuberliu Sub-District also has good drainage dominating, covering 71%, and Same Sub-District has good drainage covering 74%. Interestingly, Turiscai Sub-District has 100% of its area classified as having good drainage (**Figure 4.4**). Good drainage affects soil oxygen availability, allowing water to flow effectively, which is essential for plant water requirements.

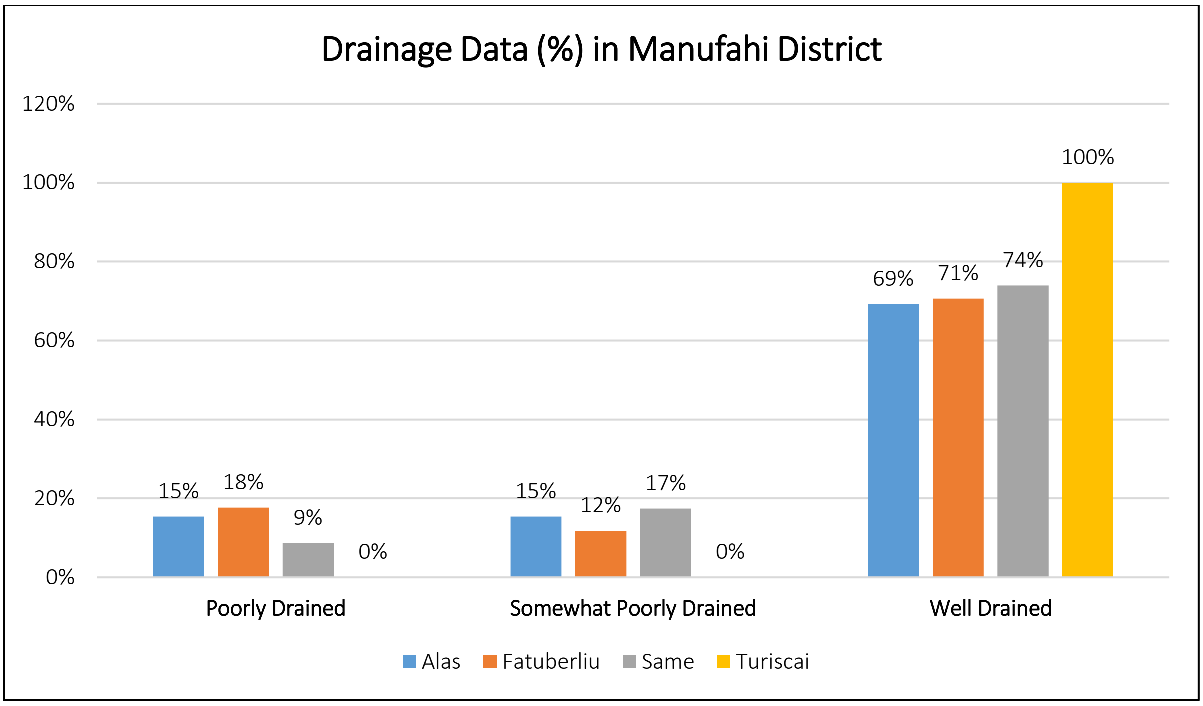


Figure 4.4 Drainage Data (%) in Manufahi District

4.5 SOIL TEXTURE

Soil texture characteristics in Manufahi District vary across the sub-districts. Same Sub-District has the most dominant soil texture class as fine, covering 46% of its total area. Fatuberliu Sub-District shows the most dominant texture as slightly fine, covering 41%, and Same Sub-District also shows slightly fine texture as the most dominant, covering 35%. Turiscai Sub-District shows fine texture as the most dominant, covering 45% (**Figure 4.5**). Finer soil texture affects organic matter availability and water retention, while coarser textures improve soil aeration.

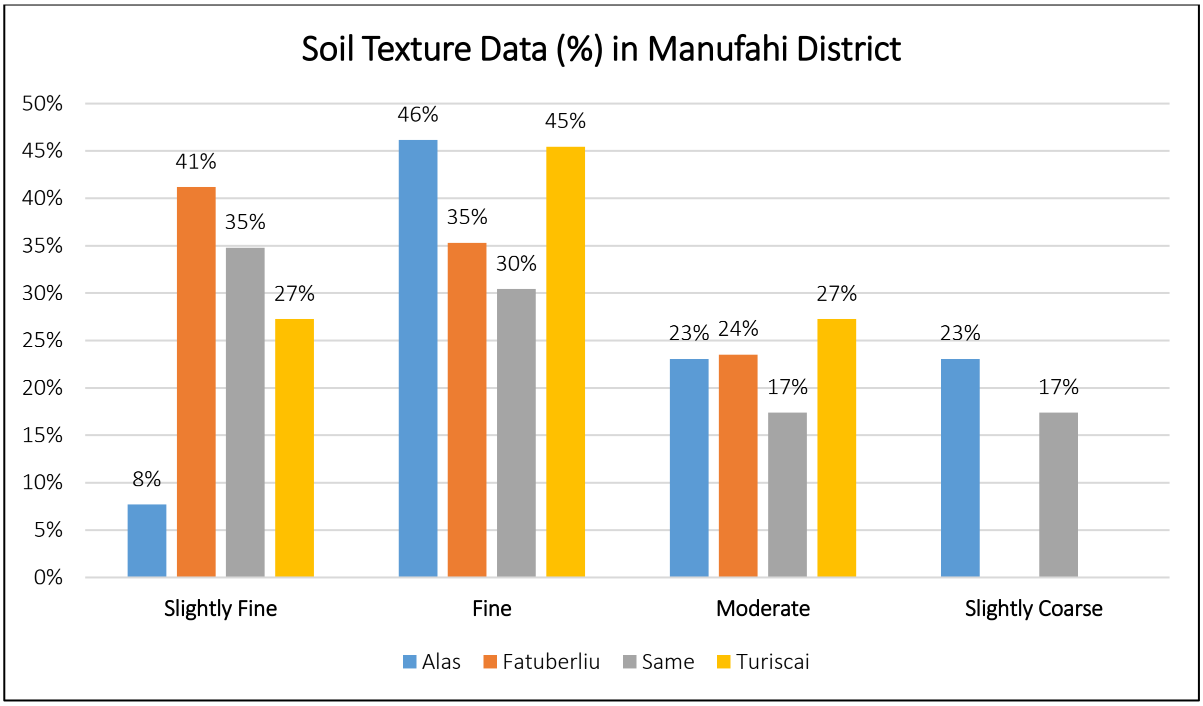


Figure 4.5 Soil Texture Data (%) in Manufahi District

4.6 COARSE FRAGMENTS

Coarse material characteristics in the soil are an important factor in determining land suitability for agriculture, as it affects the soil's ability to retain water, manage infiltration, and support plant roots. The analysis of coarse material percentage in Manufahi District shows varying soil texture distributions (**Figure 4.6**). The largest category, <5%, covers 37%, indicating that most of the region has soils with low coarse material content, which are more fertile and suitable for agriculture.

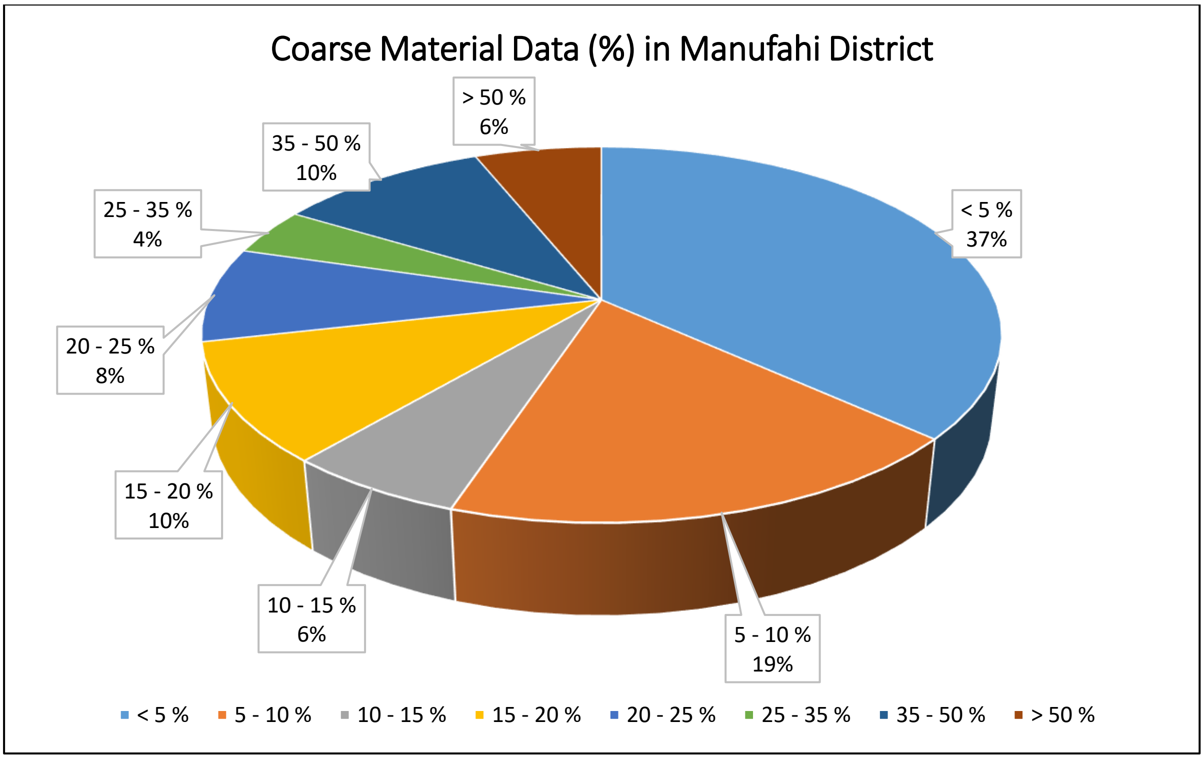


Figure 4.6 Coarse Material Data (%) in Manufahi District

The 5–10% category covers 19%, indicating that some areas have a slightly higher coarse material content, but still within manageable limits for agriculture and other land uses. The 10–15% category covers 6%, while the 15–20% category covers 10%, indicating that there are areas with coarser soil texture, which may affect water retention in the soil. The 20–25% category covers 8%, while the 25–35% category covers only 4%, suggesting that areas with moderate coarse material content are more limited compared to those with finer texture. Meanwhile, the 35–50% category covers 10%, indicating that some parts of the region have coarser soil textures and may have lower water retention capacity. Areas with the highest coarse material content (>50%) cover 6%, suggesting that a small portion of the region may face limitations in utilizing the land for intensive agriculture.

This distribution has implications for the agricultural sector in Manufahi District. Areas with low coarse material (<10%) have high potential for growing food crops such as irrigated rice, corn, and horticultural crops because the soil tends to be more fertile and can retain water well. In contrast, areas with higher coarse material content (>25%) may require soil conservation techniques to maintain fertility and prevent erosion, especially on slopes. Therefore, effective land management strategies, such as selecting appropriate crops and implementing efficient irrigation methods, are crucial to increasing agricultural productivity in this region.

4.7 SURFACE ROCK

The condition of surface rocks is an important parameter in determining land potential and management challenges. The presence of surface rocks affects land suitability for agriculture, as high surface rock content can hinder soil processing activities and reduce effective soil fertility. The analysis of surface rock percentages in Manufahi District shows that most areas have low surface rock content (**Figure 4.7**). The largest category, 0–5%, covers 63%, indicating that most of the region has soil surfaces relatively free from rocks, which supports agricultural activities and other land uses.

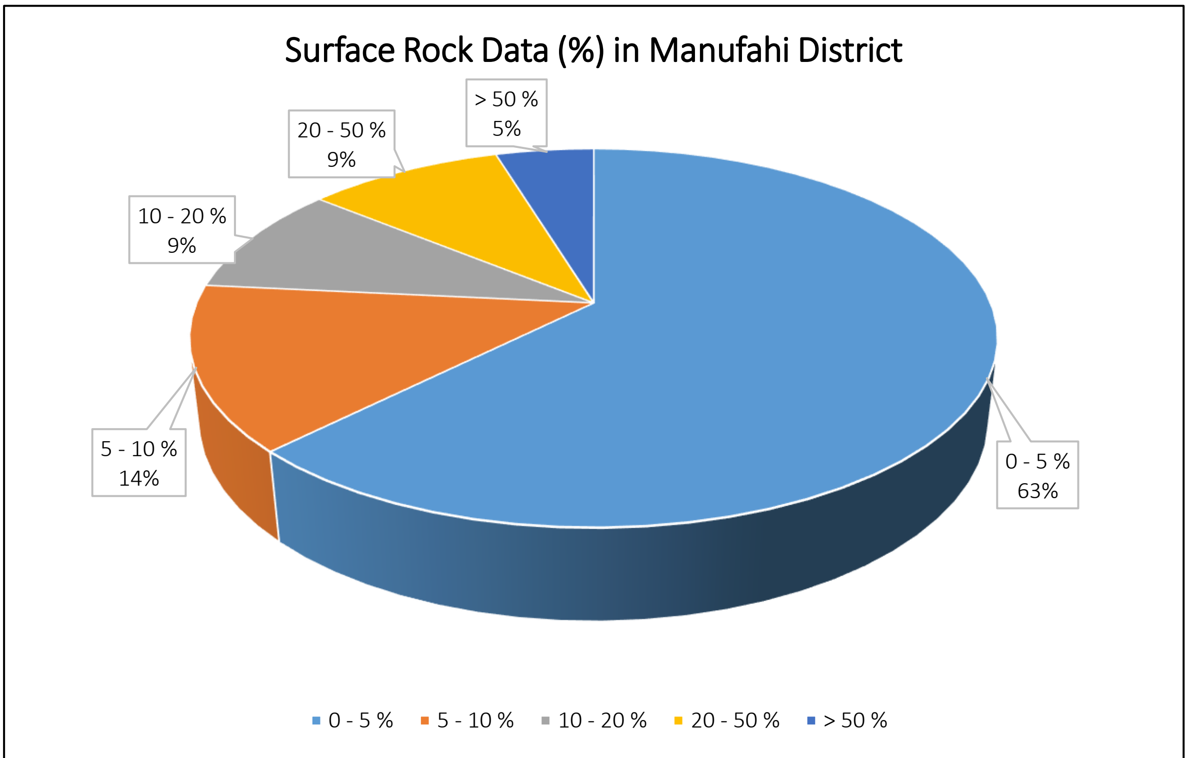


Figure 4.7 Surface Rock Data (%) in Manufahi District

The 5–10% category covers 14%, while the 10–20% category covers 9%, indicating that a small portion of the region has a higher rock content, but it is still manageable for agricultural activities. The 20–50% category covers 9%, indicating that some areas have relatively high surface rock content, which may affect soil water absorption and fertility levels. Meanwhile, the >50% category covers only 5%, indicating that a small portion of the region is dominated by very high surface rock content, which is likely less suitable for intensive agriculture.

The distribution of surface rocks has significant implications for land use in Manufahi District. Areas with low surface rock content (<10%) have high potential for intensive agriculture, particularly for food crops like irrigated rice and corn, as well as horticultural crops that require fertile soil. In contrast, areas with higher surface rock content (>20%) may be more suitable for plantations or require soil conservation techniques to reduce the risk of erosion and maintain land productivity. Therefore, proper land management strategies are essential to improve the efficiency of sustainable land use in this region.

4.8 ROCK OUTCROPS

Rock outcrops are an important indicator in assessing geological conditions and land suitability. The presence of rock outcrops can affect the physical properties of the soil, water storage capacity, and erosion levels. The analysis of rock outcrop percentages in Manufahi District shows that most areas have low rock outcrop levels (**Figure 4.8**). The largest category, 0–5%, covers 69%, indicating that most of the region has soil surfaces relatively free from exposed rocks, which strongly supports agricultural activities and infrastructure development.

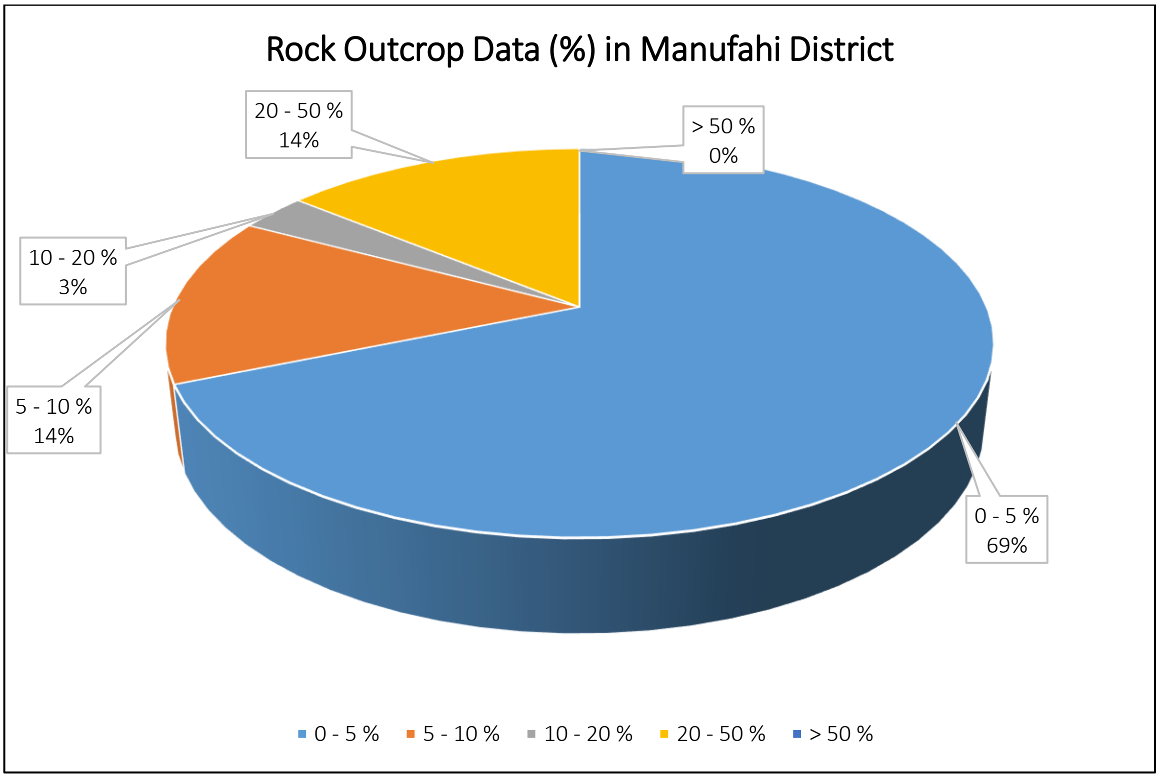


Figure 4.8 Rock Outcrop Data (%) in Manufahi District

The 5–10% category covers 14%, indicating that a small portion of the region has moderate rock outcrops, but it is still manageable for various land uses. The 10–20% category covers only 3%, indicating that the areas with higher rock outcrops are still limited. Meanwhile, the 20–50% category covers 14%, showing that some parts of the region have more dominant rock outcrops, which could be a challenge for intensive agriculture but can still be utilized for conservation or ecotourism. No area was found with rock outcrops exceeding 50%, indicating that there are no areas fully dominated by exposed surface rocks.

This distribution has implications for land use in Manufahi District. Areas with low rock outcrop levels (<10%) have high potential for intensive agriculture, particularly for food crops and horticulture that require fertile and easily tilled soil. In contrast, areas with higher rock outcrop content (>20%) may be more suitable for forestry, ecotourism, or soil conservation projects to reduce erosion risks. Therefore, appropriate land management strategies are necessary to ensure optimal and sustainable land use in this region.

V. SOIL FERTILITY STATUS

Soil fertility is the ability of the soil to supply essential nutrients in optimal and balanced amounts within a suitable environment for plant growth (Yuwono, 2007). Soil fertility aims for high plant productivity, such as fruits, seeds, leaves, flowers, tubers, and so on. Soil fertility varies depending on the soil-forming factors, namely parent material, relief, organisms, and time, which dominate the location. The soil is the main focus of soil fertility, while plants are the main indicators of soil fertility quality (Yuwono, 2007).

Soil fertility status evaluation is an essential assessment to determine the type and amount of nutrients that will be used. Soil fertility status evaluation is conducted by diagnosing nutrient problems in the soil and making fertilization recommendations. The diversity of chemical characteristics or properties of the soil can support plant life as agricultural commodities and the availability of nutrients in the soil, thus identifying fertile soil and vice versa (Utomo *et al.,* 2016). Soil fertility status assessment is important for evaluating and monitoring soil fertility to determine which nutrients are limiting for plant growth. The determination of soil fertility status aims to evaluate soil characteristics and identify the main soil fertility constraints, and then the soil fertility status is set based on the criteria of the Soil Research Centre (PPT, 1995).

The soil fertility status evaluation in Manufahi District uses several parameters, including Cation Exchange Capacity (CEC), Base Saturation (BS), C-Organic, P2O5 content, and K2O content. The results of the soil fertility evaluation in Manufahi District show three categories: low fertility status (red), followed by medium (yellow), and high (green) fertility status. The data is presented in **Figure 5.1**.

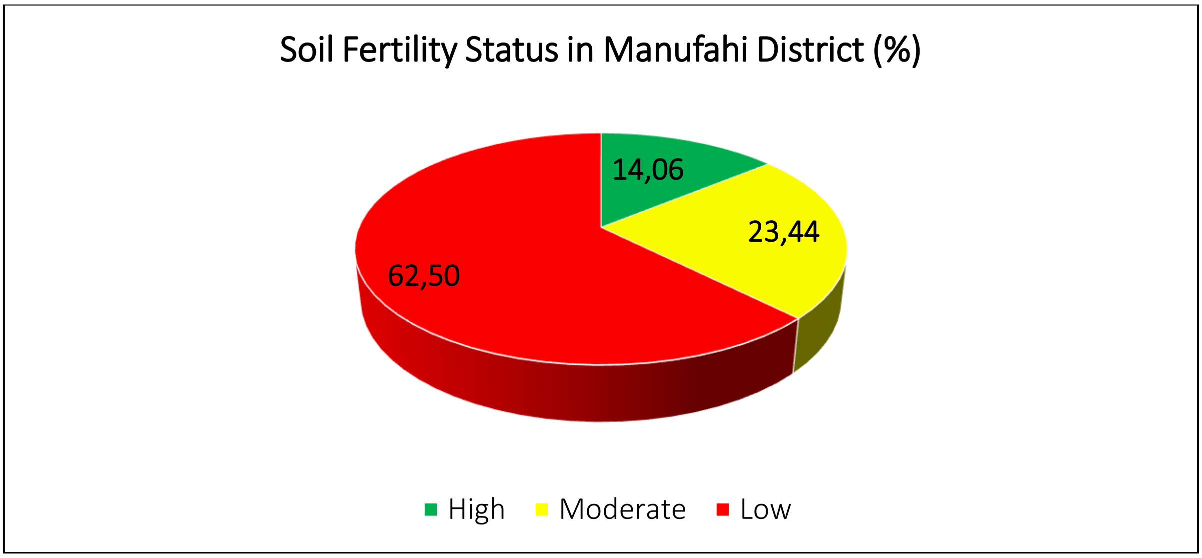


Figure 5.1 Soil Fertility Status in Manufahi District

Based on the analysis of soil fertility status in Manufahi District (**Figure 5.1**), it is observed that the majority of the area has low soil fertility, with a percentage of 64.06%. This indicates that more than half of the land in Manufahi District is less fertile and requires efforts to improve soil quality to make it more productive for agriculture. Meanwhile, soil with medium fertility covers 21.88%, meaning that there are some areas with better agricultural potential if managed properly. Soil with high fertility covers only 14.06%, indicating that highly fertile land in this area is quite limited and must be used optimally. With the dominance of low fertility land, more effective land management strategies are needed, such as the use of organic fertilizers, implementation of soil conservation techniques, and improved irrigation systems. Additionally, optimizing land with medium and high fertility can help increase agricultural yields to support food security and the well-being of local communities. Collaboration between farmers, academics, and the government is crucial to designing solutions that can enhance agricultural productivity in Manufahi District.

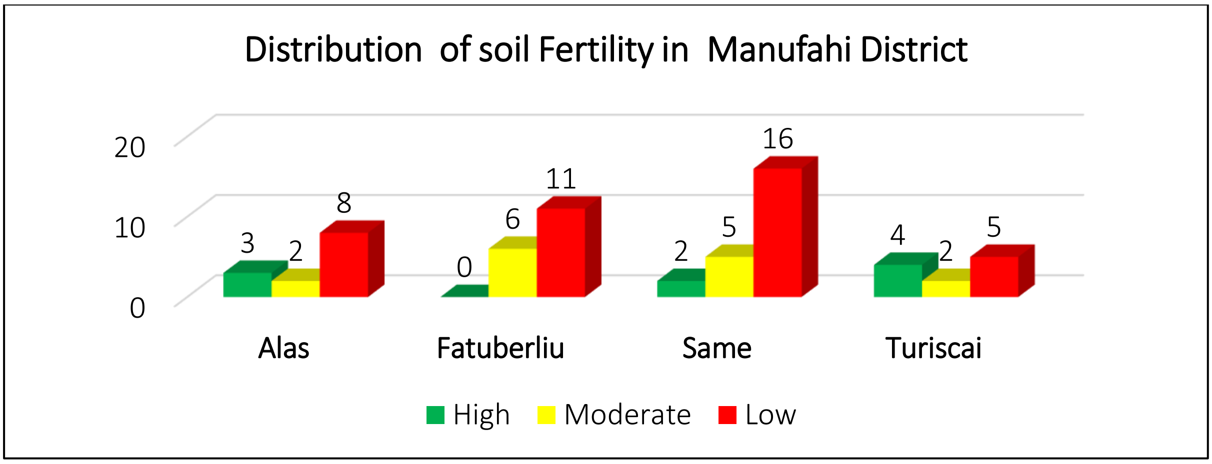


Figure 5.2 Distribution Diagram of Soil Fertility Status in Manufahi District

Based on the data of Soil Fertility Status Distribution in Manufahi District (**Figure 5.2**), it is observed that the majority of the area has low soil fertility. The sub-district with the highest amount of infertile land is Same Sub-District, with 16 land units in the low fertility category, followed by Fatuberliu Sub-District with 11 land units, and Alas Sub-District and Turiscai Sub-District each having 8 and 5 land units with low fertility. This indicates that most of the land in this area requires more attention in land management to support agricultural productivity. Fatuberliu Sub-District and Same Sub-District have some land units with medium fertility, with 6 and 5 units respectively, while Alas Sub-District and Turiscai Sub-District each have 2 land units with medium fertility. Fertile land in the high fertility category is still limited, with Turiscai Sub-District having 4 land units, Alas Sub-District having 3 land units, and Same Sub-District having 2 land units, while Fatuberliu Sub-District has no land with high fertility.

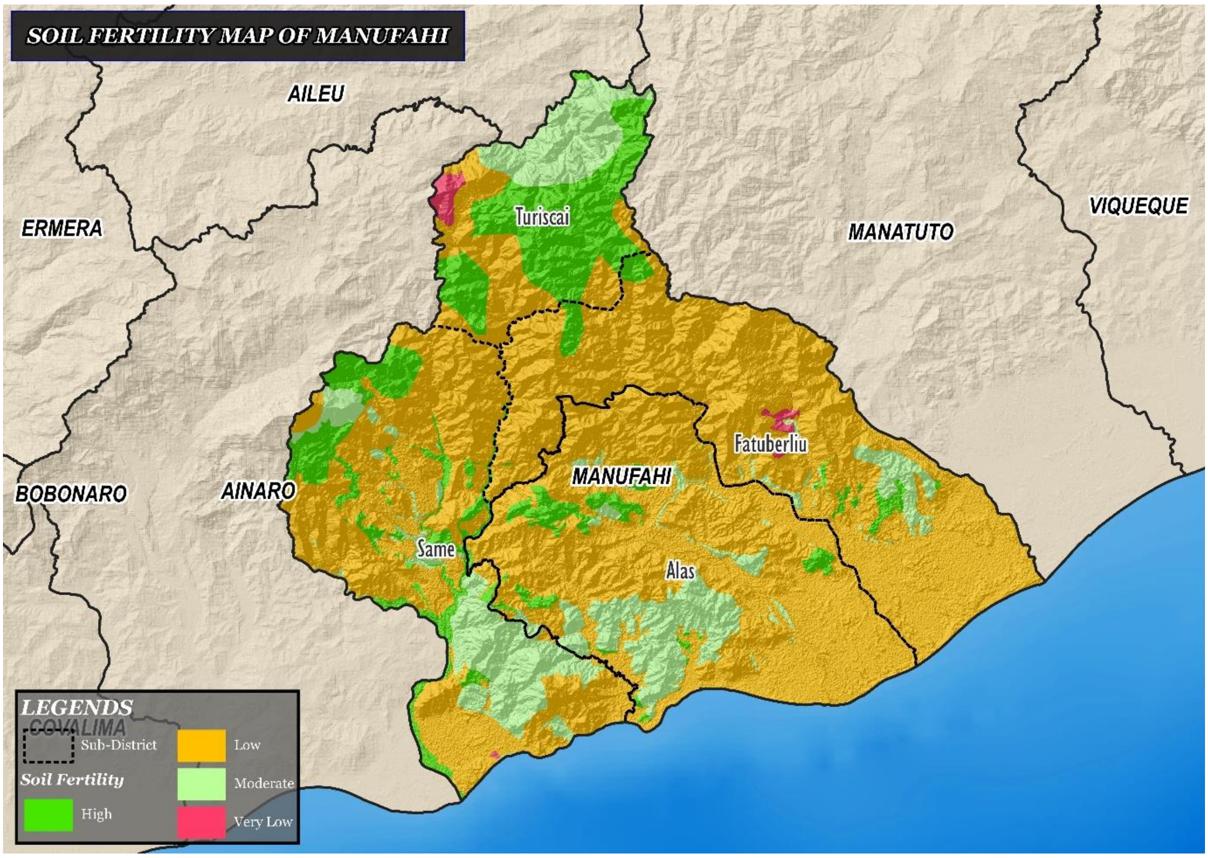


Figure 5.3 Soil Fertility Status Map in Manufahi District

Based on the Soil Fertility Status Map in Manufahi District (**Figure 5.3**), Timor-Leste, it can be observed that most of the district has low soil fertility, as indicated by the dominant red color. Sub-districts such as Fatuberliu, Alas, and most areas around the southern coast have land with low fertility. This suggests that the soil in these areas does not optimally support agriculture without proper intervention. Some areas have medium soil fertility (yellow color), which are spread across parts of Fatuberliu, Alas, and Same. Meanwhile, fertile land (green color) is more commonly found in the northern part of the district, particularly in Turiscai Sub-District and parts of Same Sub-District, indicating great potential for sustainable agriculture.

VI. EROSION AND CONSERVATION

6.1 SOIL EROSION

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

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

Manufahi District has a very high erosion rate of 40.32%, a high erosion rate of 9.11%, a moderate erosion rate of 12.99%, and a light erosion rate of 37.58%. Manufahi District has nearly equal areas of very high and light erosion. The combined very high and high erosion rates account for 49.43%, almost half of Manufahi District. This makes it one of the regions with the highest erosion risk. The soils in this area, often managed without adequate conservation techniques, require special attention to reduce damage caused by heavy surface runoff. The erosion data for Manufahi District is presented in **Figure 6.1**. The soil erosion distribution map for Manufahi District is shown in **Figure 6.2**.

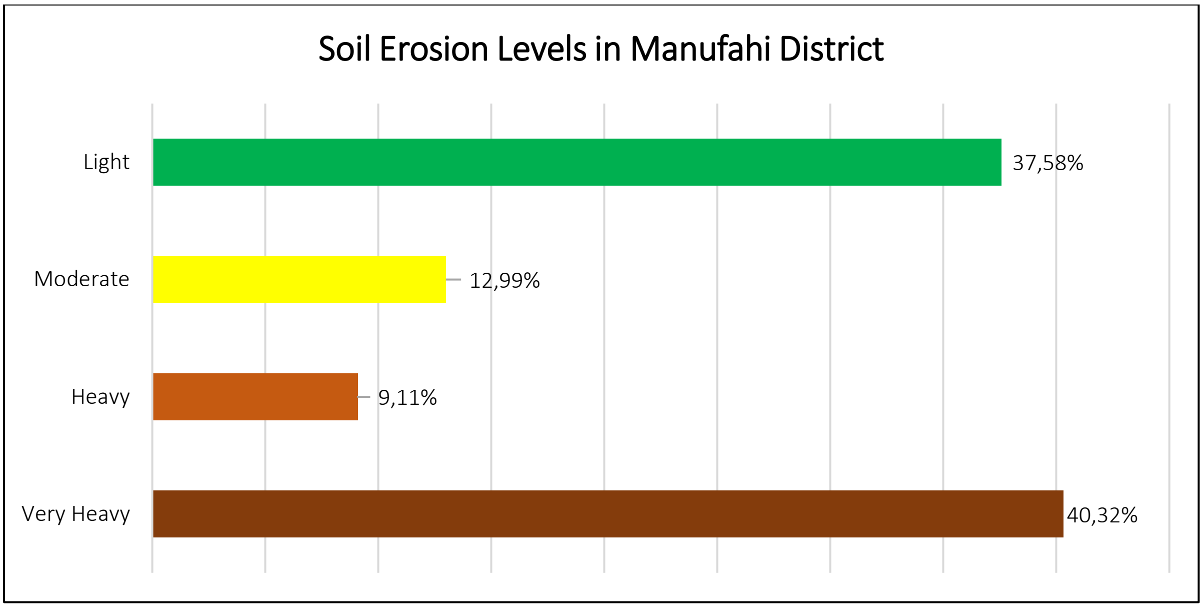


Figure 6.1 Soil Erosion Levels in Manufahi District.

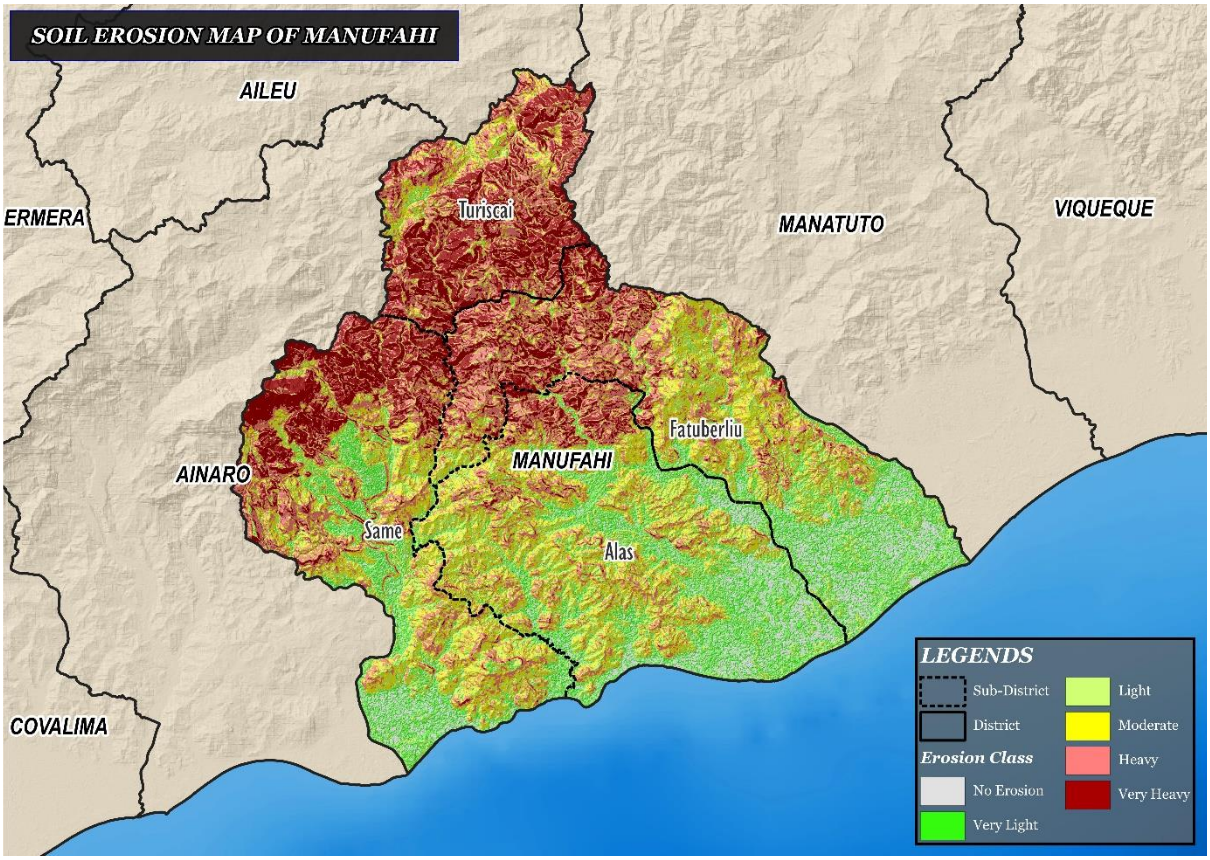


Figure 6.2 Soil Erosion Map of Manufahi District

6.2 SOIL AND WATER CONSERVATION

Conservation is an effort to manage natural resources in the long term, aimed at maintaining land quality and productivity. Conservation plays a key role in protecting soil from degradation, restoring degraded soils, enhancing infiltration, and preserving soil fertility.

Conservation in Manufahi District is based on slope gradients, ranging from very light to severe erosion. The slopes in Manufahi District are prone to erosion on lands with gradients between 15% and >45%. According to slope gradient criteria in Manufahi District, Alas, Fatuberliu, Same, and Turiscai Sub-Districts are classified as ranging from flat to very steep (0% to >45%). A slope gradient of 0-8% is found in all Sub-Districts, with the largest area in Alas Sub-District, covering 19,379.22 ha (14.65%), and in Turiscai Sub-District, covering 24.87 ha (0.02%). A slope gradient of 15-25% is spread throughout all Sub-Districts, where terracing is recommended for planting food crops, secondary crops, horticultural fruits, plantations, and industrial crops. Slopes greater than 45% are most extensive in Turiscai Sub-District, covering 5,212.7 ha or 11.5%. This means that land with such slopes can only be used for annual crops or agroforestry. The slope class data for Manufahi District is presented in **Table 6.1**, and the conservation map based on slope gradients in Manufahi District is presented in **Figure 6.3**.

Table 6.1 Slope Gradient Data for Manufahi District

Sub-District	Slope Gradient	Potential Class	Area (ha)	Area (%)
Alas	>45%	Agroforestry	702,3	0,53
Alas	25-45%	Agroforestry	3736,45	2,82
Alas	8-15%	Potential	12933,34	9,77
Alas	15-25%	Moderately Potential	3841,89	2,9
Alas	0-8%	Highly Potential	19379,22	14,65
Fatuberliu	>45%	Agroforestry	6636,94	5,02
Fatuberliu	25-45%	Agroforestry	8725,68	6,6
Fatuberliu	8-15%	Potential	2283,64	1,73
Fatuberliu	15-25%	Moderately Potential	9068,09	6,85
Fatuberliu	0-8%	Highly Potential	10785,46	8,15
Same	>45%	Agroforestry	10947,63	8,27
Same	25-45%	Agroforestry	5173,73	3,91
Same	8-15%	Potential	8248,22	6,23
Same	15-25%	Moderatly Potential	1022,42	0,77
Same	0-8%	Highly Potential	10036,63	7,59
Turiscai	>45%	Agroforestry	15212,7	11,5

Turiscai	25-45%	Agroforestry	2826,42	2,14
Turiscai	15-25%	Moderately Potential	729,69	0,55
Turiscai	0-8%	Highly Potential	24,87	0,02

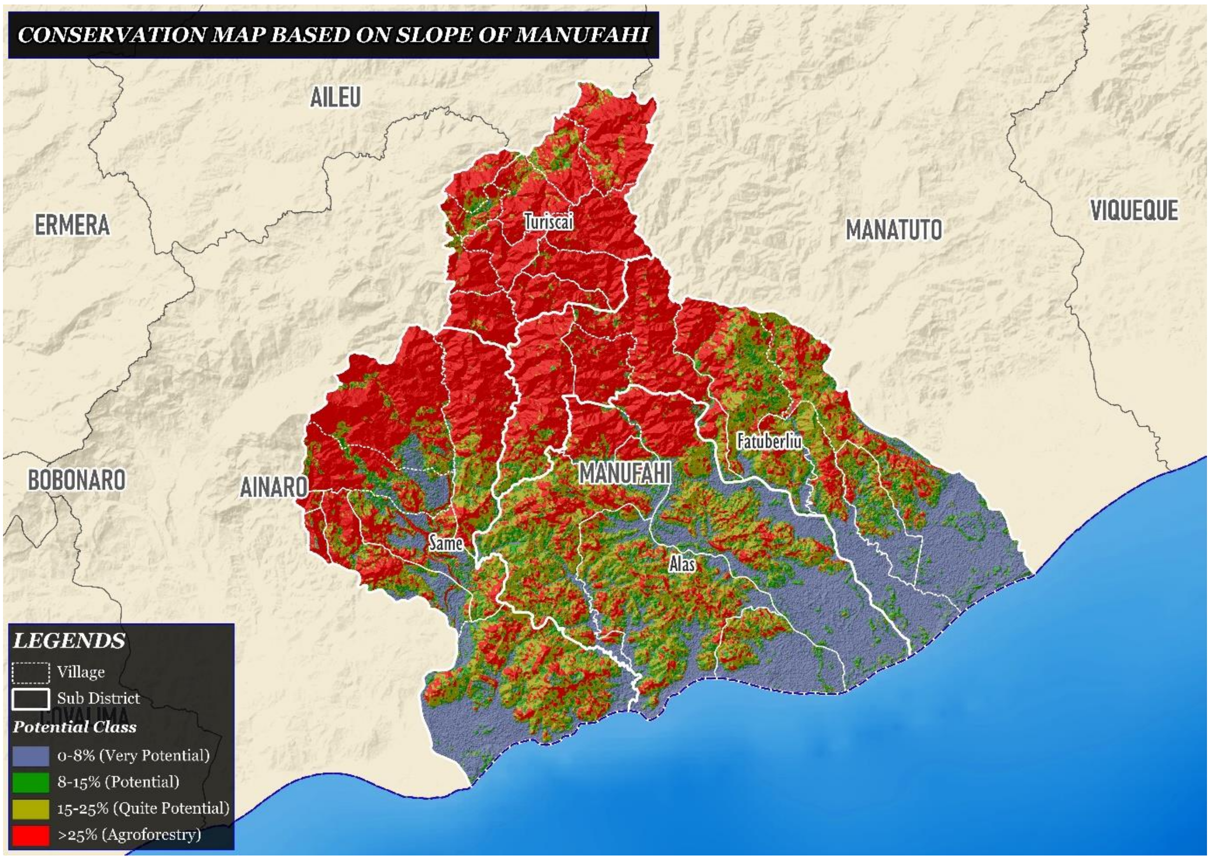


Figure 6.3 Conservation Map Based on Slope in Manufahi District

Land with a gentle slope (0-8%) covering 40,226.18 ha (30.41%) is highly suitable for the development of food crops, secondary crops, horticulture, and other plants. Land with a slope of 8-15% covering 23,465.2 ha (17.73%) requires soil conservation through terracing to make the land productive and prevent erosion. Meanwhile, land with a slope of 15-25% covering 14,662.09 ha (11.07%) is considered moderately suitable, and land with slopes greater than 25% covers 53,961.85 ha (40.79%). Overall, land highly suitable for agriculture in Manufahi District is less than land designated for agroforestry use. Land with slopes greater than 45% can be used for perennial crops (tree crops such as banyan, mahogany, lenggung, teak, gamal, leucaena, and others). If steep or very steep slopes are terraced, the planting area becomes very narrow, and the soil is prone to erosion and landslides when it rains.

Agroforestry is one of the conservation efforts in the form of a planting system that integrates forestry, agriculture, fisheries, and livestock to achieve optimal land use. This system enables efficient and optimal space/land utilization (Sanudin & Priambodo, 2013). Based on its components, agroforestry is classified into several systems:

1. Agrosilviculture System, the integration of trees and specific food crops on the same land.
2. Silvopastoral System, a combination of tree cultivation and forage crops to support livestock management.
3. Agrosilvopastoral System, planting trees, food crops, pasture, and livestock on the same land. This system aims to optimize land productivity but requires intensive management at the subsystem level.
4. Home Garden System, characterized by intensive cultivation of perennial and seasonal crops, typically including vegetables, cereals, fruit trees, grasses, and livestock management.
5. Other Systems, including the cultivation of multipurpose trees, beekeeping, and fisheries, all of which can be utilized for various agricultural and non-agricultural purposes. The agroforestry conservation model is presented in **Figure 6.4.**

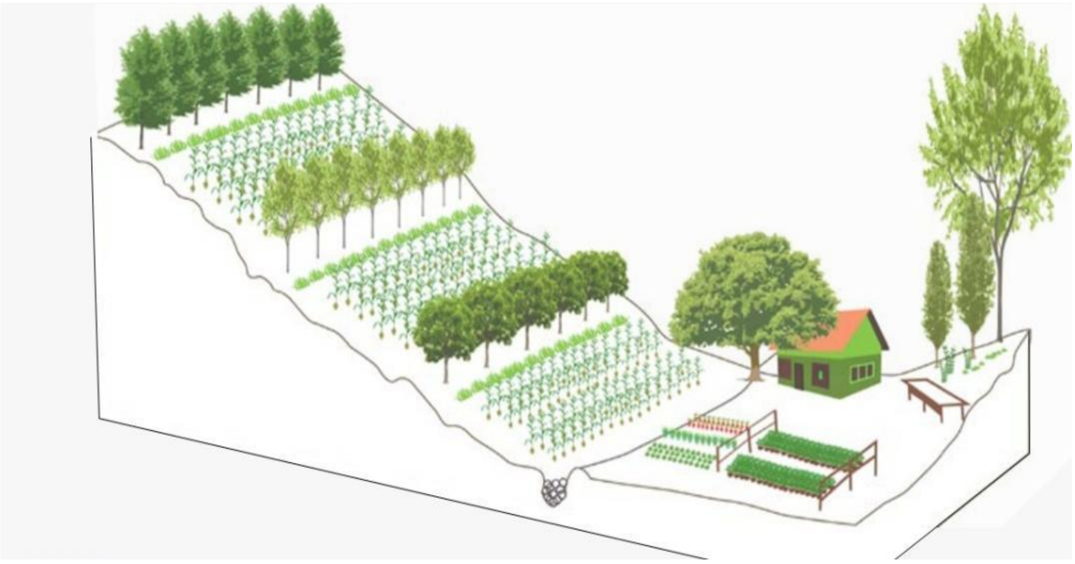


Figure 6.4 Agroforestry Conservation Model
(Source: La *et al.,* 2016)

A. Importance of Agroforestry Concept

Agroforestry plays a vital role in the production of both local commodities (firewood, timber, fruits, and livestock feed) and global commodities (coffee, tea, cocoa, rubber, and resin). It also plays a strategic role in helping countries tackle poverty, food security, and environmental sustainability. Agroforestry contributes to enhancing farmers' resilience and increasing household income through the harvest of diverse products at different times throughout the year. The combination of trees, crops, and livestock helps reduce environmental risks, creates permanent ground cover that combats erosion, minimizes flood damage, and enhances water retention beneficial to plants and pastures.

Agroforestry offers various benefits, including:

1. Improving Food Security and Nutritional Enrichment
   Agroforestry provides plant species diversity to produce various food types, contributing to food security. The integration of agroforestry components can improve agricultural productivity and increase nutritional diversity for consumers.
2. Resilient Livelihoods
   The integration of trees, crops, and livestock can reduce the vulnerability of production to climate disasters and market shocks. Additionally, agroforestry can reduce pest attacks on monoculture systems by creating a better microclimate. Agroforestry influences the climatic impacts that hinder agricultural systems and creates resilient livelihoods.
3. Climate Change Mitigation and Adaptation
   The integration of various agricultural crops helps mitigate the impacts of climate change on the agricultural sector. The use of trees in agroforestry plays a role in carbon sequestration, regulating the microclimate, reducing the rate of climate change, and influencing plant growth.
4. Environmental Protection
   Agroforestry systems regulate climate and environmental services. Perennial crops help improve air and water quality. Tree litter can be used as organic material to reduce the use of chemical fertilizers. Deep root systems help support nutrient cycles. Agroforestry components also support biodiversity by creating environments suitable for flora and fauna habitats in agricultural landscapes.
5. Poverty Alleviation
   Agroforestry can increase income diversification through the cultivation of commercial crops, timber sales, and livestock income. Diversification can enhance sustainable agricultural productivity, increase farmer income, create job opportunities, and contribute to poverty alleviation and community welfare improvement.

B. Agroforestry and Agro-Ecology in Manufahi District

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

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

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

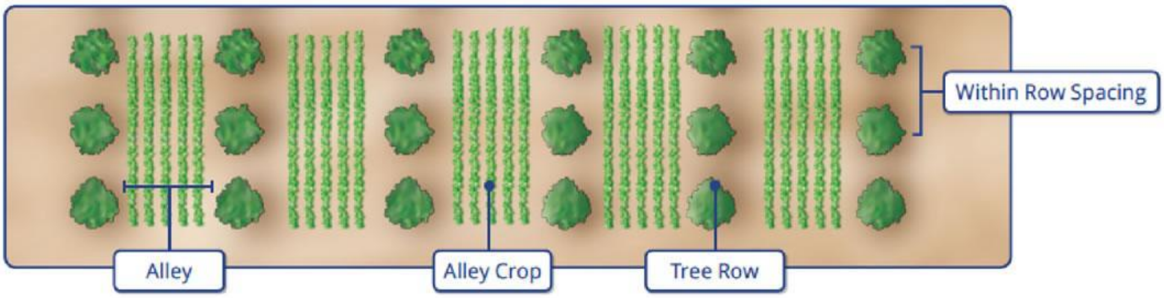


Figure 6.5 Alley Cropping Planting System Concept
(Source: https://www.fs.usda.gov/nac/practices/alley-cropping.php)

2. Hedge Planting refers to creating boundaries or fences using trees or shrubs. It is mostly applied in steep hill areas to conserve soil. The concept is shown in **Figure 6.6.**

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

3. Random Planting involves planting both woody plants and annual crops with irregular planting distances in lowland areas. The concept of random planting is presented in **Figure 6.7.**

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

4. Alternate Row Planting involves systematic planting with seasonal crops between the rows on flat and large areas of land. An example of an agroforestry model that can be applied in Manufahi District is Vanilla (wood + fruit + spice + staple food), with vanilla as the main crop and supporting plants such as casuarina, albizia, forest pepper, jackfruit, cassava, mango, banana, and cocoa. This agroforestry model can be applied at elevations of 500–1500 meters with an average annual rainfall of 1500–3000 mm.

Cogné & Lescuyer (2024) combined agro-ecological and socio-technical data to identify types of Agroforestry Systems (AFS) in Manufahi District, including home gardens that combine perennial crops, spices, and small livestock; a combination of crops and barren land for developing food crops and trees with specific spacing; planting perennial crops (papaya, banana, chili, etc.) alongside timber plants (palms); forest gardens typically located near water sources; and silvopastoral systems that integrate trees, shrubs, and grazing livestock on the same land.

Manufahi District has four agro-ecological zones (AEZ/Agro-Ecological Zones) based on agro-climatic zones. These zones have biophysical parameters such as elevation, average rainfall, and soil types, which are important for selecting suitable crops and agroforestry models to implement in Manufahi District. The agro-ecological zone data and main crops are presented in Table 6.2. The agro-climatic zone map of Manufahi District is shown in Figure 6.8.

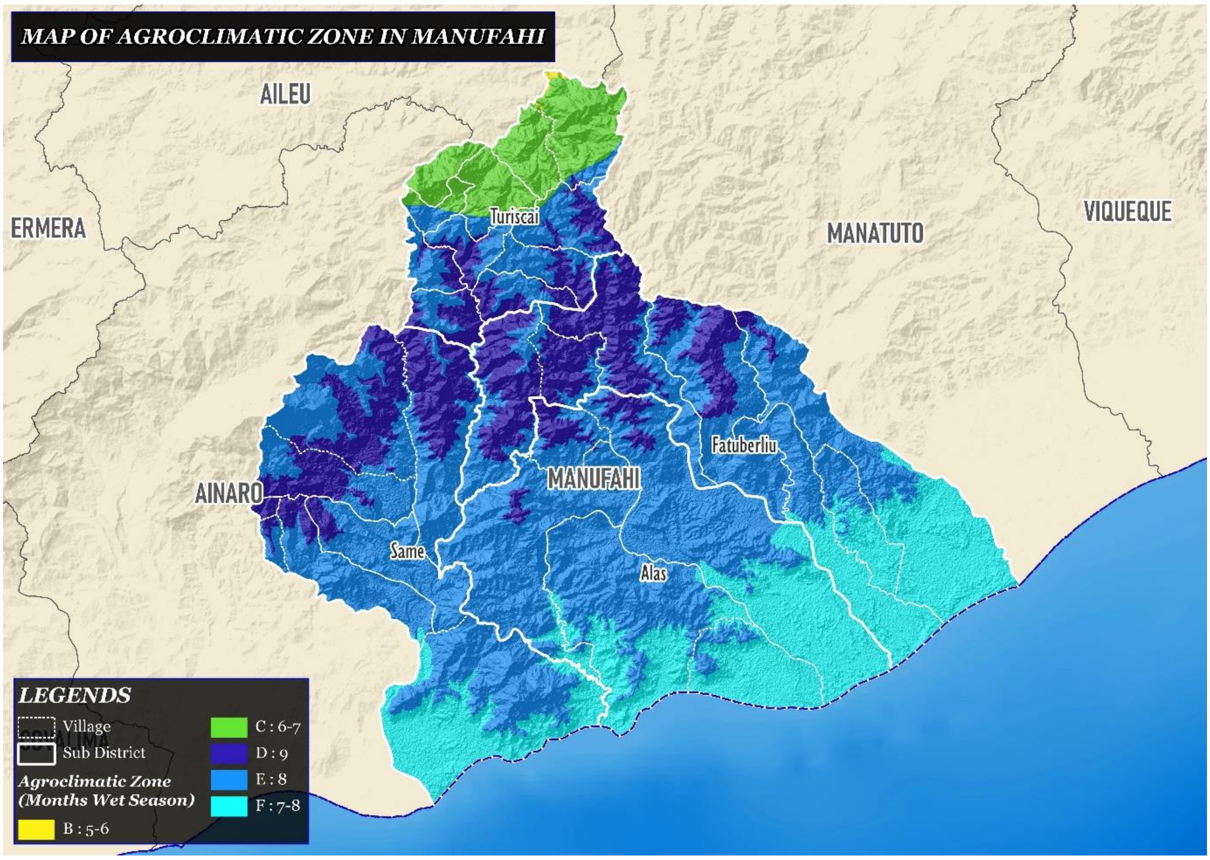


Figure 6.8 Agro-Climatic Zone Map of Manufahi District

Table 6.2 Agro-Ecological Zone Data and Main Crop Types

Zone	Elevation (m)	Rainfall (mm/th)	Main Crops
Zone C	500-1500	1500-3000	Red beans, coffee, corn, rice, cassava
Zone D	500-1500	500-1500	Corn, cassava, rice, sweet potato, cowpea
Zone E	100-500	500-1500	Corn, cassava, rice, sweet potato, cowpea
Zone F	<100	1500-3500	Rice, corn, cassava, coconut

The following are recommendations for implementing agroforestry according to agro-ecological zones based on agro-climatic zones:

1. Zone C

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

2. Zone D

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

3. Zone E

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

4. Zone F

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

C. Conservation Techniques in Manufahi District

Soil conservation techniques are operational and managerial strategies aimed at maintaining and enhancing the production capacity of lands 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 in Asia, such as returning agricultural land to forests or grasslands, terracing, mulching, and soil management (Huang *et al.,* 2022).

1. Check Dam

A check dam is a small, low dam constructed in a riverbed or other water channels to reduce the flow velocity, decrease erosion, and promote sedimentation of eroded material through the spillway. Dams are beneficial for preserving agricultural land and reinforcing the structures of embankment dams in hilly and disaster-prone areas. Several types of dams include

a. ***Brushwood****,* A dam made from wood or branches, suitable for small riverbeds. Typically, it has an effective height of about 1 meter above the ground surface, and the minimum foundation depth for the posts is 0.75 to 1 meter. The brushwood conservation model is shown in Figure 6.9. Steps to build a brushwood dam*:*

1) Dig a trench about 5 cm wide, and install wooden posts (150-200 cm) with a depth of about one-third to half the length of the posts. The posts should be spaced 30-50 cm apart.
2) The center of the dam should be lower than the sides to create a gap for maximum water flow retention.
3) Branches from trees (such as mahogany, rosewood, sesbania) and shrubs are woven between the posts until the desired height is reached.
4) The ends of the tied materials should extend into the riverbed at least 30 cm
5) The back of the dam should be filled with soil.
6) The sides of the brushwood dam, approximately 1.5-2.0 times the height of the dam, should be protected from erosion and installed with galvanized wire.
7) Side walls should be constructed to direct water flow to the dam.
8) Repair the steep slope of the riverbed head.

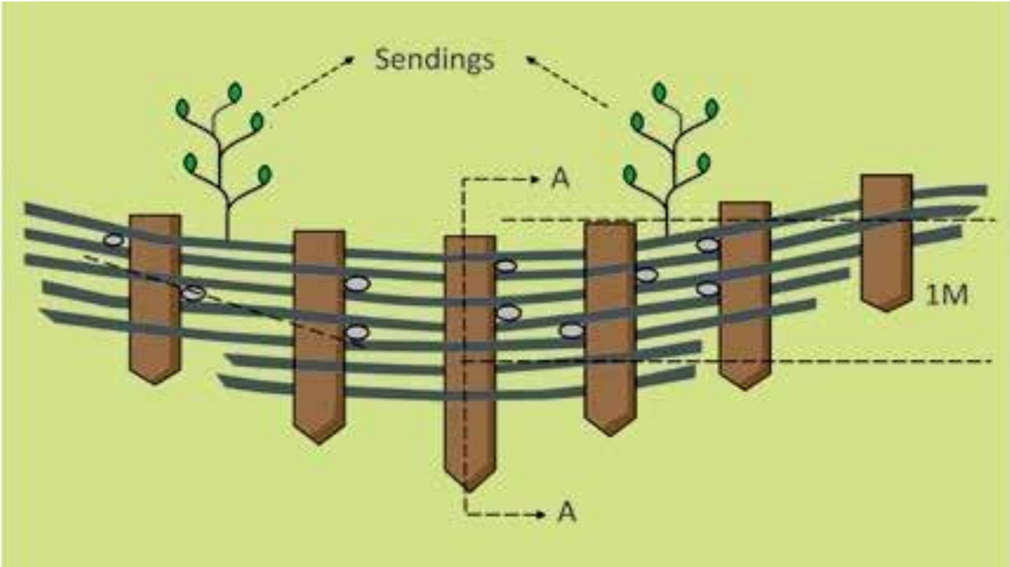


Figure 6.9 Brushwood Check Dam
(Source: Godinho *et al.,* 2023)

b. **Loose Stone**: Made from loose stones to block small to medium riverbeds. Similarly, boulder is a dam made from large stones, following the same principle as the loose stone dam. These dams typically have an effective height of between 1-2 meters, a minimum foundation depth of half the effective height, and a drainage channel thickness between 0.5 - 1 meter. The loose stone model is presented in **Figure 6.10**. The steps for building a loose stone or boulder dam include:
   1) Clear the site and mark the construction line using string.
   2) The sides of the riverbed are cut with a 1:1 slope. The foundation of the wing walls should be greater than 0.5 meters. The height of the wing walls should be the same as the depth of the drainage channel.
   3) The dam foundation should be longer than the drainage channel.
   4) For larger dams, two wing walls should be constructed with foundations matching the height to force water flow into the drainage channel or gap, preventing damage to the riverbed edges.
   5) Boulder stones are used in the gap and downstream sides for the drainage channel. The center should remain low for the drainage flow.
   6) If there is a high volume of water flow, concrete should be used in the gap and top of the dam or cover the entire structure with wire mesh.
   7) An apron of stones should be built beneath the dam.

8) Large stones are placed at the bottom of the dam, and stones of approximately 50 x 30 cm are used throughout the entire dam.
9) At the upstream side, the dam should receive soil fill to enhance its stability.

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

c. **Gabion**, A dam made with hexagonal or square wire baskets filled with stones. The general specifications for gabions include an effective height of less than 5 meters, a maximum foundation depth of half the effective height, and a dam thickness in the drainage channel of less than 1 meter. The gabion conservation concept is presented in **Figure 6.11**. Steps for constructing a gabion include:
   1) The structure should extend at least 0.5 meters into the riverbed and must be protected from floodwater with wing walls.
   2) Wing walls with suitable foundations should be constructed above to direct the flow into the drainage channel or gap, preventing damage to the riverbank. 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 drainage channel.
   4) Large stones should be placed along the sides of the gabion box, while smaller stones are used to fill the center. The size of the stones used in construction should be larger than the wire mesh size (mesh size 10 x 10 cm and 15 x 15 cm).

5) If there is debris material, a concrete layer in front of the dam is required to protect the gabion wire from damage.
6) The dimensions of the drainage channel are calculated based on the maximum flow from the riverbed catchment area.
7) An apron should be built beneath the dam.
8) The back of the retaining dam should be filled with soil to enhance the dam's strength.
9) The gabion box should be tied with 12-gauge wire.

Figure 6.11 Gabion Check Dam
(Source:*https://i.pinimg.com/originals/32/6e/5e/326e5e1d490cc5da1dd6a6ba9bdd477d.jpg*)

2. Terracing

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

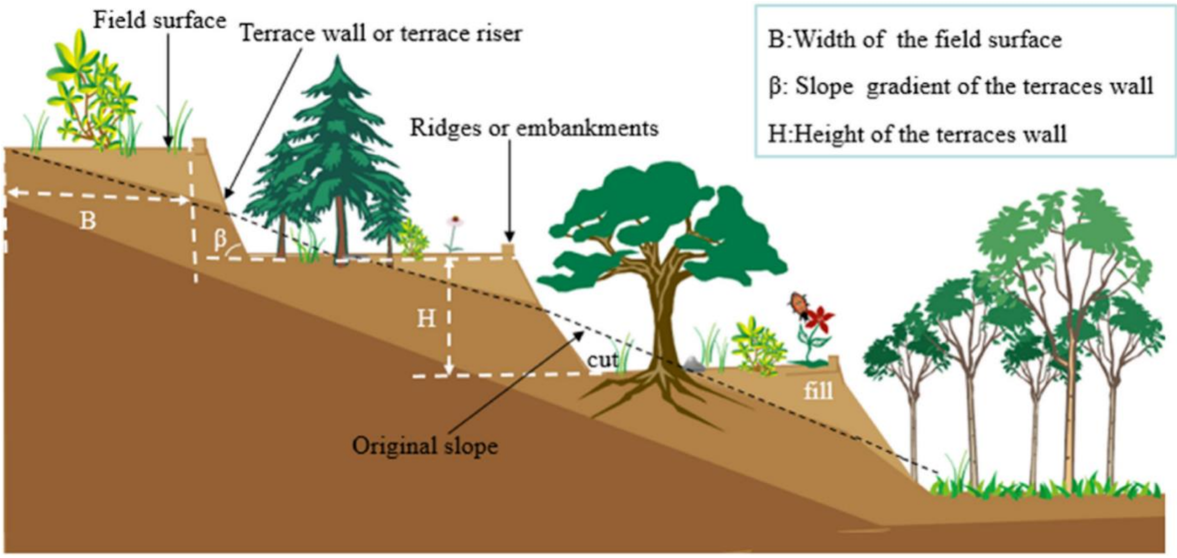


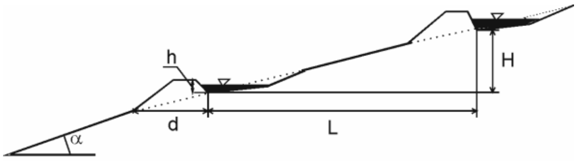
Figure 6.12 Terracing Conservation Concept
(Source: Deng *et al.,* 2021)

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

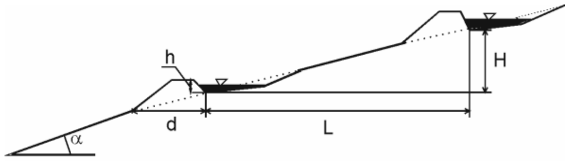
a. **Broad Channel Terraces**, typically built to capture and channel excess water in fields, these terraces are suitable for wet areas with slopes no greater than 20%.

b. **Ridge Terraces**, designed to capture and hold excess water by spreading it across the land between hilltops, ridge terraces are widely applied on gentle slopes (<3%) because the water is spread more widely without the need to create tall ridges. Ridge terraces feature water channels at the back of the ridge (ridge crests) to channel surface water into drainage systems and enhance water absorption into the soil. These terraces divide the slope into smaller hydrological units, which helps reduce water flow paths and influences water circulation on the slope and throughout the watershed.

   According to Prochal (1984) in Baryła & Pierzgalski (2008), ridge terraces are divided into two types: with and without water outflow. Ridge terraces without water outflow, these terraces are parallel to the contour and are built on permeable soils with relatively low rainfall. The flowing water is retained in the embankments and absorbed into the soil. Ridge terraces with water outflow, these terraces have surface or subsurface drainage. In terraces with subsurface drainage, water is drained through wells or underground pumps to ditches, rivers, or reservoirs. These terraces are used in areas with high precipitation and soils with low water absorption capacity. The concept of ridge terraces distribution is presented in **Figure 6.13.**



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



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

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

c. **Bench (Step) Terraces**, used on slopes of 20-50%, step terraces transform the land into a series of steps separated by vertical walls, which are covered with stones or vegetation for protection. Step terraces can be made flat, sloping inward (known as "*goler kampak*"), or sloping outward, typically constructed in ecosystems such as rainfed rice fields, dryland farming areas, and various agroforestry systems.
d. **Individual Terraces,** these terraces are constructed for each individual plant, primarily for perennial crops. This type of terrace is commonly built in plantation areas or fruit orchards.
e. **Orchard Terraces,** a type of terrace designed for perennial crops, especially plantation crops and fruits. The terraces are created with varying intervals according to planting distances.

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

1) Terrace Length, typically, the maximum length is 100 meters in one direction of the drainage channel for humid tropical climate conditions. The length of the terrace is limited by the size and shape of the land, the degree of cutting, and the soil type.
2) Terrace Width, the optimal width ranges from 2.5 to 5 meters (manually constructed) and 3.5 to 8 meters (machine or tractor constructed). The width of the terrace is adjusted according to soil depth, tillage equipment, crop type, and other requirements.

3) Terrace Gradient, the horizontal gradient of the terrace ranges between 0.5 to 1%, depending on the climate and soil type.
4) Height and Slope of Sub-Terraces, sub-terraces are made from compacted soil and are protected with grass or stones. The height of the sub-terraces should ideally not exceed 2 meters. The Vertical Interval (VI) between two consecutive terraces can be calculated using the following formula:

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

   Description:

   S = Slope (%)

   Wb = Width of the bench (m)

   U = Slope of the sub-terrace (m)

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

3. Biopore Infiltration Holes

A biopore hole is a cylindrical hole drilled into the ground to increase water infiltration, reduce flooding, convert organic waste into compost, reduce 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, thereby improving soil moisture and maximizing groundwater reserves. Additionally, biopores can enhance soil fertility by converting kitchen waste into compost.

The construction of biopores can be done by digging or using a drill to create holes with depths ranging from 30 to 100 cm. The distance between holes is about 0.5 to 1 meter. Biopore holes created around trees can be arranged in three holes in an equilateral triangle around the tree. The edges of the holes should be reinforced with cement or short PVC pipe pieces to prevent erosion.

Only organic waste (kitchen waste and/or garden waste) should be placed in the holes. The waste should not be too compacted as this will interfere with the water infiltration process. The compost produced usually takes about 2 to 8 weeks. The concept of biopore infiltration hole implementation is presented in **Figure 6.15.**

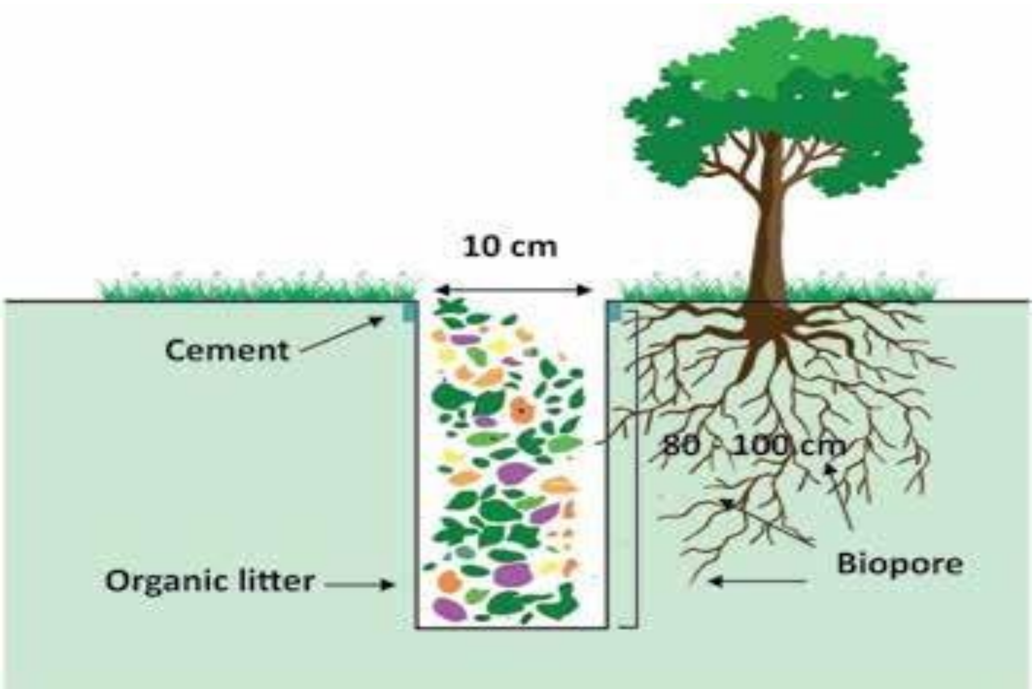


Figure 6.15 Biopore Infiltration Holes
(Source: Godinho *et al.,* 2023)

4. Riverbank Protection

Riverbank protection is a soil and water conservation technique applied along riverbanks to prevent landslides, reduce soil erosion, improve water quality, and reduce sedimentation. Riverbank protection can be applied in open areas along riverbanks that are vulnerable to erosion and landslides, steep riverbanks, barren 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 frames. The concept of riverbank protection using vegetation is presented in **Figure 6.16.**

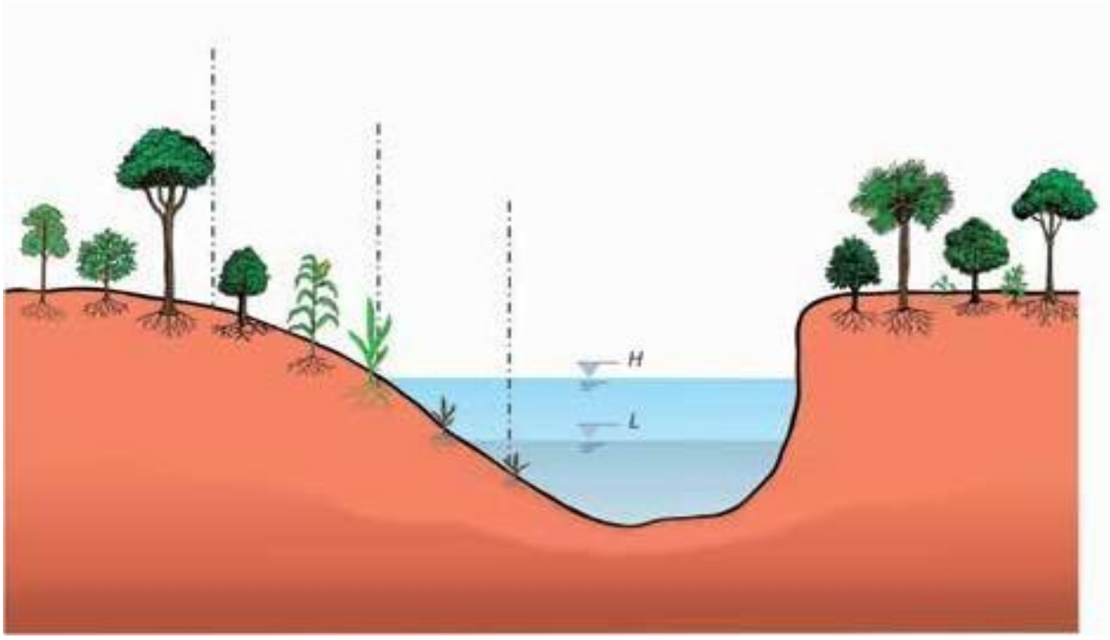


Figure 6.16 Riverbank Protection with Various Layers of Trees, Shrubs, and Grass (Source: Godinho *et al.,* 2023)

5. Grass Planting

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

Grass planting can be carried out in three ways:

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

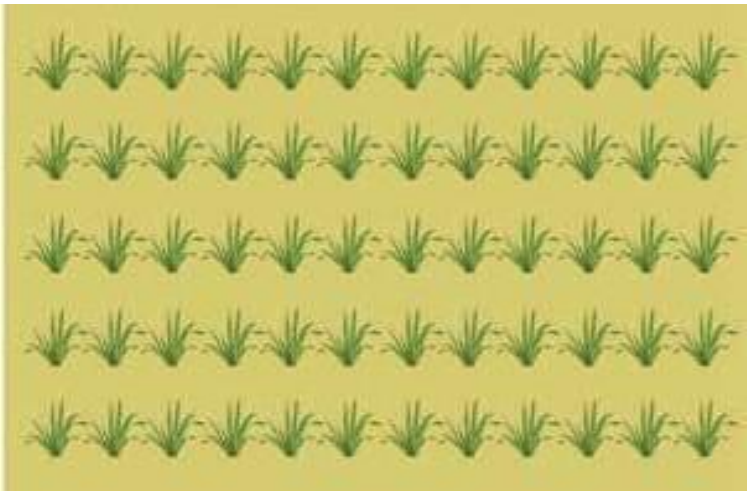


Figure 6.17 Horizontal Grass Planting
(Source: Godinho *et al.,* 2023)

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

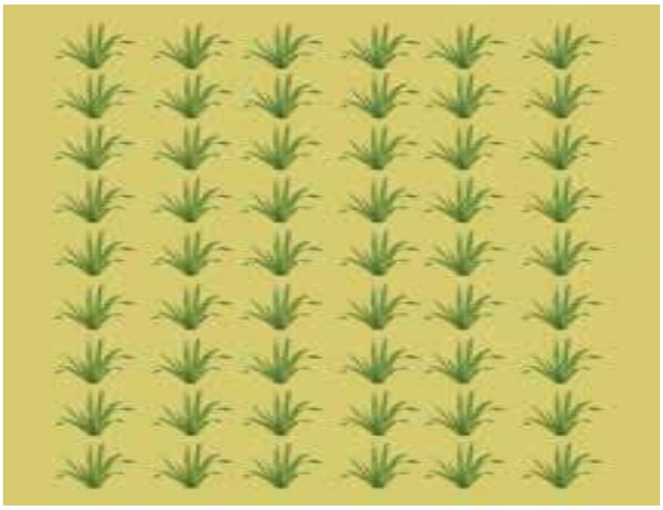


Figure 6.18 Vertical Grass Planting
*(*Source: Godinho *et al*., 2023*)*

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

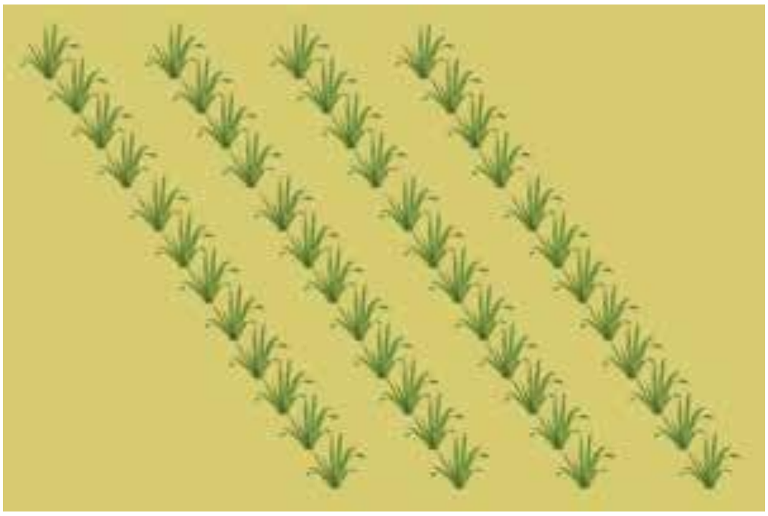


Figure 6.19 Diagonal Grass Planting
(Source: Godinho et al., 2023)

6. Rainwater Reservoir

A rainwater reservoir is a water storage pond used to provide irrigation during the dry season, prevent or reduce flooding during the rainy season, increase water infiltration, enhance soil productivity, extend the planting period, and increase farmer income. This conservation technique can be applied in areas with high rainfall and high surface runoff on slopes of 8-30%. The construction of a rainwater reservoir involves excavation, clay lining, and the creation of drainage channels. During excavation, the embankments or edges of the reservoir should be higher than the surrounding ground surface to prevent soil from entering the reservoir. Drainage channels are created to prevent the reservoir from overflowing, with the distance from the drainage channel to the reservoir surface ranging from 25-50 cm. Next, the clay lining is used to reinforce the walls or embankments of the reservoir, which are typically made 25 cm thick. The reservoir wall cover should have a slope of 70-80 degrees or be tiered to prevent landslides. For sandy soil, the dam wall should be lined with plastic, cement, or a mixture of lime and clay (1:1 ratio) to prevent water from seeping too quickly. Finally, the overflow channel should be directed towards the area to be irrigated, with a width of 15-25 cm and a depth of 10-15 cm. In addition, the rainwater reservoir should be maintained by cleaning the drainage channels, reservoir edges, and dam walls, and removing the sedimented mud. The concept of rainwater reservoir construction is presented in **Figure 6.20.**

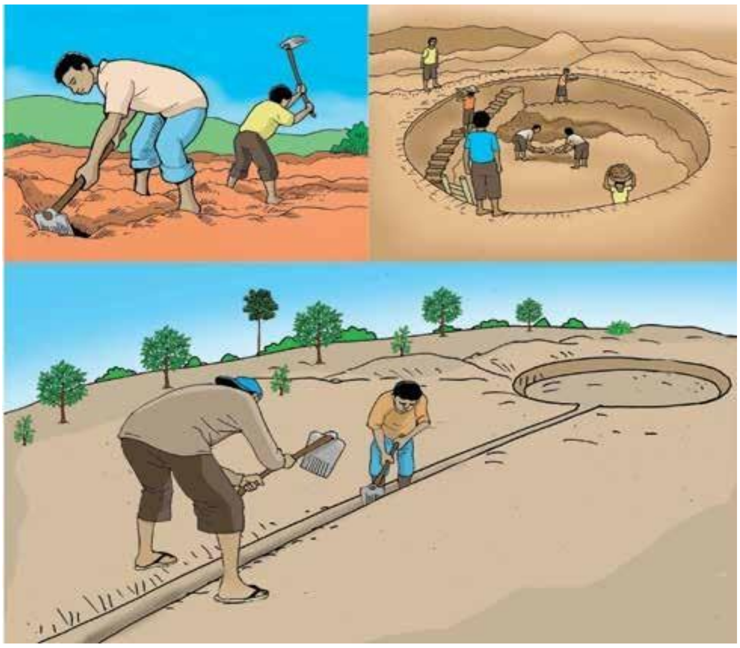


Figure 6.20 Construction Rainwater Reservoir
(Source: Godinho et al., 2023)

7. Drainage Channel Construction

Drainage channels are used to direct water to areas where it can be absorbed into the soil or collected. The construction of drainage channels is often equipped with small waterfalls to prevent erosion and landslides by controlling the water flow. The construction of a drainage channel begins by excavating the soil to a minimum depth of 50 cm from the cultivation area, with a base width of 50 cm. The base of the channel on the bench terrace is made with a slope of 0.1 - 0.5% outward. Along the 1-meter length of the drainage, grass is planted 20 cm wide across the drainage channel. Next, the waterfall construction involves installing two or three split bamboo poles horizontally across the waterfall at a depth of 0.5 m, with the outer part of the bamboo placed on the outside. Maintenance efforts include cleaning the channel from sediment, trimming weeds, and repairing any damaged bamboo structures. The concept of the drainage channel is presented in **Figure 6.21.**

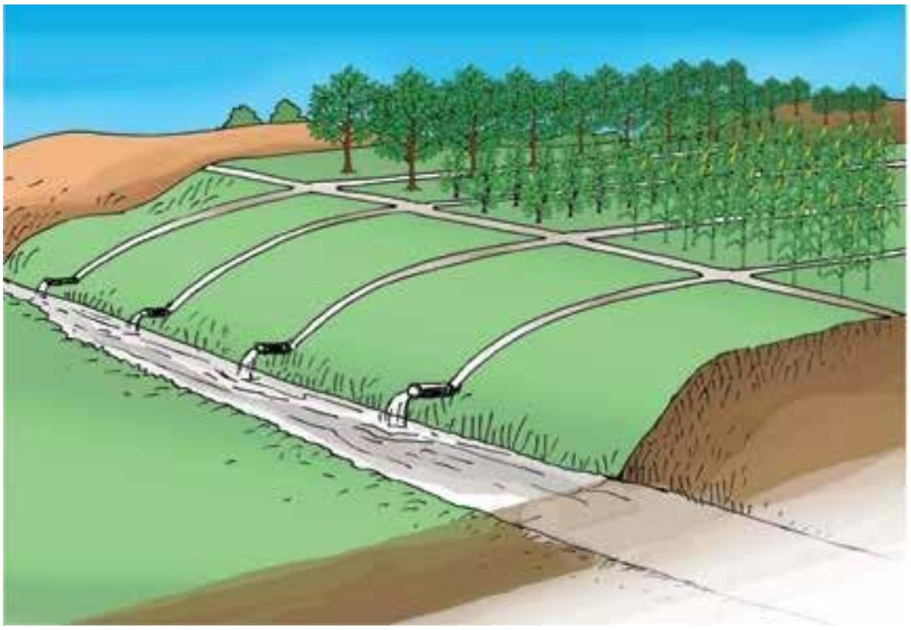


Figure 6.21 Drainage Channel
(Source: Godinho et al., 2023)

8. Wattle Fence / Live Check Dam

Wattle fence is a row of short fences or walls made from vegetative materials, constructed along the contours, designed to capture debris moving down the slope, strengthen, and modify the slope. This conservation technique creates microconditions for various plant species. The wattle fence is made by cleaning vegetation materials (wood or branches) to be used as posts. Next, 100 cm long posts are driven into the ground at a distance of 100 cm along the fence line. Place two posts, each 50 cm long, between the main posts, ensuring they protrude about 20-30 cm above the ground surface. Dig a trench (minimum depth of 15 cm) following the contour between the installed posts. Place the bottom ends of the plant cuttings in the trench, then weave the cuttings between the posts and compact the soil back into the trench. The concept of wattle fence application is presented in **Figure 6.22.**

Figure 6.22 Wattle Fence

9. Vegetative Actions

Vegetative actions aim to achieve better soil and water conservation efficiency through the alternating planting of fruit trees, spices, and food crops. The conservation practices implemented should minimize soil disturbance (minimum tillage), increase soil cover, and incorporate crop rotation, which is necessary to enhance agricultural sustainability (Huang *et al.,* 2022).

a. **Conservation Forests,** in soil and water conservation, conservation forests help reduce surface runoff erosion and maintain or restore soil fertility. Tree species and stand structure are the most important factors determining the effectiveness of conservation. Native tree species and layered vegetation structures (e.g., trees + shrubs + spices) become the preferred greening pattern.
b. **Plant Fences,** the use of plant fences is also effective in controlling slope soil erosion, trapping runoff, and improving soil fertility. Some of the plant species that can be used for fencing 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 covering, primarily for areas that are prone to erosion, such as mountains, riverbanks, and reservoirs.
    2) Half covering, land cover is implemented only during certain seasons.
    3) Rotational covering, applied in lightly eroded areas divided into several sub-zones for rotational covering.
    4) Covering combined with planting, for areas with moderate erosion and very low vegetation cover.

Additionally, increasing vegetation cover can be achieved using mulching, which involves the use of leaves, compost, and manure to cover the soil surface. Mulching can prevent a decrease in soil moisture due to evaporation, reduce soil erosion, and control weeds. Materials that can be used for mulching include rice and corn straw, legume and vetiver grass residues, as well as plastic film (Huang *et al.,* 2022).

d. **Crop Rotation**, crops planted in rotation yield higher results than those produced continuously. The benefits of crop rotation also depend on seasonal weather conditions and long-term practices. Long-term crop diversification can enhance agroecosystem productivity compared to monoculture systems and lead to a reduction in input use. The combination of legume and brassica crops tends to have a positive impact on the soil, as the combination of taproots and fibrous roots contributes to making soil organisms more complex and diverse (Quintarelli *et al.,* 2022).

e. **Water Reservoir,** according to Rustam (2010), a water reservoir is an artificial structure designed to capture and store water with a small specific volume capacity, smaller than the capacity of a reservoir/dam. Embungs are typically constructed by damming small rivers or can be built away from rivers. The embung pond stores water during the rainy season, which is then used by a village only during the dry season to meet the needs in the following priority order: population, livestock, and gardens or rice fields. The amount of water required determines the height and storage capacity of the embung. An example of the conservation concept through the construction of an embung is presented in **Figure 6.23.**

Figure 6.23 Application of Water Reservoir

VII. AGRICULTURAL LAND SUITABILITY EVALUATION

Land suitability refers to how well an area of land is suited for a specific use. For example, land may be classified as highly suitable for rice cultivation, moderately suitable for coffee, or marginally suitable for orange crops. Land suitability can be evaluated based on two conditions: the current condition and the condition after improvements.

7.1 LAND SUITABILITY FOR AGRICULTURE

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

Potential land suitability refers to land suitability after improvements have been made. For example, land that is marginally suitable (S3) due to nutrient deficiencies may become moderately suitable (S2) or even highly suitable (S1) after improvements, such as fertilization. The assessment of potential land suitability involves making improvements to address the limiting factors affecting land quality, which may lead to increased suitability. Through technology, lands with naturally low suitability classes (current land suitability) can, with improvements, be upgraded to higher suitability classes (potential land suitability). However, not all land qualities or characteristics can be improved with current technologies, or high management levels may be required for improvements. In land use planning, the primary focus is on potential land suitability, as this assessment provides an overview of the land's maximum potential for various uses after improvements are made. Therefore, potential land suitability helps in planning land use effectively and sustainably, as well as determining the necessary improvement measures to achieve optimal outcomes. Efforts to improve current land characteristics to make them suitable for potential use, according to the level of management, are presented in **Table 7.1.**

Table 7.1 Types of Efforts to Improve Current Land Characteristics to Potential Suitability According to Management Levels

No	Land Quality/Characteristics	Types of Improvement Efforts	Management Level
1.	Radiation Regime (Length/Duration of Sunlight Exposure)	Improvement Not Possible	-
2.	Temperature Regime: Average annual temperature Average temperature of the coldest month Average temperature of the hottest month	 Improvement Not Possible Improvement Not Possible Improvement Not Possible	 - - -
3.	Humidity Regime: Relative humidity	 Improvement Not Possible	 -
4.	Water Availability: Dry months Rainfall	 Irrigation system Drainage system	 Moderate, high Moderate, high
5.	Rooting Medium: Drainage Texture Effective depth	 Improvement of the drainage system, such as construction of drainage channels. Addition of organic material. Improvement cannot be made. Generally, improvement cannot be made except in soft and thin hardpan layers, which can be removed during land preparation.	- -
6.	Nutrient retention: CEC pH	 Liming or addition of organic material.	 Moderate, high
7.	Nutrient availability: N total P_2O_5 K_2O	 Urea and ZA fertilization SP36 and TSP fertilization KCl fertilization	 Moderate, high
8.	Diversity: Salinity	 Addition of organic material	 Moderate, high
9.	Erosion hazard	Efforts to reduce erosion rate,	Moderate, high

		construction of terraces, contour planting, planting of cover crops	
10.	Flood hazard Frequency period	Construction of water barriers and drainage channels to facilitate water management.	High
11.	Toxicity: Aluminum saturation Pyrite layer	Liming Management of soil water system, groundwater table level must be above the sulfide material layer.	Moderate, high Moderate, high
12.	Ease of soil cultivation	Soil moisture management to facilitate soil cultivation	Moderate, high
13.	Terrain/mechanism potential	Improvement cannot be made	-

Description:

1) Moderate management level; management can be carried out at the farmer level with moderate capital/agricultural techniques.
2) High management level; management can only be carried out with relatively large capital, generally 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		Type of Improvement
		Moderate	High	
1	Radiation regime	-	-	-
2	Temperature regime	-	-	-
3	Air humidity regime	-	-	-
4	**Water availability**			
	Dry months	+	++	Crop combination
	Rainfall	+	++	Irrigation
5	**Root media**			
	Drainage	+	++	Drainage channels*)
	Soil texture	-	+	Addition of organic material
	Effective depth	-	+	Planting hole creation and Addition of organic material
	Peat, maturity	-	-	-
	Peat thickness	-	-	-
6	**Nutrient retention:**			Addition of organic material
	Cation exchange capacity	-	+	
	Base saturation	-	+	
	pH	+	+	
	Organic carbon	+	++	
7	**Nutrient availability:**			
	Total Nitrogen	+	++	Urea fertilizer
	Available Phosphorus	+	++	SP36 and TSP fertilizers
	Available Potassium	+	++	KCl fertilizer
8	**Flood hazard:**			
	Period	+	++	-
	Frequency	+	++	-
9	**Salinity:**			
	Salinity	+	++	Irrigation and addition of organic material
10	**Toxicity**			
	Aluminum saturation	+	++	Lime
	Pyrite depth	-	+	Groundwater management
11	Ease of cultivation	-	+	Mechanization
12	Terrain (land) mechanization potential	-	+	Terracing
13	Erosion hazard	+	++	Soil conservation efforts

Decription:

- Improvement cannot be made

\+ Improvement can be made and will result in an increase of one class higher (S3 to S2)

++ Increase of two classes higher (S3 to S1)

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

7.2 LAND SUITABILITY CLASSIFICATION STRUCTURE

The land suitability classification system according to the Framework of Land Evaluation (FAO, 1976) is currently 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). Land suitability is systematically described as follows:

Table 7.3 Land Suitability Classification System (FAO, 1976)

Order	:	Indicates whether a land is suitable or not for a specific use.
Class	:	Indicates the level of suitability of a land
Subclass	:	Indicates the type of limitations or improvements that must be carried out within each class.
Unit	:	Indicates the variations in the degree of limiting factors that affect the management of the subclass.

Order and class are typically used in land mapping at the reconnaissance scale, subclass in semi-detailed land mapping, and unit in detailed land mapping. Order is also used in land mapping at a coarse scale (exploration).

Suitability Order

Suitability order describes the general suitability of land, meaning whether the land is suitable or unsuitable for a specific land use that has been considered. At the suitability order level, land is categorized into suitable (S) and unsuitable (N) land.

Suitable Order (S)

Land included in this order can be used for a long period for a planned land use. The benefits of land management will be satisfactory after accounting for the inputs provided, with little or no risk of resource degradation.

Unsuitable Order (N)

Land in this order has various limitations, either physically (such as very steep slopes, rocky terrain, etc.) or economically (where inputs are not balanced with outputs, making it unfeasible for the intended use).

Suitability Class

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

Highly Suitable Class (S1)

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

Moderately Suitable Class (S2)

Land with moderate limitations that require higher management to maintain the necessary management level. These limitations reduce productivity or profitability and increase the inputs required.

Marginally Suitable Class (S3)

Land with severe limitations for maintaining the required management level. These severe limitations can decrease productivity and profitability, and additional inputs are required to achieve the expected output.

Not Suitable Class (N1)

Land with very severe and difficult-to-overcome limitations, preventing sustainable use in the long term.

N2 Class: Permanently Not Suitable

Land with permanent limitations that prevent any possibility of sustainable use in the long term.

Suitability Subclass

The subclass reflects the type and intensity of limiting factors that hinder land use or the type of improvements needed. Each class can consist of one or more subclasses, depending on the types of limitations present. These limitations are indicated by lowercase letters placed after the class symbol. For example, class S2 with an effective depth limitation (s) can become subclass S2s. A subclass can have one, two, or at most three limiting symbols, with the most dominant limitation listed first. For example, in subclass S2ts, the topographic limitation (t) is the most dominant, and the effective depth limitation (s) is the secondary or additional limitation.

Suitability Unit

Suitability at the unit level is a more detailed division of subclasses based on the intensity of the limiting factors affecting the land. All units within a subclass share a similar suitability level and have the same types of limiting factors at the subclass level.

Table 7.4 Land Suitability Classification Structure (FAO, 1976)

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

The difference between one unit and another usually lies in its production capacity or additional aspects of management required. It is often a more detailed distinction of the limiting factors. Detailed knowledge of these limitations facilitates interpretation and planning for land management. The unit level is indicated by adding Arabic numerals separated by a hyphen after the subclass symbol. For example, S2e-1, S2e-2, and so on. The number of units in a subclass is unlimited. The symbols at the unit level are created by adding Arabic numerals separated by a hyphen from the subclass symbol. For example, S2e-1, S3e-2, and so on. The number of units in a subclass is not limited.

7.3 LAND SUITABILITY ASSESSMENT RESULTS

Land suitability analysis is a fundamental step in designing sustainable land resource management strategies. This evaluation process uses an integrated approach, including the utilization of geospatial data, field observations, and laboratory analysis of soil's physical and chemical properties. This approach allows for the identification of the bio-physical potential and limitations of the land, which serve as the basis for developing agricultural, horticultural, and forestry commodities.

Geospatial data is used to map topography, land use, and rainfall patterns, while field observations provide direct information on bio-physical conditions, such as slope, vegetation cover, and drainage quality. Laboratory analysis of soil samples complements this evaluation by providing data on macro-nutrient content (N, P, K), organic matter, cation exchange capacity (CEC), pH, and soil texture. The data obtained is analyzed based on the actual growth requirements of each crop type, as well as the potential suitability after land improvement measures have been applied. This process results in comprehensive information that determines commodity development priorities, identifies limiting factors, and designs relevant technical solutions.

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

Manufahi District in Timor-Leste has diverse land characteristics, which offer significant potential for the development of various agricultural commodities, including food crops, horticulture, industrial crops, and forestry. However, this development requires attention to limiting factors such as effective soil depth, slope gradient, erosion hazards, and soil fertility levels. Through a land suitability-based management approach, the potential to increase productivity and sustain land use can be optimized.

The rice fields in Same, Fatuberliu, and Alas Sub-Districts show high prospects for the cultivation of food crops such as irrigated rice, rainfed rice, upland rice, corn, sorghum, cassava, and peanuts. Meanwhile, Turiscai shows great potential for the development of industrial crops such as coconut, robusta coffee, and arabica coffee. Horticultural commodities such as chili, tomato, durian, and rambutan also have development potential in various sub-districts, with additional potential from spice crops such as jatropha, turmeric, aromatic ginger, lemongrass, and pepper in certain locations. The implementation of this strategy is expected to support ecosystem stability while reducing the risks of erosion and land degradation in Manufahi District.

A. Land Suitability Evaluation of Alas Sub-District

Alas Sub-District shows significant potential for agricultural development, considering its land suitability and agro-climatic conditions. A variety of commodities can be cultivated, ranging from wetland food crops such as irrigated rice and rainfed rice, to dryland food crops like upland rice, sorghum, taro, and cassava. Horticultural commodities also have development opportunities, including vegetables (cucumber, chili, broccoli), fruits (mango, avocado, passion fruit, guava, custard apple, pineapple), and ornamental plants (rose, aster, sunflower). Spices and medicinal plants such as lemongrass, aromatic ginger, galangal, and turmeric, as well as industrial crops (kapok, coconut, cacao, robusta coffee), further expand agricultural diversification. To support the livestock sector, the development of elephantgrass and setaria as forage crops can be achieved through soil quality improvement, particularly by adding organic material.

However, the development of agricultural commodities in Alas Sub-District faces several technical limitations, including **the dry season period, rainfall intensity, slope gradient, erosion risk, drainage, flood potential, and soil depth**. These challenges can still be addressed through the optimization of irrigation systems, construction of drainage channels, addition of organic material, and the application of soil conservation techniques such as terracing combined with supporting and cover crops. On the other hand, there are permanent limitations that cannot be improved, such as temperature, surface rocks, and rock outcrops. Land management approaches such as rock removal and planting hole creation are still feasible to improve the efficiency and productivity of cultivation.

Overall, Alas Sub-District has a land suitability level that supports the development of sustainable agriculture. However, some commodities, such as **wheat, potato, carrot, shallot, garlic, snow pea, and arabica coffee**, are not recommended for development due to permanent temperature limitations. Information on other potentially developable commodities in this area can be seen in Table 7.5.

B. Land Suitability Evaluation of Fatuberliu Sub-District

Fatuberliu Sub-District shows significant potential for agricultural development, considering its land suitability and agro-climatic conditions. A variety of commodities can be cultivated, ranging from food crops such as upland rice, mung beans, and corn. Horticultural commodities also have development opportunities, including vegetables (broccoli, eggplant, tomato vegetable), fruits (orange, watermelon, papaya, rambutan), and ornamental plants (rose, aster, sunflower). Spices and medicinal plants such as turmeric, aromatic ginger, galangal, and cardamom, as well as industrial crops (tobacco, coconut, cashew, melinjo, and sugarcane), further expand agricultural diversification. To support the livestock sector, the development of legumes, Setaria, and elephantgrass as forage crops can be achieved through soil quality improvement by adding organic material.

Although the development potential is broad, several limiting factors affect land productivity. These factors include **rainfall intensity, dry season period, slope gradient, erosion risk, drainage, flood potential, soil depth, and nutrient content such as total nitrogen (Total Nitrogen), available phosphorus (P-tersedia), and available potassium (K-tersedia).** These challenges can be addressed through land management interventions, such as optimizing irrigation systems, constructing drainage channels, balanced fertilization, adding organic material, and applying soil conservation techniques like terracing with strengthening and cover vegetation.

However, there are also permanent limitations that cannot be technically improved, such as temperature, surface rocks, and rock outcrops. Land management approaches such as rock removal and planting hole creation can still improve the efficiency and productivity of cultivation. Adaptive approaches like rock cleaning and modification of planting holes can be applied to enhance land utilization effectiveness.

Overall, Fatuberliu Sub-District has a land suitability level that supports the development of sustainable agriculture. However, some commodities, such as **wheat, potato, carrot, garlic, snow pea, and arabica coffee**, are not recommended for development due to permanent temperature limitations. Information on other potentially developable commodities in this area can be seen in **Table 7.5.**

C. Land Suitability Evaluation of Same Sub-District

Same Sub-District shows significant potential for agricultural development, considering its land suitability and agro-climatic conditions. A variety of commodities can be cultivated, ranging from wetland food crops such as irrigated rice, rainfed rice, to dryland food crops like upland rice, wheat, taro, corn, and cowpea. Horticultural commodities also have development opportunities, including vegetables (chili, bell pepper, broccoli, cucumber), fruits (orange, watermelon, melon, papaya, banana, snakefruit, rambutan), and ornamental plants (rose, aster). Spices and medicinal plants such as cardamom and turmeric, as well as industrial crops (tobacco), further diversify agriculture. To support the livestock sector, the development of Setaria and legumes as forage crops can be achieved through soil quality improvement by adding organic material.

However, the development of agricultural commodities in Same Sub-District faces several technical limitations, including **the dry season period, rainfall intensity, slope gradient, erosion risk, drainage, flood potential, soil depth, and nutrient content such as total nitrogen (Total Nitrogen), available phosphorus (P-tersedia), and available potassium (K-tersedia).** These challenges can be addressed through land management interventions, such as optimizing irrigation systems, constructing drainage channels, adding organic material, balanced fertilization, and applying soil conservation techniques like terracing with strengthening and cover crops.

In addition, there are permanent limitations that cannot be improved, such as temperature, surface rocks, and rock outcrops. Adaptive approaches such as rock cleaning and modification of planting holes can be applied to enhance land utilization effectiveness.

Overall, Same Sub-District has a land suitability level that supports the development of sustainable agriculture. However, some commodities, such as **wheat, potato, carrot, garlic, snow pea, and arabica coffee**, are not recommended for development due to permanent temperature limitations. Information on other potentially developable commodities in this area can be seen in **Table 7.5.**

D. Land Suitability Evaluation of Turiscai Sub-District

Turiscai Sub-District shows significant potential for agricultural development, considering its land suitability and agro-climatic conditions. A variety of commodities can be cultivated, ranging from food crops such as upland rice, sorghum, and corn. Horticultural commodities also have development opportunities, including vegetables (broccoli, chili, tomato vegetable), fruits (breadfruit, orange, snakefruit, pineapple), and ornamental plants (rose, aster, sunflower). Spices and medicinal plants such as galangal and cardamom, as well as industrial crops (tobacco, robusta coffee, arabica coffee, and cotton), further diversify agriculture. To support the livestock sector, the development of elephantgrass, Setaria, and legumes as forage crops can be achieved through soil quality improvement by adding organic material.

Although the development potential is broad, several limiting factors affect land productivity. These factors include **rainfall intensity, dry season period, slope gradient, erosion risk, drainage, flood potential, soil depth, and nutrient content such as total nitrogen (Total Nitrogen), available phosphorus (P-tersedia), and available potassium (K-tersedia).** These challenges can be addressed through land management interventions, such as optimizing irrigation systems, adjusting planting patterns, constructing drainage channels, balanced fertilization, adding organic material, and applying soil conservation techniques like terracing with strengthening and cover crops.

However, there are also permanent limitations that cannot be technically improved, such as temperature, surface rocks, and rock outcrops. Land management approaches such as rock cleaning and planting hole creation can still improve the efficiency and productivity of cultivation. Adaptive approaches like rock cleaning and modification of planting holes can be applied to enhance land utilization effectiveness.

Overall, Turiscai Sub-District has a land suitability level that supports the development of sustainable agriculture. However, some commodities, such as **wheat, potato, carrot, garlic, snow pea, and arabica coffee**, are not recommended for development due to permanent temperature limitations. Wetland commodities like **irrigated rice and rainfed rice** have less potential for development. Information on other potentially developable commodities in this area can be seen in **Table 7.5.**

Table 7.5 Matrix Analysis of Land Suitability Evaluation in Manufahi District

Commodities	Sub-District	Limiting Factors	Potential Land Suitability / Improvement Efforts
FOOD COMMODITIES			
Irrigated Rice	• Alas • Fatuberliu • Same	**S2** : Soil Texture, Coarse Materials, Total Nitrogen, K2O **S3** : Rock Outcrops **N** : Slope Gradient, Erosion Risk	**S2** : Soil Texture, Coarse Materials, Effective Depth, Slope Gradient, Erosion Risk **S3** : Rock Outcrops
Rainfed Rice	• Alas • Fatuberliu • Same • Turiscai	**S3** : Total Nitrogen, Surface Rocks, Rock Outcrops	**S2** : Slope Gradient, Erosion Risk **S3** : Surface Rocks, Rock Outcrops

		N : Slope Gradient, Erosion Risk	
DRYLAND FOOD COMMODITIES			
Upland Rice	• Alas • Fatuberliu • Same • Turiscai	**S3** : Total Nitrogen, Surface Rocks, Rock Outcrops **N** Slope Gradient, Erosion Risk	**S2** : Slope Gradient, Erosion **S3** : Surface Rocks, Rock Outcrops
Sorghum **Mung Beans** **Cowpea**	• Alas • Fatuberliu • Same • Turiscai	**S3** : Soil Drainage, Total Nitrogen, K_2O, Erosion Risk **N** : Rainfall, Slope Gradient	**S2** : Rainfall, Soil Drainage, Slope Gradient, Erosion Risk, Flooding
Cassava	• Alas • Fatuberliu • Same • Turiscai	**S2** : Soil Texture, Coarse Materials, Organic C, K_2O **S3** : Total Nitrogen, Rock Outcrops	**S2** : Soil Texture, Coarse Materials, Slope Gradient **S3** : Effective Depth, Rock Outcrops
Corn	• Alas • Fatuberliu • Same • Turiscai	**S2** : Temperature, Total Nitrogen, P_2O_5, K_2O **S3** : Rainfall, Soil Drainage, Erosion Risk **N** : Slope Gradient	**S2** : Temperature, Soil Drainage, Slope Gradient, Erosion Risk
Soybean **Mung Beans**	• Alas • Fatuberliu • Same • Turiscai	**S2** : Temperature, pH, Total Nitrogen, K_2O **S3** : Soil Drainage, Slope Gradient, Erosion Risk	**S2** : Temperature, Soil Drainage, Slope Gradient, Erosion Risk
Taro	• Alas • Fatuberliu • Same • Turiscai	**S2** : Soil Texture, pH, Total Nitrogen, P_2O_5, K_2O, Surface Rocks **S3** : Soil Drainage, Slope Gradient, Erosion Risk	**S2** : Soil Drainage, Soil Texture, Slope Gradient, Erosion Risk, Surface Rocks, Flooding
Wheat	• Alas • Fatuberliu • Same • Turiscai	**S3** : Surface Rocks **N** : Temperature, Rainfall, Effective Depth, Erosion Risk	**S2** : Rainfall, Erosion Risk **S3** : Effective Depth, Surface Rocks **N** : Temperature

Sweet Potato	• Alas • Fatuberliu • Same • Turiscai	**S2** : emperature, Soil Texture, Effective Depth, Total Nitrogen, P_2O_5, K_2O **S3** : Soil Drainage, Erosion Risk	**S2** : Temperature, Soil Drainage, Soil Texture, Effective Depth, Erosion Risk
HORTICULTURAL COMMODITIES (VEGETABLES)			
Potato	• Alas • Fatuberliu • Same • Turiscai	**S2** : Soil Texture, Coarse Materials, Effective Depth, Cation Exchange Capacity, Organic C, Rock Outcrops, Surface Rocks **S3** : Rainfall, Soil Drainage, Total Nitrogen, P_2O_5, K_2O, Erosion Risk **N** : Temperature, Slope Gradient	**S2** : Soil Texture, Coarse Materials, Effective Depth, Slope Gradient, Erosion Risk, Rock Outcrops, Surface Rocks **N** : Temperature
Carrot	• Alas • Fatuberliu • Same • Turiscai	**S2** : Soil Texture, Cation Exchange Capacity, Organic C, Rock Outcrops, Surface Rocks **S3** : Rainfall, Soil Drainage, Coarse Materials, Effective Depth,, Total Nitrogen, P_2O_5, K_2O **N** : Temperature, Slope Gradient, Erosion Risk	**S2** : Soil Texture, Coarse Materials, Effective Depth, Slope Gradient, Erosion Risk, Rock Outcrops, Surface Rocks **N :** Temperature
Garlic	• Alas • Fatuberliu • Same • Turiscai	**S2** : Effective Depth,, C-organic, P_2O_5, K_2O, Rock Outcrops, Surface Rocks **S3** : Soil Drainage, Total Nitrogen, Erosion Risk **N** : Temperature, Rainfall, Salinity, Slope Gradient	**S2** : Rainfall, Effective Depth, Slope Gradient, Erosion Risk, Rock Outcrops, Surface Rocks **S3 :** Salinity **N :** Temperature

Shallot	• Alas • Fatuberliu • Same • Turiscai	**S2** : Soil Texture, Cation Exchange Capacity, Organic C, Rock Outcrops, Surface Rocks **S3** : Soil Drainage, Coarse Materials, Effective Depth, Total Nitrogen, P_2O_5, K_2O **N** : Rainfall, Slope Gradient, Erosion Risk	**S2** : Soil Texture, Coarse Materials, Effective Depth, Slope Gradient, Erosion Risk, Rock Outcrops, Surface Rocks **N** : Temperature
Chili **Bell Pepper**	• Alas • Fatuberliu • Same • Turiscai	**S2** : Effective Depth, Cation Exchange Capacity pH, P_2O_5, Surface Rocks, Rock Outcrops **S3** Rainfall, Soil Drainage, Soil Texture, Coarse Materials, Total Nitrogen, K_2O, Erosion Risk **N** : Slope Gradient	**S2** : Soil Texture, Coarse Materials, Effective Depth, Slope Gradient, Erosion Risk, Rock Outcrops, Surface Rocks
Caisim	• Alas • Fatuberliu • Same • Turiscai	**S2** : Temperature, Cation Exchange Capacity, pH, Organic C, P_2O_5 **S3** : Soil Drainage, Soil Texture, Coarse Materials, Effective Depth, Total Nitrogen, K_2O, Rock Outcrops, Surface Rocks **N** : Rainfall, Slope Gradient, Erosion Risk	**S2** : Temperature, Rainfall, Soil Texture, Coarse Materials, Effective Depth, Slope Gradient, Erosion Risk, Rock Outcrops, Surface Rocks
Green Beans **Broccoli**	• Alas • Fatuberliu • Same • Turiscai	**S2** : Temperature, Soil Texture, Cation Exchange Capacity	**S2** : Temperature, Soil Texture, Coarse Materials, Effective Depth, Slope Gradient, Erosion Risk,

		S3 : Rainfall, Soil Drainage, Coarse Materials, Effective Depth, Total Nitrogen, P_2O_5, K_2O, Rock Outcrops, Surface Rocks **N** : Slope Gradient, Erosion Risk	Rock Outcrops, Surface Rocks
Snow Pea	• Alas • Fatuberliu • Same • Turiscai	**S2** : Rainfall, Cation Exchange Capacity, pH, P_2O_5, Rock Outcrops, Surface Rocks **S3** : Soil Drainage, Soil Texture, Coarse Materials, Effective Depth, Total Nitrogen, K_2O, Erosion Risk **N** : Temperature, Slope Gradient	**S2** : Soil Texture, Coarse Materials, Effective Depth, Slope Gradient, Erosion Risk, Rock Outcrops, Surface Rocks **N** : Temperature
Cucumber	• Alas • Fatuberliu • Same • Turiscai	**S2** : pH, P_2O_5, Rock Outcrops, Surface Rocks **S3** : Rainfall, Soil Drainage, Soil Texture, Coarse Materials, Effective Depth, pH, Total Nitrogen, K_2O, Erosion Risk **N** : Slope Gradient	**S2** : Soil Texture, Coarse Materials, Effective Depth, Slope Gradient, Erosion Risk, Rock Outcrops, Surface Rocks
Eggplant **Bitter Melon** **Tomato** **Vegetable**	• Alas • Fatuberliu • Same • Turiscai	**S2** : Temperature, Rainfall, Rock Outcrops, Surface Rocks **S3** : Soil Drainage, Soil Texture, Coarse Materials, Effective Depth, pH, Total Nitrogen, K_2O **N** : Slope Gradient, Erosion Risk	**S2** : Temperature, Soil Texture, Coarse Materials, Effective Depth, Slope Gradient, Erosion Risk, Rock Outcrops, Surface Rocks

Cabbage **Long Beans**	• Alas • Fatuberliu • Same • Turiscai	**S2** : Temperature, Soil Texture, Cation Exchange Capacity **S3** : Rainfall, Soil Drainage, Coarse Materials, Effective Depth, Total Nitrogen, P_2O_5, K_2O, Rock Outcrops, Surface Rocks **N** : Slope Gradient, Erosion Risk	**S2** : Temperature, Soil Texture, Coarse Materials, Effective Depth, Slope Gradient, Erosion Risk, Rock Outcrops, Surface Rocks
HORTICULTURAL COMMODITIES (FRUITS)			
Mango **Guava** **Breadfruit**	• Alas • Fatuberliu • Same • Turiscai	**S2** : Rainfall, Rock Outcrops, Surface Rock **S3** : Texture, Coarse Fragment, Cation Exchange Capacity, Total Nitrogen, P_2O_5, K_2O **N** : Effective Depth, Slope Gradient, Erosion Hazard	**S2** : Texture, Coarse Fragment, Slope Gradient, Erosion Hazard, Rock Outcrops, Surface Rock **S3 :** Effective Depth
Orange	• Alas • Fatuberliu • Same • Turiscai	**S2** : Temperature, Dry Months, Texture **S3** : Coarse Fragment, Total Nitrogen, P_2O_5, K_2O, Rock Outcrops **N** : Effective Depth, Slope Gradient, Erosion Hazard, Surface Rock	**S2** : Temperature, Dry Months, Texture, Coarse Fragment, Slope Gradient, Erosion Hazard, Rock Outcrops **S3 :** Effective Depth, Surface Rock
Watermelon **Melon**	• Alas • Fatuberliu • Same • Turiscai	**S2** : Cation Exchange Capacity, pH, Organic Carbon, Rock Outcrops, Surface Rock **S3** : Rainfall, Drainage, Texture, Coarse Fragment, Effective	**S2** : Texture, Coarse Fragment, Effective Depth, Slope Gradient, Erosion Hazard, Rock Outcrops, Surface Rock

		Depth, Total Nitrogen, P_2O_5, K_2O **N** : Slope Gradient, Erosion Hazard	
Banana	• Alas • Fatuberliu • Same • Turiscai	**S2** : Temperature, Surface Rock **S3** : Dry Months, Drainage, Cation Exchange Capacity, Total Nitrogen, P_2O_5, K_2O Slope Gradient, Erosion Hazard **N** : Coarse Fragment, Effective Depth, Rock Outcrops	**S2** : Temperature, Dry Months, Slope Gradient, Erosion Hazard, Rock Outcrops, Surface Rock **S3 :** Coarse Fragment, Effective Depth
Papaya	• Alas • Fatuberliu • Same • Turiscai	**S2** : Temperature, Texture, Cation Exchange Capacity, pH, Organic Carbon, P_2O_5 **S3** : Rainfall, Drainage, Coarse Fragment, Total Nitrogen, K_2O, Rock Outcrops, Surface Rock **N** : Effective Depth, Slope Gradient, Erosion Hazard	**S2** : Temperature, Texture, Coarse Fragment, Slope Gradient, Erosion Hazard, Rock Outcrops, Surface Rock **S3 :** Effective Depth
Rambutan	• Alas • Fatuberliu • Same • Turiscai	**S2** : Temperature, Cation Exchange Capacity, Rock Outcrops, Surface Rock **S3** : Rainfall, Texture, Coarse Fragment, Total Nitrogen, P_2O_5, K_2O **N** : Effective Depth, Slope Gradient, Erosion Hazard	**S2** : Temperature, Texture, Coarse Fragment, Slope Gradient, Erosion Hazard, Rock Outcrops, Surface Rock **S3 :** Effective Depth

Avocado	• Alas • Fatuberliu • Same • Turiscai	**S2** : Rainfall, Cation Exchange Capacity, pH, Organic Carbon, Surface Rock **S3** : Drainage, Texture, Total Nitrogen,, P_2O_5, K_2O **N** : Coarse Fragment, Effective Depth, Slope Gradient, Erosion Hazard, Rock Outcrops	**S2** : Texture, Slope Gradient, Erosion Hazard, Surface Rock **S3 :** Coarse Fragment, Effective Depth, Rock Outcrops
Jackfruit	• Alas • Fatuberliu • Same • Turiscai	**S2** : Temperature, Cation Exchange Capacity, pH, Organic Carbon, P_2O_5, Rock Outcrops, Surface Rock **S3** : Rainfall, Drainage, Texture, Coarse Fragment, Total Nitrogen, K_2O, Slope Gradient **N** : Effective Depth, Erosion Hazard	**S2** : Temperature, Texture, Coarse Fragment, Slope Gradient, Erosion Hazard, Rock Outcrops, Surface Rock **S3 :** Effective Depth
Soursop	• Alas • Fatuberliu • Same • Turiscai	**S2** : Temperature, Cation Exchange Capacity, Rock Outcrops, Surface Rock **S3** : Texture, Coarse Fragment, Total Nitrogen, K_2O **N** : Effective Depth, Slope Gradient, Erosion Hazard	**S2** : Temperature, Texture, Coarse Fragment, Slope Gradient, Erosion Hazard, Rock Outcrops, Surface Rock **S3 :** Effective Depth

Snakefruit **Longan** **Durian** **Pineapple**	• Alas • Fatuberliu	**S2** Temperature, Rainfall, Cation Exchange Capacity, Organic Carbon, P_2O_5, Rock Outcrops, Surface Rock **S3** : Drainage, Texture, Coarse Fragment, pH, Total Nitrogen, K_2O **N** : Effective Depth, Slope Gradient, Erosion Hazar	**S2 :** Rock Outcrops, Surface Rock
Custard Apple	• Alas • Fatuberliu • Same • Turiscai	**S2** : Temperature, Rainfall, Cation Exchange Capacity, pH, Organic Carbon, P_2O_5, Rock Outcrops, Surface Rock **S3** : Drainage, Texture, Coarse Fragment, Total Nitrogen, K_2O **N** : Effective Depth, Slope Gradient, Erosion Hazard	**S2** : Temperature, Texture, Coarse Fragment, Slope Gradient, Erosion Hazard, Rock Outcrops, Surface Rock **S3 :** Effective Depth
Strawberry	• Alas • Fatuberliu • Same • Turiscai	**S2** : Temperature, Rainfall, Effective Depth, Rock Outcrops, Surface Rock **S3** : Drainage, Texture, Coarse Fragment, Cation Exchange Capacity, Total Nitrogen, P_2O_5, K_2O **N** : Slope Gradient, Erosion Hazard	**S2** : Temperature, Texture, Coarse Fragment, Slope Gradient, Erosion Hazard, Rock Outcrops, Surface Rock **S3 :** Effective Depth
Grape	• Alas • Fatuberliu • Same • Turiscai	**S2** : Temperature, Dry Months, Texture, Surface Rock	**S2** : Temperature, Dry Months, Texture, Slope Gradient, Erosion Hazard,

		S3 : Drainage, Cation Exchange Capacity, Total Nitrogen, P_2O_5, K_2O, Slope Gradient, Erosion Hazard **N** : Coarse Fragment, Effective Depth, Rock Outcrops	Rock Outcrops, Surface Rock **S3 :** Coarse Fragment, Effective Depth
Passion Fruit	• Alas • Fatuberliu • Same • Turiscai	**S2** : Rainfall, Texture **S3** : Temperature, Coarse Fragment, Total Nitrogen, P_2O_5, K_2O, Rock Outcrops **N** : Dry Months, Effective Depth, Slope Gradient, Erosion Hazard, Surface Rock	**S2** : Texture, Coarse Fragment, Slope Gradient, Erosion Hazard, Rock Outcrops **S3 :** emperature, Dry Months, Effective Depth, Surface Rock
HORTICULTURAL FLOWER COMMODITIES			
Rose **Aster**	• Alas • Fatuberliu • Same • Turiscai	**S2** : Temperature, pH, Organic Carbon, Total Nitrogen, P_2O_5, K_2O **S3** : Soil Drainage, Slope Gradient, Erosion Hazard	**S2** : Temperature, Soil Drainage, Slope Gradient, Erosion Hazard
Sunflower	• Alas • Fatuberliu • Same • Turiscai	**S2** : Temperature, pH, Organic Carbon, Total Nitrogen, P_2O_5, K_2O **S3** : Rainfall, Soil Drainage, Slope Gradient, Erosion Hazard	**S2** : Temperature, Rainfall, Soil Drainage, Slope Gradient, Erosion Hazard
SPICE AND MEDICINAL COMMODITIES			
Ginger	• Alas • Fatuberliu • Same • Turiscai	**S3** : Soil Drainage, Soil Depth, Total Nitrogen, K_2O, Slope Gradient, Erosion Hazard **N** : Rainfall	**S2** : Rainfall, Soil Drainage, Soil Depth, Slope Gradient, Erosion Hazard

Vetiver Root	• Alas • Fatuberliu • Same • Turiscai	**S2** : Temperature, Total Nitrogen, P_2O_5, K_2O, Slope Gradient, Erosion Hazard **S3** : Rainfall, Soil Drainage	**S2** : Temperature, Soil Drainage, Slope Gradient, Erosion Hazard
Lemongrass	• Alas • Fatuberliu • Same • Turiscai	**S2** : Temperature, Total Nitrogen, P_2O_5, Slope Gradient, Erosion Hazard **S3** : Soil Drainage, K_2O **N** : Rainfall	**S2** : Temperature, Rainfall, Soil Drainage, Slope Gradient, Erosion Hazard
Vanilla	• Alas • Fatuberliu • Same • Turiscai	**S2** : Temperature, Effective Depth, Total Nitrogen, P_2O_5, K_2O, Slope Gradient, Erosion Hazard	**S2** : Temperature, Effective Depth, Slope Gradient, Erosion Hazard
Candlenut	• Alas • Fatuberliu • Same • Turiscai	**S2** : Dry Months, Cation Exchange Capacity, Total Nitrogen, P_2O_5, K_2O, Slope Gradient, Erosion Hazard **S3** : Soil Drainage, Effective Depth	**S2** : Dry Months, Soil Drainage, Effective Depth, Slope Gradient, Erosion Hazard
Cinnamon	• Alas • Fatuberliu • Same • Turiscai	**N**: Dry Months **S3 :** Drainage, Slope, Rock Outcrops **S2 :** Temperature, Rainfall, Erosion, Surface Rock	**S3 :** Dry Months **S2 :** Temperature, Surface Rock, Rock Outcrops
Nutmeg Pepper	• Alas • Fatuberliu • Same • Turiscai	**S2** : Dry Months, Cation Exchange Capacity, Total Nitrogen, K_2O, Erosion Hazard **S3** : Effective Depth, Slope Gradient **N** : Rainfall	**S2** : Rainfall, Dry Months, Effective Depth, Slope Gradient, Erosion Hazard
Jatropha	• Alas	**S3** : Rainfall, Effective Depth, Cation Exchange	**S2** : Effective Depth, Slope Gradient, Erosion Hazard

	• Fatuberliu • Same • Turiscai	Capacity, Total Nitrogen, Slope Gradient, Erosion Hazard	
Aromatic Ginger Turmeric Galangal	• Alas • Fatuberliu • Same • Turiscai	**S3** : Effective Depth, Total Nitrogen, Erosion Hazard, Rock Outcrops **N** : Slope Gradient	**S2** : Effective Depth, Slope Gradient, Erosion Hazard
Cardamom	• Alas • Fatuberliu • Same • Turiscai	**S3** : Soil Drainage, Effective Depth, Total Nitrogen, K_2O, Erosion Hazard **N** : Rainfall, Slope Gradient	**S2** : Rainfall, Soil Drainage, Effective Depth, Slope Gradient, Erosion Hazard
Sesame	• Alas • Fatuberliu • Same • Turiscai	**N**: Rainfall, Dry Months, Slope, Flood Hazard **S3 :** Effective Depth **S2 :** Soil Drainage, Surface Rock, Rock Outcrops	**S3 :** Dry Months **S2 :** Rainfall, Dry Months, Slope, Surface Rock, Rock Outcrops, Flood Hazard
INDUSTRIAL COMMODITIES			
Rubber	• Alas • Fatuberliu • Same • Turiscai	**S2** : Temperature, Dry Months, K_2O **S3** : Rainfall, Base Saturation, pH, Total Nitrogen, Surface Rock **N** : Effective Depth	**S2** : Temperature, Dry Months **S3** : Surface Rock, Effective Depth
Coconut	• Alas • Fatuberliu • Same • Turiscai	**S2** : Dry Months, Erosion Hazard **S3** : Total Nitrogen, Slope Gradient, Surface Rock **N** : Effective Depth	**S2** : Dry Months, Slope Gradient, Erosion Hazard **S3** : Effective Depth, Surface Rock

Oil Palm	• Alas • Fatuberliu • Same • Turiscai	**N :** Dry Months **S3 :** Rainfall, Slope, Total Nitrogen, Available Phosphorus, Available Pottasium **S2 :** Erosion, Effective Depth, Rock Outcrops, Surface Rock	**S3 :** Dry Months **S2 :** Rock Outcrops, Surface Rock
Arabica Coffee	• Turiscai	**S2** : Temperature **S3** : Rainfall, Effective Depth, Slope Gradient, Erosion Hazard	**S2** : Temperature, Effective Depth, Slope Gradient, Erosion Hazard
Robusta Coffee	• Alas • Fatuberliu • Same • Turiscai	**S2** : Temperature, Rainfall, P_2O_5, K_2O **S3** : Soil Texture, Effective Depth, pH, Total Nitrogen, Slope Gradient, Erosion Hazard	**S2** : Temperature, Soil Texture, Effective Depth, Slope Gradient, Erosion Hazard
Cacao, Clove	• Alas • Fatuberliu • Same • Turiscai	**S3** : Soil Texture, Total Nitrogen, K_2O, Slope Gradient **N** : Effective Depth, Erosion Hazard	**S2** : Soil Texture, Slope Gradient, Erosion Hazard **S3** : Effective Depth
Tea	• Alas • Fatuberliu • Same • Turiscai	**S2** : Temperature, Rainfall, Rock Outcrops, Surface Rock **S3** : Drainage, Texture, Coarse Fragment, Effective Depth, pH, Total Nitrogen, K_2O **N** : Slope Gradient, Erosion Hazard	**S2** : Temperature, Texture, Coarse Fragment, Effective Depth, Slope Gradient, Erosion Hazard, Rock Outcrops, Surface Rock
Tobacco	• Alas • Fatuberliu • Same • Turiscai	**N :** Rainfall **S3 :** Erosion, Slope, Total Nitrogen,	**S2:** Rock Outcrops, Surface Rock

		Available Phosphorus, Available Pottasium S2: Rock Outcrops, Surface Rock	
Sugarcane	• Alas • Fatuberliu • Same • Turiscai	S3 : Rainfall, Soil Drainage, Effective Depth, Total Nitrogen, K_2O, Slope Gradient, Erosion Hazard	S2 : Soil Drainage, Effective Depth, Slope Gradient, Erosion Hazard
Cashew	• Alas • Fatuberliu • Same • Turiscai	S3 : Soil Drainage, Effective Depth, Total Nitrogen, K_2O	S2 : Soil Drainage, Effective Depth
Melinjo	• Alas • Fatuberliu • Same • Turiscai	S3 : Rainfall, Soil Drainage, Effective Depth, Surface Rock	S2 : Soil Drainage, Effective Depth
Cotton	• Alas • Fatuberliu • Same • Turiscai	S3 : Soil Drainage, Effective Depth, Total Nitrogen, K_2O	S2 : Soil Drainage, Effective Depth
Kapok	• Alas • Fatuberliu • Same • Turiscai	S3 : Rainfall, Soil Texture, Slope Gradient N : Effective Depth, Erosion Hazard	S2 : Soil Texture, Slope Gradient, Erosion Hazard S3 : Effective Depth
Quinine	• Alas • Fatuberliu • Same • Turiscai	S2 : Temperature S3 : Effective Depth, Total Nitrogen, K_2O, Slope Gradient, Erosion Hazard	**S3 :** Temperature **S2 :** Effective Depth, Rock Outcrops, Surface Rock
GRAZING AND FORAGE AREA			
Elephantgrass	• Alas • Fatuberliu • Same • Turiscai	**S3 :** Rainfall, Slope, Erosion **S2 :** Rock Outcrops, Surface Rock, Drainage, pH, Total Nitrogen, Available Phosphorus, Available Pottasium	**S2 :** Rock Outcrops, Surface Rock

Setaria	• Alas • Fatuberliu • Same • Turiscai	**S2 :** Rock Outcrops, Surface Rock, Drainage, Erosion, Slope, pH, Total Nitrogen, Available Phosphorus, Available Pottasium	**S2 :** Rock Outcrops, Surface Rock
Leguminosa	• Alas • Fatuberliu • Same • Turiscai	**N:** Slope **S3 :** Erosion **S2 :** Rock Outcrops, Surface Rock, Drainage, Rainfall, pH, Total Nitrogen, Available Phosphorus, Available Pottasium	**S2 :** Slope, Rock Outcrops, Surface Rock
Grazing	• Alas • Fatuberliu • Same • Turiscai	**N**: Dry Months **S3 :** Rock Outcrops, Slope, pH **S2 :** Surface Rock, Rainfall, Erosion, Total Nitrogen, Available Phosphorus, Available Pottasium	**S3 :** Rock Outcrops, Dry Months **S2 :** Surface Rock

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

VIII. FORESTRY POTENTIAL

8.1 LAND SUITABILITY EVALUATION RESULTS

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

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

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

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

A. Land Suitability Evaluation of Alas Sub-District

Alas Sub-District shows significant potential for the development of forestry plants, as assessed from land suitability and agro-climatic conditions. Based on the evaluation results, several plants can be developed with an S2 (moderately suitable) rating, such as teak, mahogany, agathis, altingia, eucalyptus, melaleuca, pine, and sandalwood, all of which support sustainable natural resource management. The main constraints in the development of forestry plants in Alas Sub-District are **dry months, effective depth, surface rock, and rock outcrops.**

These factors can technically be addressed through planting during the rainy season, adding organic matter, and applying soil conservation techniques, such as ground cover plants. However, there are also limiting factors, such as **surface rocks and rock outcrops, which are permanent and cannot be improved**. Despite this, land management is still possible through methods like surface rock removal and creating planting holes between rock outcrops, which can support efficiency and productivity in plant cultivation. This area has a fairly good land suitability potential to support sustainable agriculture. **In addition to the plants mentioned, other plants that can be developed in Alas Sub-District are presented in Table 8.1.**

B. Land Suitability Evaluation of Fatuberliu Sub-District

Fatuberliu Sub-District has significant potential for forestry development, based on land suitability and its agroclimatic conditions. According to the evaluation results, several trees can be developed, such as sandalwood and melaleuca, which have high economic value, along with teak, mahogany, agathis, altingia, eucalyptus, pine, albizia, and agathis, which were rated as S2 (suitable) for supporting sustainable natural resource management. On the other hand, **albizia, leucaena, and acacia** are not recommended due to highly unsuitable temperature conditions. The main limiting factors for forestry development in Fatuberliu Sub-District are **effective soil depth, surface rocks, and rock outcrops.**

These factors can still be addressed technically through planting during the rainy season, adding organic matter, and applying soil conservation techniques, including ground cover plants. However, there are also limiting factors in the form of **surface rocks and rock outcrops that are permanent and cannot be corrected**. Nevertheless, land management can still be carried out through surface rock clearing methods and creating planting holes between the rock outcrops, which can support the efficiency and productivity of cultivation. This area has fairly good land suitability potential to support sustainable agriculture.

C. Land Suitability Evaluation of Same Sub-District

Same Sub-District shows potential for the development of high-value forestry plants, including **teak, mahogany, sandalwood, and melaleuca** (suitable), which play an important role in supporting sustainable natural resource management. On the other hand, **albizia and acacia** are not recommended due to temperature conditions that are unsuitable for their growth requirements. The main limiting factors for forestry development in this area include **the length of the dry season, limited effective soil depth, and the presence of surface rocks and rock outcrops**. Some of these constraints can still be addressed through technical approaches, such as **planting during the rainy season, adding organic matter, and applying soil conservation techniques with ground cover plants.** However, surface rocks and rock outcrops are permanent factors that cannot be corrected. Nevertheless, land management remains possible through surface rock clearing and creating planting holes between rock outcrops, thus improving land use efficiency and plant productivity. Overall, this area has a fairly good level of land suitability to support the development of sustainable agriculture.

D. Land Suitability Evaluation of Turiscai Sub-District

Turiscai Sub-District has significant potential for the development of forestry plants, as assessed from land suitability and agro-climatic conditions. Based on the evaluation results, several plants can be developed, such as sandalwood (moderately suitable), which was once abundant in this area, and melaleuca (moderately suitable), which has high economic value, as well as teak, mahogany, and agathis (moderately suitable), all of which support sustainable natural resource management. On the other hand, **sengon and leucaena** are not recommended due to highly unsuitable temperature conditions. The main constraints in the development of forestry plants in Turiscai Sub-District are **dry months, effective depth, surface rock, and rock outcrops.**

These factors can technically be addressed through planting during the rainy season, adding organic matter, and applying soil conservation techniques, such as ground cover plants. However, there are also limiting factors, such as **surface rocks and rock outcrops, which are permanent and cannot be improved**.

Despite this, land management is still possible through methods like surface rock removal and creating planting holes between rock outcrops, which can support efficiency and productivity in plant cultivation. This area has a fairly good land suitability potential to support sustainable agriculture.

Tabel 8.1 Land Suitability Evaluation Matrix for Forestry in Manufahi District

Commodities	Sub-District	Limiting Factors	Potential Land Suitability/Improvement Efforts
FORESTRY COMMODITIES			
Teak	• Alas • Fatuberliu • Same • Turiscai	**N :** Effective Depth	**S2 :** Effective Depth
Mahogany	• Alas • Fatuberliu • Same • Turiscai	**N :** Effective Depth	**S2 :** Effective Depth
Agathis	• Alas • Fatuberliu • Same • Turiscai	**S2** : Temperature, Surface Rock **N** : Rainfall, Effective Depth	**S2** : Temperature, Rainfall, Effective Depth, Surface Rock
Altingia	• Alas • Fatuberliu • Same • Turiscai	**S3 :** Effective Depth	**S2 :** Dry Months, Effective Depth
Sengon	• Alas • Fatuberliu • Same • Turiscai	**N** : Temperature, Effective Depth, Surface Rock	**S3** : Effective Depth **N** : Temperature, Surface Rock
Leucaena	• Alas • Fatuberliu • Same • Turiscai	**N** : Temperature, Effective Depth, Surface Rock	**S3** : Effective Depth **N** : Temperature, Surface Rock
Acacia	• Alas • Fatuberliu • Same • Turiscai	**N** : Temperature, Effective Depth, Surface Rock	**S3** : Effective Depth **N** : Temperature, Surface Rock
Eucalyptus	• Alas • Fatuberliu • Same • Turiscai	**S2** : Dry Months, Effective Depth, Surface Rock, Rock Outcrops	**S2** : Dry Months, Rock Outcrops

Melaleuca	• Alas • Fatuberliu • Same • Turiscai	**S3** : Drainage, Slope Gradient, Erosion Hazard **N** : Effective Depth	**S2** : Effective Depth, Slope Gradient, Erosion Hazard
Pine	• Alas • Fatuberliu • Same • Turiscai	**N** : Rainfall	**S2** : Rainfall
Sandalwood	• Alas • Fatuberliu • Same • Turiscai	**S3 :** Drainage, Total Nitrogen, Available Phosphorus, Total Pottasium **S2 :** Effective Depth, Surface Rock, Rock Outcrops	**S2 :** Rock Outcrops, Effective Depth, Surface Rock

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

8.2 LAND IMPROVEMENT EFFORTS

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

On the other hand, soil chemical parameters, such as low organic carbon content and essential macro-nutrients (N, P, K), further degrade soil fertility. The poor chemical quality of the soil not only limits plant productivity but also impacts the efficiency of forestry inputs, leading to increased production costs and disrupting the sustainability of cultivation systems. The recommended improvement efforts for each limiting factor serve as the basis for implementing suitability enhancement.

8.3 FORESTRY PLANT DEVELOPMENT ZONING

The research results indicate that Manufahi District has significant land resource potential to support the development of the forestry sector.

Manufahi District has forestry development potential, which is divided into several main categories, including agroforestry with an area of 340.00 km^2

(25.70%), protected forests covering 335.68 km² (25.37%), and mangroves covering 7.35 km² (0.56%). With structured and sustainable management efforts, the large potential in this area can be optimized through synergy between the government, policymakers, and local communities, ensuring that the benefits are shared by all parties. The area suitable for commodity development is presented in **Figure 7.1** (**Chapter VII**), which illustrates the spatial distribution of the development area percentage per Sub-District in Manufahi District.

A. Agroforestry

The agroforestry system is spread across several Sub-Districts, with the largest proportion in Fatuberliu (10.29%), followed by Alas (9.02%), Same (4.18%), and Turiscai (2.21%). The differences in distribution reflect variations in biophysical suitability, access to resources, and land use intensity. The commodities cultivated include food crops, fruits, and forestry plants such as corn, cassava, papaya, cowpea, upland rice, coconut, pine, betel nut, pineapple, teak, acacia, leucaena, tobacco, mahogany, sandalwood, mango, and banana. The planting system, which combines 70% forestry vegetation and 30% agricultural crops, has proven effective in reducing slope length and the value of cover factors, maintaining soil moisture, and stabilizing base flow to support irrigation in the downstream areas. The integration of these various plants not only strengthens the economic resilience of local communities but also contributes to soil conservation, increased vegetation cover, and ecosystem stabilization.

The development of coffee cultivation in Manufahi District has been prioritized due to its high economic value. In this agroforestry zone, coffee plants are often found alongside forestry plants as shade. The recommended coffee varieties are Robusta and Arabica, as the agro-climatic conditions, especially elevation and temperature, support optimal growth, such as the development of Robusta coffee in Alas Sub-District, Fatuberliu Sub-District, Same Sub-District, and Turiscai Sub-District, which generally have elevations of 700 meters above sea level, and Turiscai Sub-District, which has potential for Arabica coffee development at elevations >1100 meters. In the recommended Sub-Districts, land suitability is marginal, with the primary limiting factor being the dry months. Therefore, the solution is to plant according to the rainy season.

Thus, the development of coffee commodities in this region is more advisable to focus on Robusta and Arabica varieties, which are more adaptable to local conditions. However, the development of Arabica coffee requires additional technical interventions such as selecting cooler microclimate locations, using tolerant varieties, and applying proper shading and soil conservation systems. This approach aims to minimize the risk of cultivation failure and optimize land potential sustainably.

B. Protected Forests and Conservation

The protected forest area in Manufahi District covers an area of 335.68 km², or 25.37% of the total area. Generally, protected forests are located in the mountains and upstream areas with slopes greater than 30% and high elevations. This zone is designated as a non-conversion area due to its function as an erosion buffer, infiltration regulator, and sediment controller, which are vital for the sustainability of lowland irrigation systems. The largest distribution of protected forests is found in Turiscai Sub-District, covering 10.66%, followed by Fatuberliu Sub-District (6.95%), Same Sub-District (6.67%), and Alas Sub-District (1.09%).

There are several protected areas (AP) in Manufahi District with varying sizes. These areas play an important role in maintaining ecosystem balance, conserving biodiversity, and supporting the ecological and social functions of the surrounding communities. The protected areas include AP Ribeira de Clere, which covers 5603.68 ha (34.12%), Area Protegida Lagoa Modomahut with 4045.95 ha (24.63%), PN Kay Rala Xanana Gusmao with 3878.33 ha (23.61%), AP Lagoa Welenas with 2253.02 ha (13.72%), and AP Monte Diatuto with 644.86 ha (3.93%). Detailed information is presented in Figure 8.1.

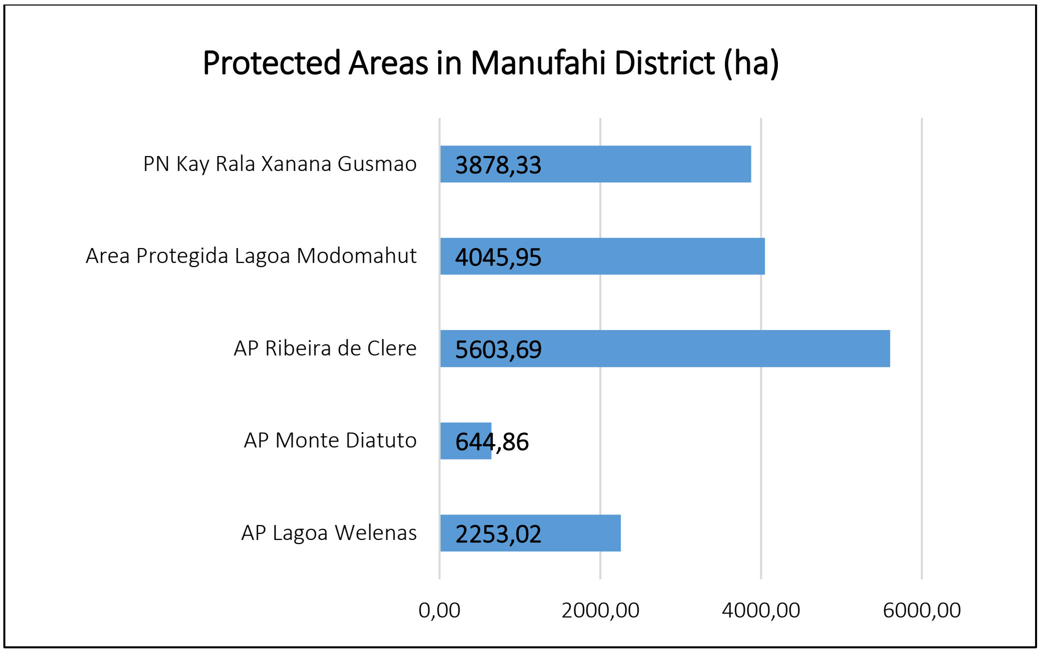


Figure 8.1 Protected Areas in Manufahi District

C. Mangrove Forest

In the coastal area, the mangrove ecosystem occupies the estuarine zone with low elevation and high salinity levels. Mangroves function as blue carbon absorbers, wave breakers, flood control mechanisms, and vital habitats for fishery resources. All interventions in the coastal area designate mangroves as a permanent conservation zone that cannot be converted, to maintain ecological stability and coastal resilience sustainably. In Manufahi District, the mangrove forest zone covers only 652.76 ha or 0.49% (Fatuberliu), 58.19 ha or 0.04% (Same), and 23.85 ha or 0.02% (Alas).

8.4 POTENTIAL FOR SANDALWOOD PLANT DEVELOPMENT

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

From an economic perspective, sandalwood has significant prospects as a long-term source of income. The price of sandalwood wood and oil in international markets is relatively high, making it a potential contributor to improving the welfare of local communities and regional income. Furthermore, sandalwood development can encourage rural economic diversification, expand employment opportunities, and enhance regional competitiveness through the use of local resources. In addition to its economic benefits, sandalwood also plays a role in environmental conservation, such as through soil conservation, erosion prevention, and improving land cover quality.

Specifically, in Manufahi District, there are several Sub-Districts that have the potential for sandalwood development, including Alas Sub-District, Fatuberliu Sub-District, Same Sub-District, and Turiscai Sub-District. These four areas have biophysical conditions suitable for sandalwood growth, in terms of climate, soil type, and topography. The presence of sandalwood in these Sub-Districts is a valuable foundation for further development efforts. With planned management, community participation, and support from local government policies, Manufahi District has the potential to become one of the centers for sustainable and highly competitive sandalwood development at both the national and regional levels.

Based on the land suitability evaluation for sandalwood development in Manufahi District, the land suitability ranges from S2 (moderately suitable) to S3 (marginally suitable), with limiting factors including effective depth, rock outcrops, surface rocks, and slope. Improvements that can be made include surface rock removal and its use as rock terraces or soil-retaining walls, planting sandalwood in sufficiently deep soil gaps, and using organic mulch and host plants tolerant to rocky conditions to support sandalwood growth.

On sloping land, the application of soil and water conservation techniques such as terracing, bundling, or rorak is essential to reduce erosion, along with planting ground cover vegetation and planting along contours. In addition, an additional strategy would involve selecting planting locations with adequate soil depth, managing water through reservoirs or infiltration wells, and applying agroforestry systems with food crops or shade trees to help increase land productivity while improving environmental conditions for sandalwood growth.

IX. LIVESTOCK POTENTIAL

9.1 INTRODUCTION

Timor-Leste is a country whose majority of the territory consists of mountains and highlands. Administratively, Timor-Leste is divided into 14 Districts: Ainaro, Aileu, Autoridade Administrativa Ataúro, Bobonaro, Baucau, Covalima, Dili, Ermera, Lautém, Liquiçá, Manufahi, Manatuto, Região Administrativa Especial Oe-Cusse Ambeno (RAEOA), and Viqueque. The country experiences two seasons: the dry season from June to November, and the rainy season from December to May. The topography, dominated by hills, combined with its proximity to the Australian continent, causes Timor-Leste to be influenced by the dry east monsoon winds. As a result, some regions tend to experience drought. Additionally, the low rainfall affects the growth of vegetation across various regions of the country.

The hilly topography and low rainfall not only affect vegetation growth and agricultural life but also impact the availability of forage for the livestock sector. The development of the livestock sector is highly dependent on land resource potential, the accuracy of land use, and management methods. These factors are crucial in the provision of livestock forage, which generally consists of grasses and legume.

Livestock forage can come from both natural sources and cultivated products, including grazing fields (Priyanto, 2016). Optimal use of livestock land is highly influenced by anthropogenic factors and the biophysical conditions of the land. Therefore, the implementation of various technological innovations and institutional improvements needs to be pursued so that land resources can be used effectively and optimally (Suryana and Rahman, 2006).

In general, the livestock sector in Timor-Leste faces various obstacles. One of the main causes is the traditional and extensive livestock management system, which results in suboptimal production. The low level of awareness, knowledge, and technological mastery among farmers is also a limiting factor, particularly in terms of providing livestock forage, both in terms of type and quality. Livestock is generally kept as a household savings asset that can be sold at any time for emergency needs. Additionally, some communities still use livestock as labor for land cultivation with a traditional management system.

The success of livestock enterprises is closely linked to three main factors: breeding, feed, and management (Aman *et al.,* 2019). These three factors form an integrated system that is interrelated: if one of them is neglected or receives insufficient attention, the management of the other factors, even if excellent, will not yield optimal results. Livestock productivity, particularly ruminants, heavily depends on effective feed management, in terms of both quantity, quality, and sustainable availability (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 livestock health. The quality of livestock forage is influenced by the variety of forage, genotype, harvest maturity, season, and management practices (Adesogan *et al.,* 2015).

One of the initial steps that can be pursued in the development of the livestock sector in Timor-Leste is the optimization of land use for the sustainable provision of livestock forage. For this land utilization, it is necessary to ensure compatibility between the land characteristics and the types of forage to be cultivated. Therefore, land suitability evaluation is an essential approach to assess 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 information for a given area. This assessment is carried out by identifying various land characteristics, such as topography, climate, soil conditions and quality, as well as other physical environmental properties (Iswan *et al.,* 2019). Through this evaluation process, information regarding bio-physical land resources, including climate and soil, is obtained, allowing for the determination of land suitability classes and the identification of limiting factors that need to be improved (Jawang *et al.,* 2018).

9.2 RESEARCH METHODS

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

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

A. Research Procedure

1. Observation of Livestock Production and Socio-Economic Aspects

Observations were conducted using interview techniques with the following parameters:

1) Livestock types
2) Livestock population
3) Land area
4) Husbandry/breeding systems
5) Feed and nutrition management systems
6) Water sources
7) Breeding system
8) Livestock health management system
9) Livestock products
10) Marketing
11) Infrastructure
12) Farmer characteristics

13) Customs/traditions

2. **Forage Land Suitability for Livestock**

The procedure for evaluating the suitability of land for livestock forage has been described in **Chapter III** (Research Methods).

9.3 GENERAL DESCRIPTION

A. General Existing Conditions

The livestock sector plays an important role in supporting the livelihoods of many households in Manufahi District. The distribution of households engaged in livestock shows significant differences across each Sub-District. Same Sub-District has the highest number of households involved in livestock, reaching 474 households (80.34%). In contrast, Turiscai Sub-District has the fewest households involved in livestock, with only 24 households (4.07%).

Nevertheless, their contribution remains significant in meeting local needs while preserving the livestock traditions that have become an integral part of local life. With these differences, each Sub-District makes its own contribution to the sustainability of the livestock sector in Manufahi. The number of agricultural households involved in the livestock sector is presented in **Figure 8.1.**

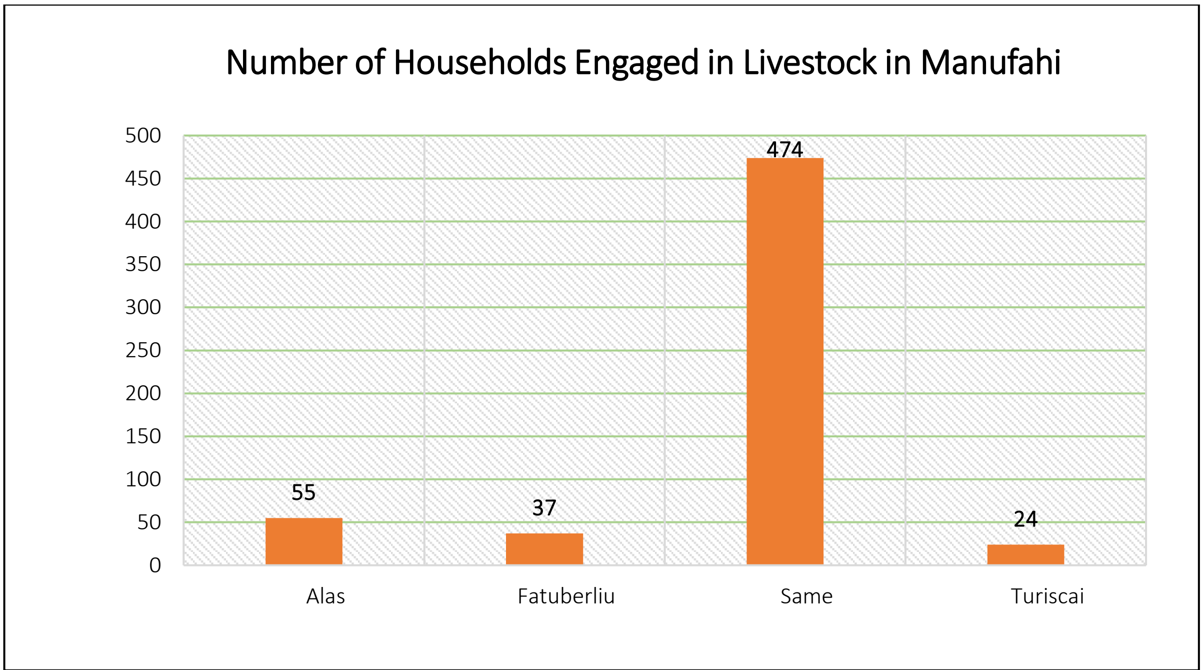


Figure 9.1 Number of Households Engaged in Livestock
(Source: Timor-Leste Agriculture Census, 2019)

Based on **Figures 9.2 and 9.3**, the majority of livestock in Manufahi District are cattle. Same Sub-District has the highest number of cattle-keeping households, reaching 1,440 households (49.47%) with a total cattle population of 5,829 heads. In contrast, Turiscai Sub-District has the smallest number of cattle-keeping households, with 303 households (10.41%) and a population of 1,014 heads.

The largest number of horse-keeping households is found in Turiscai Sub-District, with 501 households (36.38%) and a population of 1,030 heads. Conversely, the lowest number of horse-keeping households is found in Alas Sub-District, with 156 households (11.33%) and a population of 423 heads.

For buffalo, Alas Sub-District shows dominance in buffalo-keeping with 369 households (30.75%) and a population of 2,330 heads. Conversely, the lowest number of buffalo-keeping households is found in Fatuberliu Sub-District, with 28 households (3%) and a population of 1,617 heads. Meanwhile, dairy cattle are only kept by households in Turiscai Sub-District, although in very small numbers, with only 2 households (100%).

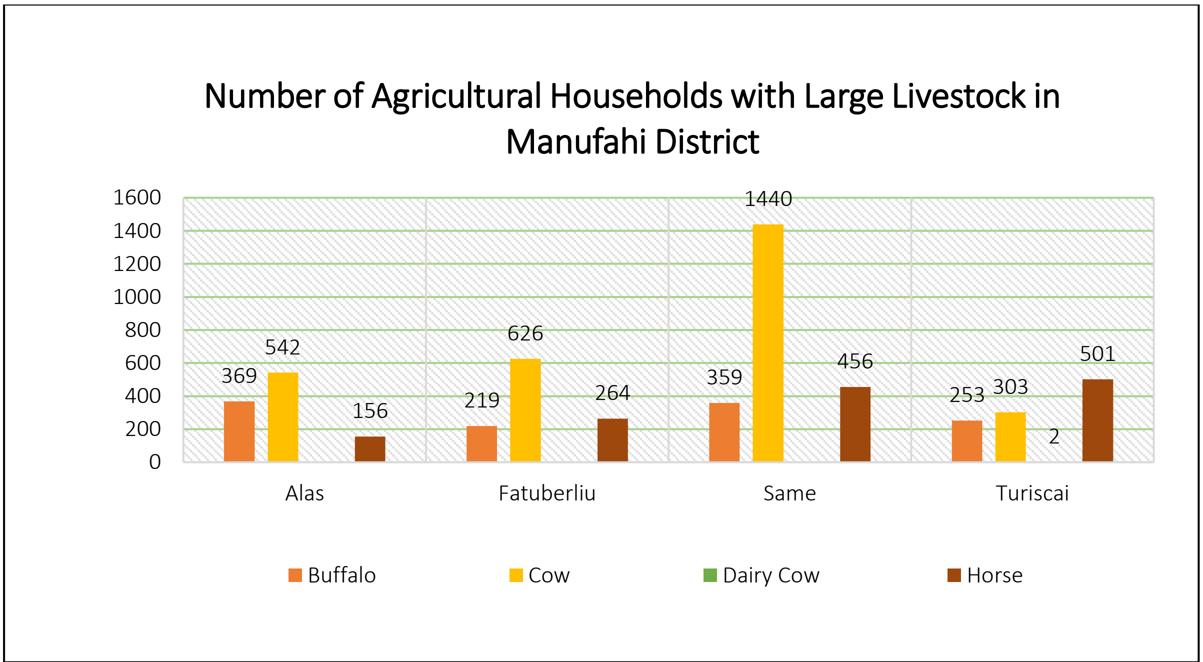


Figure 9.2 Number of Agricultural Households with Large Livestock in Manufahi District (Source: Timor-Leste Agriculture Census, 2019)

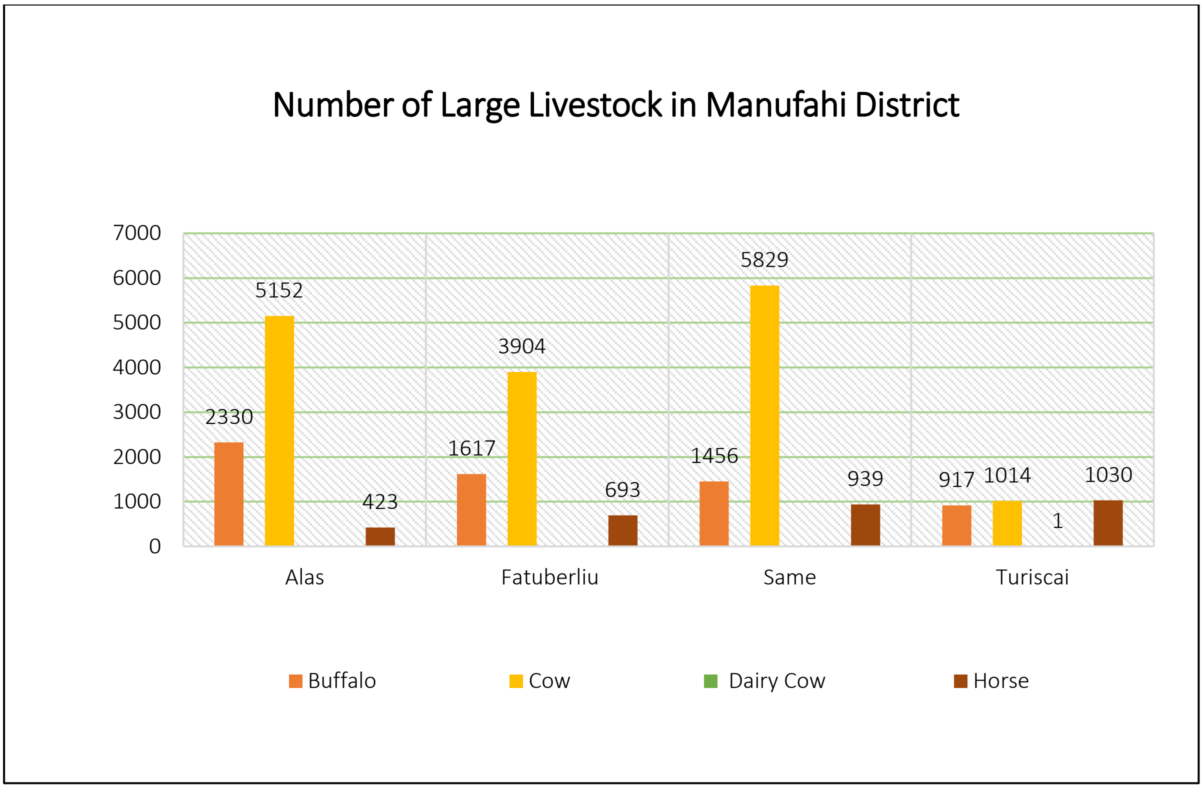


Figure 9.3 Number of Large Livestock in Manufahi District
(Source: Timor-Leste Agriculture Census, 2019)

Pigs are the most commonly kept small livestock in Manufahi District. Same Sub-District has the highest number of pig-keeping households, with 2,923 households (56.25%) and a population of 10,937 pigs. In contrast, Turiscai Sub-District has the lowest number, with 668 households (12.86%) and a population of 1,484 pigs **(Figures 9.4 and 9.5).**

The number of households keeping goats shows a varied distribution. Same Sub-District has the highest number of goat-keeping households, with 540 households (46.31%) and a population of 1,968 goats, while the fewest goat-keeping households are found in Alas Sub-District, with 114 households (9.78%) and a population of 570 goats.

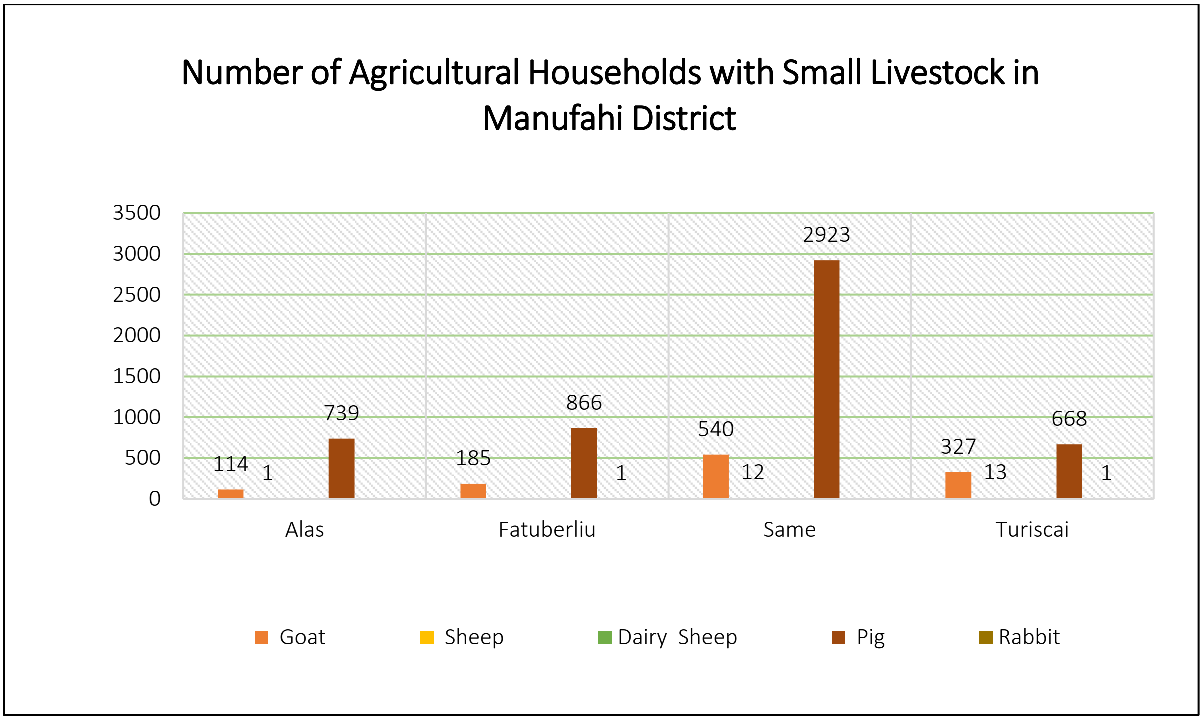


Figure 9.4 Number of Agricultural Households with Small Livestock in Manufahi District (Source: Timor-Leste Agriculture Census, 2019)

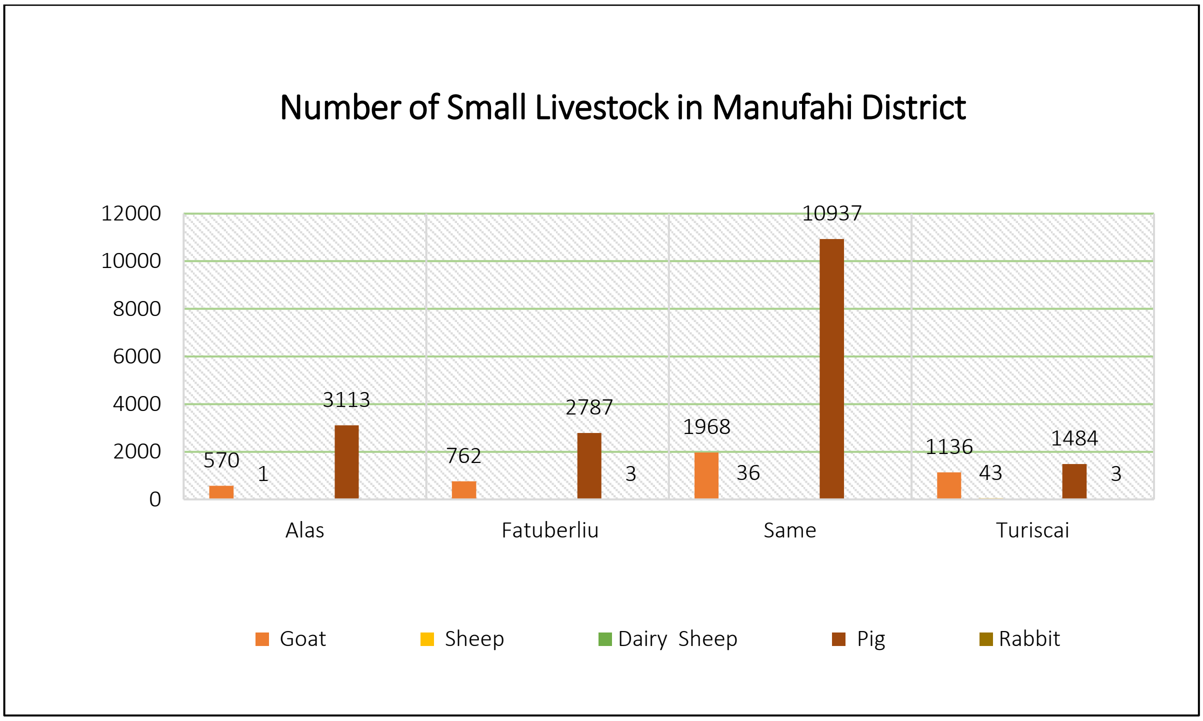


Figure 9.5 Number of Small Livestock in Manufahi District (Source: Timor-Leste Agriculture Census, 2019)

The number of households keeping poultry in Manufahi District shows significant differences between Sub-Districts, with chickens being the most commonly kept poultry. Same Sub-District has the highest number of chicken-keeping households, with 3,184 households, or about 54.37%, and a population of 33,849 chickens. Meanwhile, Turiscai Sub-District has the lowest number of chicken-keeping households, with 742 households, or 12.67%, and a population of 5,041 chickens **(Figures 9.6 and 9.7).**

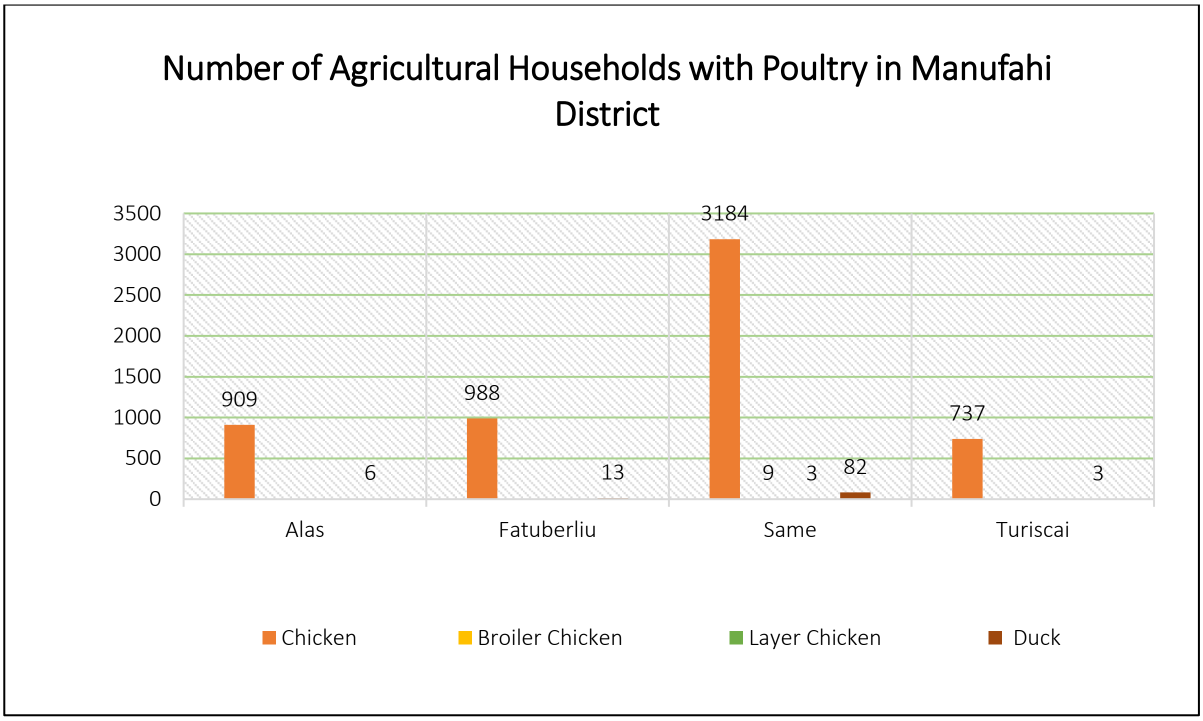


Figure 9.6 Number of Agricultural Households with Poultry in Manufahi District
(Source: Timor-Leste Agriculture Census, 2019)

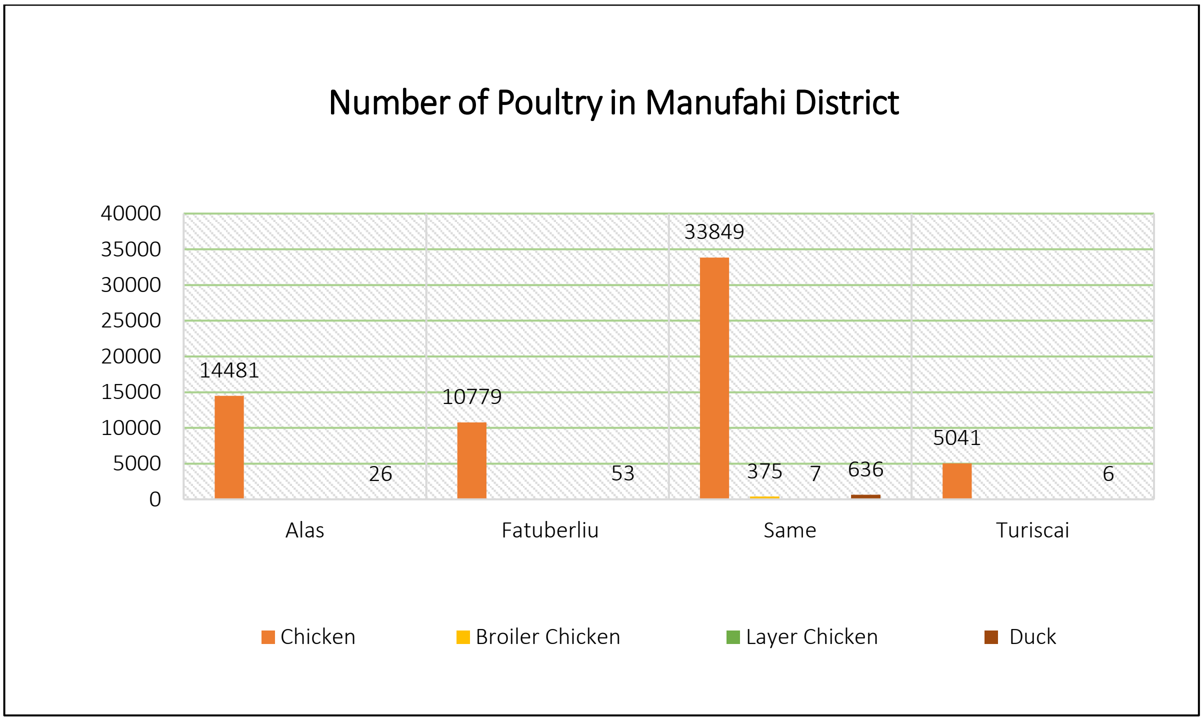


Figure 9.7 Number of Poultry in Manufahi District
(Source: Timor-Leste Agriculture Census, 2019)

The potential of grazing fields is an important asset that can serve as a primary source of livestock feed, especially for animals such as cattle, goats, and sheep that require high-quality grass to support growth and production in sustainable livestock farming. Manufahi District has two types of grazing fields: temporary and permanent grazing fields.

Turiscai Sub-District has the largest permanent grazing field area, covering 27.05 ha (66.62%). Based on this data, Turiscai Sub-District has a significant advantage in permanent land area, making it the Sub-District with the largest grazing land dominance compared to other Sub-Districts. This indicates great potential for permanent grazing in the area. Meanwhile, Same Sub-District has the largest temporary grazing field area, measuring 8.25 ha (50.37%). Alas Sub-District does not have any temporary grazing land and only has 0.05 ha of permanent grazing land, which is the lowest among all Sub-Districts. The grazing land area is presented in **Figure 9.8.**

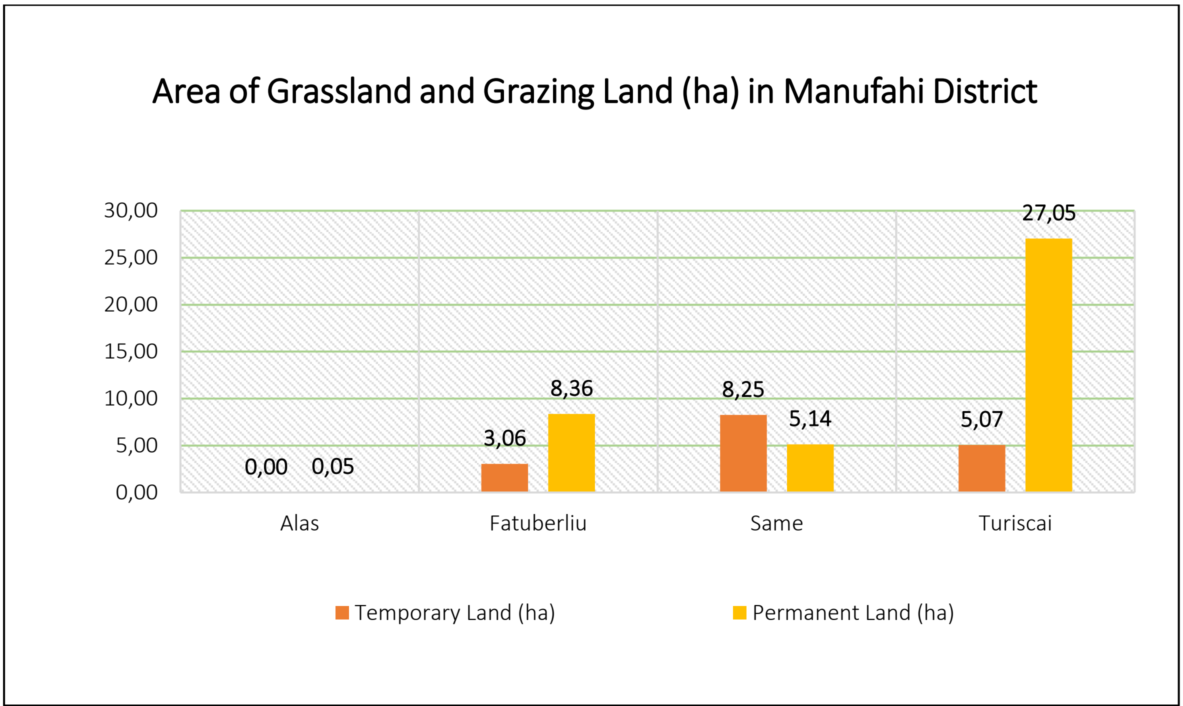


Figure 9.8 Area of Grassland and Grazing Land (ha) in Manufahi District
(Source: Timor-Leste Agriculture Census, 2019)

B. Existing Conditions of the Survey Location

The Karau Timor Susubeen (KTS) Dotik Center is the first center established, with a total land area of 30 ha. Various types of livestock have been cultivated at this location, including goats, buffalo, Bali cattle, local chickens, ducks, and geese. Basic infrastructure, such as guesthouses, employee housing, and a training center, is available, although still under development. Of the total land area, approximately 6 ha has been utilized for planting livestock forage (HPT), including gamal, leucaena, and elephant grass. However, observations indicate that the productivity of the forage is still relatively low, which is suspected to be due to suboptimal soil conditions, especially during the dry and rainy seasons. Therefore, the application of soil conservation technology, the selection of forage varieties that are resistant to environmental stress, and the implementation of rotational systems and land management that adapt to extreme climate conditions are necessary.

Figure 9.9 Existing Conditions of the Survey Location in Manufahi
(Source: Researcher Documentation, 2025)

In the Babulu and Betano areas, 3 ha of land have been utilized for horticultural crop cultivation, particularly corn and legumes. Currently, the development of livestock forage is being planned as part of the integration of agricultural and livestock systems. Leucaena taramba has started to be cultivated as one of the forage sources, but other forages such as king grass have not yet been planted. Further development is needed to ensure the sustainable availability of feed to support the livestock sector in the area.

9.4 DISCUSSION

A. Land Suitability Evaluation for Livestock Forage

Land suitability analysis for livestock forage in Manufahi District is a method used to evaluate the suitability of various types of livestock forage and grasses for grazing fields in a particular area. The purpose of this analysis is to facilitate the development of livestock feed resources while ensuring their optimal availability. According to Djaenudin *et al*. (2003), land suitability is defined as the degree to which land is appropriate for a specific use. Land suitability can be assessed based on current conditions (actual land suitability) or after improvements (potential land suitability). The land suitability evaluation in Timor-Leste is conducted using a matching method, comparing land characteristics and quality data with suitability criteria based on the growth requirements of the plants being evaluated. Several types of livestock forage commodities mapped according to land resource potential include elephant grass (*Pennisetum purpureum*), legumes, and pasture grasses.

The results of the land suitability evaluation for Manufahi District's Sub-Districts of Alas, Fatuberliu, Same, and Turiscai show potential for the development of livestock forage, including elephant grass, Setaria, legumes, and grazing fields, as presented in **Table 7.5** of this book. The table shows that, in terms of actual land suitability, grazing land varies significantly, ranging from S2 (moderately suitable) to N (not suitable), with limiting factors including rainfall, effective depth, pH, total nitrogen, available potassium, slope, and erosion. Additionally, there is a limiting factor of dry months for grazing. These factors can still be addressed through technical improvements, such as crop pattern management, planting hole creation, the addition of ZA/Urea and Potassium fertilizers, adding organic matter, planting support plants for terraces, creating terraces, and establishing irrigation systems such as sprinklers. Furthermore, temperature is a limiting factor for legumes that is permanent and cannot be improved.

In order to improve livestock development, particularly livestock forage in Manufahi District, there are several important steps that need to be taken to enhance the quantity and quality of forage, namely:

1. Planting Legume Forages

Planting legume forages is a priority, as legumes generally have higher nutritional content compared to grasses. However, since legumes have limitations in their use, attention must be given to the proportion of legumes in relation to grasses. As a reference, Susetyo (1980) recommends that the ideal composition for grazing fields consists of 60% grasses and 40% legumes. Furthermore, according to Skerman (1977), legume species also play a role in controlling erosion, even more effectively than forests, due to their strong and deep root systems.

2. Increasing Forage Species Diversity, Including Legumes and Grasses

Increasing the diversity of forage species, both legumes and grasses, is an important aspect of livestock feed development. The greater the diversity of forage species consumed by livestock, particularly ruminants, the higher the likelihood of meeting their complete nutritional needs. Some legume species with high nutritional content that have potential for development include Indigofera, Kaliandra, Turi, and Stylo. A commonly found local legume species is Leucaena taramba. It is important to be cautious when providing Leucaena to pregnant livestock. Although it has high nutritional content, Leucaena leaves contain anti-nutritional substances such as mimosine and cyanogenic acid, which are toxic when consumed in excess. This can be mitigated by giving Leucaena in moderate amounts, mixed with other feed, and ensuring that it is provided in a wilted (air-dried) form so that the anti-nutritional content can be reduced.

B. Livestock Ecological Potential and Suitability

Manufahi District has a total area of 132,110.49 ha, with 58,312.16 ha designated for livestock sector development. The potential of this land must be utilized optimally through human resource empowerment and the use of available land. One important factor in determining the potential of a region for livestock development is the ecological suitability or environmental conditions of the area. Areas that do not meet the ecological suitability indicators are categorized as less potential for livestock development. Therefore, livestock development in Manufahi District must consider ecological suitability aspects.

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

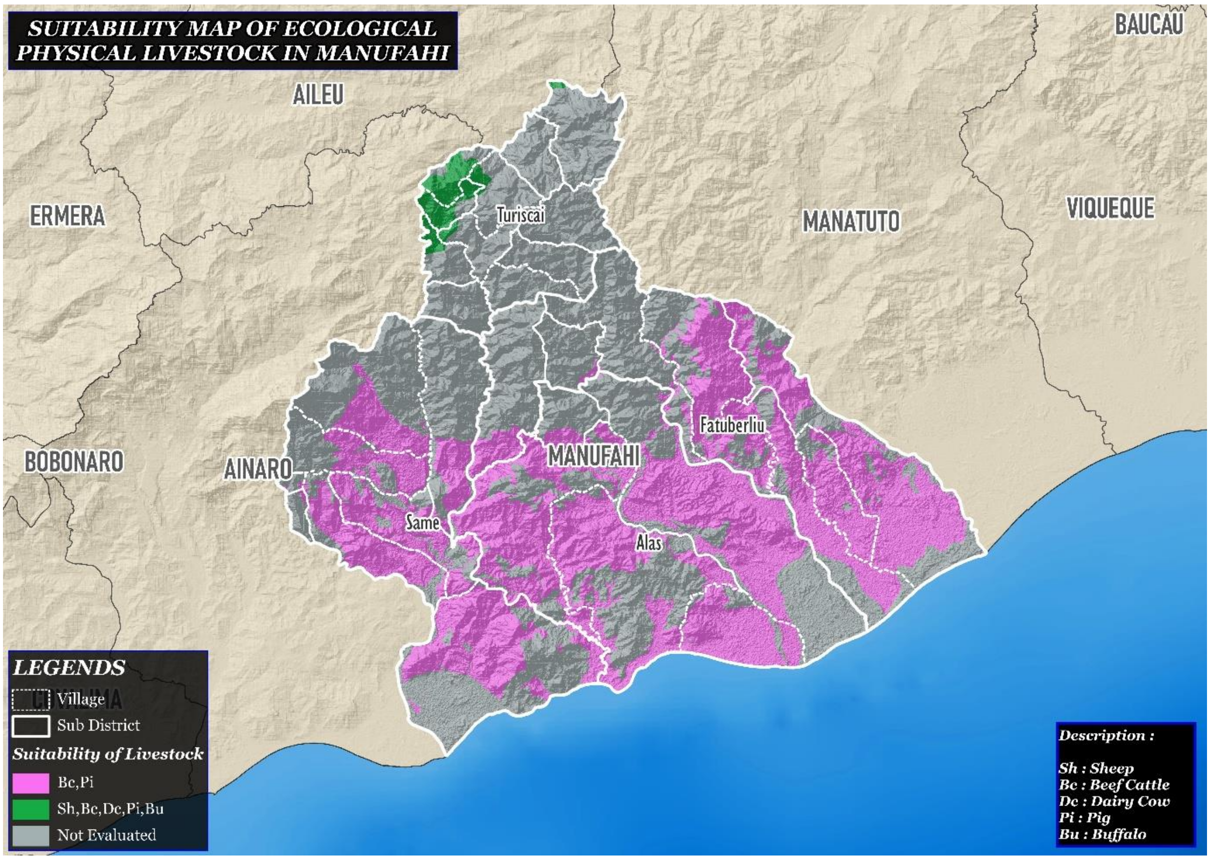


Figure 9.10 Map of Ecological Physical Suitability for Livestock in Manufahi District

The available land for livestock development in Manufahi District consists of areas designated for mixed plantations and grazing fields. These lands are categorized as available because they are assumed to be capable of producing livestock forage, including grasses, legumes, and agricultural crop residues. On the other hand, lands categorized as not available for livestock development include those designated for forests and rice fields. Technically, this factor can be addressed through proper housing systems that provide good air circulation and ventilation. However, for dairy cattle, temperature is a critical factor that must be met for successful cultivation.

Tabel 9.1 Livestock Development Area in Manufahi District

Sub-District	Livestock Development Suitability Results					Area (ha)
	Sheep	Beef Cattle	Dairy Cattle	Pigs	Buffalo	
Alas	N	S	N	S	N	23.938,17
Fatuberliu	N	S	N	S	N	17.070,38
Same	N	S	N	S	N	15.484,43
Turiscai	N	S	S	S	S	1.819,18

Based on the data analysis presented in **Table 9.1**, Turiscai Sub-District shows a high level of suitability for the development of beef cattle, dairy cattle, pigs, and buffalo. The biophysical conditions of this area, particularly temperature and rainfall, are within the optimal range that supports the growth and productivity of these four types of livestock. However, the land suitability for sheep development in Turiscai Sub-District is considered low, due to limitations in climate factors, especially temperature and rainfall, which do not meet the ecological requirements for sheep. Meanwhile, Alas Sub-District, Fatuberliu Sub-District, and Same Sub-District show suitability only for the development of beef cattle and pigs. The unsuitability for developing sheep, dairy cattle, and buffalo in these three Sub-Districts is due to the temperature and rainfall conditions that do not optimally support livestock growth and productivity.

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

To support the livestock development program, it is necessary to identify and map areas that serve primarily as livestock farming locations and forage cultivation sites. It is known that Manufahi District has an average environmental temperature of about 24.35°C with annual rainfall of 1,968.21 mm, which provides an ecological potential conducive to supporting optimal livestock farming sustainability. This condition also supports the availability of sustainable livestock forage throughout the year. Environmental temperature plays a central role in determining thermal comfort and livestock productivity. If the environmental temperature is too low, it can cause cold stress in livestock, triggering an increase in body heat production and basal metabolic rate. If this condition persists without adequate feed support, the livestock's metabolic energy will decrease, thus reducing their resistance to extreme temperatures. This impacts the growth of livestock, lowers productivity, and significantly increases the risk of disease outbreaks.

On the other hand, if the environmental temperature is too high, livestock will reduce their feed intake and instead increase their water consumption. This reduction in nutrient intake directly impacts livestock performance. Therefore, optimal environmental management, particularly proper temperature and humidity regulation, is a crucial prerequisite for sustainable livestock farming systems. These efforts aim to create conditions that support the physiological balance of livestock, ensuring that productivity can be maximized.

C. Social and Economic Aspects of Livestock Farming in the Community

For the people of Manufahi District, livestock plays a very important and multifunctional role, far beyond just being a food source. Livestock has become an integral part of the subsistence farming system and the evolving civilization. It is still common for people to use livestock, such as cattle, buffalo, and horses, as draft animals for plowing fields. The use of draft animals allows farmers to cultivate larger areas of land and significantly increase agricultural productivity. Furthermore, in some cultures, livestock also has social, economic, or ritual significance. For example, in some cultures, livestock is used as a dowry or offering during ceremonies. Additionally, the number of livestock owned by a person is often seen as a measure of wealth and social status within the community.

One endemic type of livestock in Timor-Leste is the Timor buffalo (*karaw timor*). The Timor buffalo holds an important role in the social life of Timor-Leste, especially as an offering during funeral, birth, and marriage ceremonies. The Timor buffalo is also used in traditional transactions such as land sales, its manure is used as fertilizer for crops, and in past traditions, people consumed buffalo milk as a source of animal protein. It is no surprise that Timor buffaloes are highly valued.

Buffalo milk has been consumed by the community since ancient times and is one of the most popular types of milk, along with cow and goat milk. Buffalo milk is thicker and has a distinct aroma compared to cow milk. In the past, the community would consume Timor buffalo milk directly without further processing, making buffalo milk a symbol of cultural identity.

Livestock farming is generally still carried out with a traditional free-range grazing system, also known as an extensive system. According to Williamson and Payne (1993), in the extensive management system, livestock are kept freely and graze on natural forage. In this system, animals are left to roam with a mix of males and females within a population. The main characteristic of this extensive system is that there are no barns and no supplemental feed provided (Jamili, M. A., 2022). The advantages of the extensive management system include minimal labor, short working hours, and livestock's ability to graze on pasturelands and former agricultural fields. However, the challenges faced by livestock include difficulty in controlling their nutritional feed intake and vulnerability to diseases and deaths. Livestock that is allowed to roam without supervision also leads to social problems, such as livestock theft and damage to farmers' fields.

Livestock farming practices still rely heavily on local knowledge passed down through generations. The absence of large-scale livestock industries has resulted in suboptimal production levels, with many aspects still needing improvement. Livestock distribution in the community is relatively low due to limited capital and poor breeding practices. This is because increasing livestock numbers requires substantial costs and a long period of time. Therefore, the community does not consider livestock as a primary income source, which contributes to the low livestock production in the area (Serey *et al.,* 2014).

From interviews, it is known that the community received cattle and buffalo assistance in 2014 from MAPPF. However, over time, due to low oversight and insufficient community education, the assistance has not developed as initially intended. The community used the livestock for household needs or as dowry (belis). As a result, attention to the sustainability of livestock breeding has been neglected, which could potentially hinder long-term development.

Another significant challenge faced by livestock farming is complex, ranging from pre-production to post-production, along with the need for better infrastructure. In terms of breeding, the community still applies a natural breeding system without the use of artificial insemination (AI) technology, making breeding for sustainability difficult. Additionally, the community lacks knowledge of good livestock management practices and is not educated about the best feed for optimal productivity. From a marketing perspective, livestock farmers are only able to sell live animals, making it difficult to increase the selling price of livestock products. Although access from Dili to other districts has improved, infrastructure such as roads is still inadequate. This remains a barrier for the community in marketing their livestock products to broader markets.

Given the many challenges faced from pre-production to post-production, it is crucial to address these issues to form the basis for designing a master plan for livestock development. Recommended improvements include educating the community on breeding practices and introducing AI technology. Additionally, education on the importance of livestock management is necessary to motivate the community to shift towards an economically-driven approach to livestock farming, rather than just as a family savings mechanism. The government should not only focus on educating but also provide financial support in the form of credit loans to help smooth the operations of livestock businesses. Increasing the marketability of livestock products can be achieved by educating the community and opening new marketing channels for livestock, which should not be limited to selling live animals.

X. FRESHWATER FISHERIES POTENTIAL

10.1 INTRODUCTION

Manufahi District is one of the administrative regions in Timor-Leste with considerable potential for the development of freshwater aquaculture. The biophysical conditions of this area, including variations in topography, soil characteristics, water quality, and climate, provide significant opportunities for communities in lowland and coastal areas to develop fisheries enterprises. This potential not only supports food security but also creates opportunities for sustainable enhancement of the local economy.

To ensure the success of aquaculture enterprises, a comprehensive land suitability assessment is required. Site selection is a primary factor because each fish species has different tolerances to environmental conditions. Analysis of topographic and hydrological aspects, soil conditions, water quality, and climate constitutes an essential initial step to ensure that aquaculture activities can operate effectively and in accordance with land carrying capacity.

This study employed an evaluation matrix that assigned weights to each factor according to its level of importance. Through this approach, clear data-based recommendations regarding land suitability in Manufahi District are expected to be obtained. The results of this assessment can serve as a reference for both local government and communities in planning and developing efficient and sustainable freshwater aquaculture production systems.

In addition to technical aspects, this study also emphasized the importance of local policies, community participation, and customary values in water resource management. The integration of biophysical analysis with sociocultural aspects is expected to produce recommendations that are applicable and acceptable to the community. Accordingly, freshwater aquaculture in Manufahi District can be developed optimally to support food security, strengthen the local economy, and promote sustainable development in Timor-Leste.

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**.

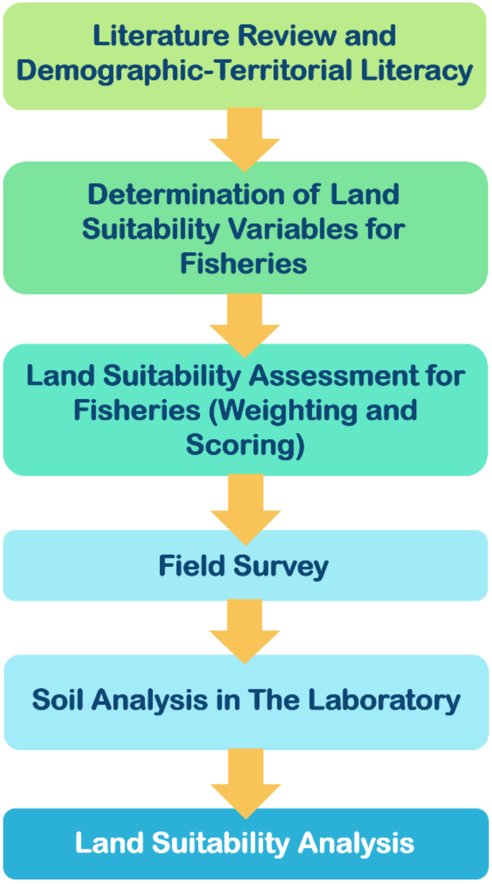


Figure 10.1 Flowchart of the research process for land suitability in the aquaculture sector

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 average condition of weather over a long period is known as climate. An important climatic element for pond aquaculture is rainfall. Rainfall of 2,000 to 3,000 mm/year with 2 to 3 dry months is considered suitable for pond culture (Mustafa et al., 2011). According to the climate classification of Schmidt and Ferguson (1951), dry months are defined as months with rainfall < 60 mm. Pond preparation is one of the activities that must be carried out prior to stocking.

During pond preparation, ponds are dried to improve soil physical properties, enhance the mineralization of organic matter, and eliminate toxic substances such as hydrogen sulfide, ammonia, and methane. Therefore, the presence of a certain number of dry months each year is required.

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 Manufahi District

No.	Schedule	Sub-District	Village	Purpose (Ownership)
1	14 May 2025	Alas	Uma Berloic	Business (Private)
2	14 May 2025	Fatuberliu	Clacuc	Non-Business (Government)
3	14 May 2025	Same	Letefoho	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	Indicator of latent soil acidity	Low pH → physiological stress on fish and

	significantly lower pH_{FOX} indicates potential acid sulfate soils, which is important for wetland restoration or land use planning.	→ affects water column pH.	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

Manufahi District holds significant potential in the fisheries sector, which can support local economic growth and food security. This district, located in the central part of Timor-Leste, has access to the sea and rich aquatic resources, particularly along the coastline bordering the Timor Sea. According to data from the Directorate of Fisheries, Aquaculture, and Marine Resource Management in 2022, the aquaculture production in Manufahi District was recorded at 25,842 kg in 2019, which then saw a drastic increase to nearly double in 2020, reaching 52,882 kg. This upward trend continued, stabilizing in subsequent years with production of 53,939 kg in 2021, 55,018 kg in 2022, and an estimated increase to 56,118 kg in 2023.

A. Capture Fisheries

According to official reports from the Ministry of Agriculture and Fisheries of Timor-Leste, the development of the fisheries sector in Manufahi District has shown positive trends in recent years, driven by efforts to improve infrastructure, train fishermen, and adopt modern technology. The availability of abundant natural resources, combined with government support and community participation, creates significant opportunities to strengthen this sector.

1. Number of Fishing Households

In terms of the number of fishing households in Manufahi District, Same Sub-District has the highest number, with 50 households (46.73%). In contrast, Turiscai Sub-District has the fewest fishing households, with only 6 households (5.61%). This may indicate limited involvement of the local community in fisheries activities.

This distribution shows differences in potential and challenges in each sub-district in managing the fisheries sector. Same Sub-District, with the dominant number of fishing households, has great opportunities for further development through improvements in fishing technology, fisherman training, and market access. Meanwhile, Turiscai Sub-District has initial potential that can be enhanced through empowerment programs and infrastructure support to encourage 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. Graphs illustrating the number of fishing households are shown in **Figure 10.2** and **Figure 10.3.**

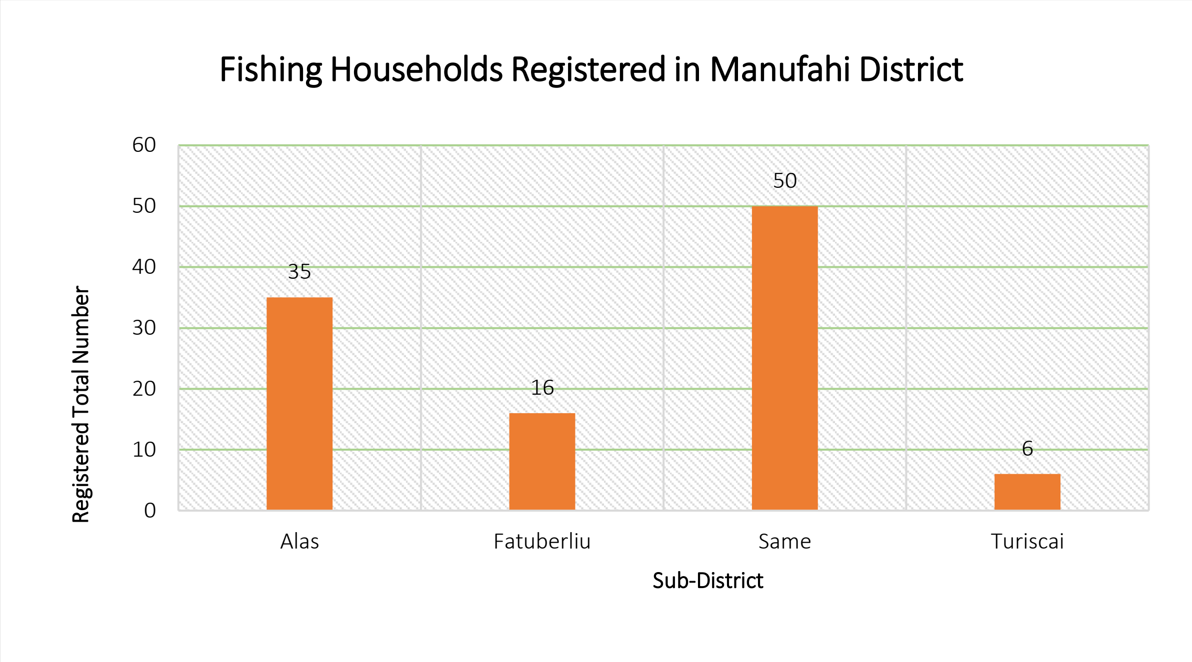


Figure 10.2 Fishing Households in Manufahi District
(Source: Timor-Leste Agriculture Census, 2019)

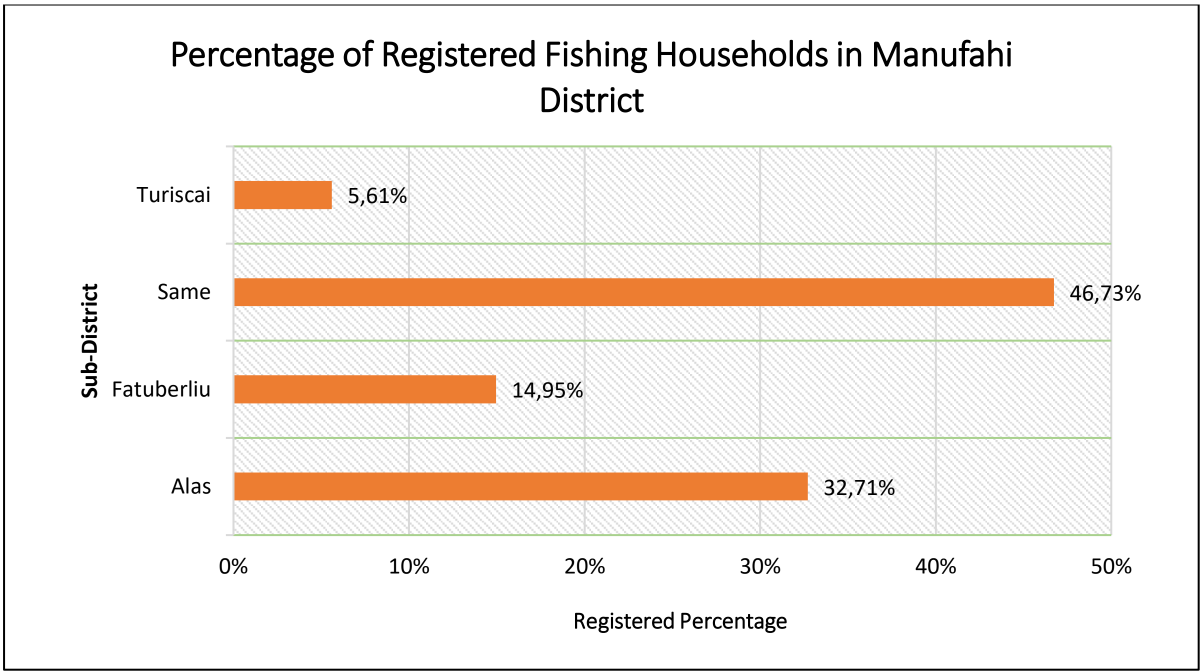


Figure 10.3 Percentage of Fishing Households in Manufahi District
(Source: Timor-Leste Agriculture Census, 2019)

2. Households Involved in Fishing Activitites

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

Same Sub-District has the highest number of households involved in fish capture for consumption and occasional sales, with a total of 40 households (48.78%). In contrast, Turiscai Sub-District has the fewest households in this category, with only 2 households (2.44%), reflecting a significant difference in the scale of fisheries activities between the two areas. Meanwhile, Fatuberliu Sub-District has the highest number of households engaged in fish capture for consumption and social obligations, with 8 households (42.11%). Same and Alas each have 3 households (15.79%). Same Sub-District is the only sub-district with households involved in direct fish sales, with a total of 8 households. This indicates Same as a region with a wider diversification of fisheries activities compared to other sub-districts. The number of households involved in fish capture activities is shown in **Figure 10.4** and **Figure 10.5.**

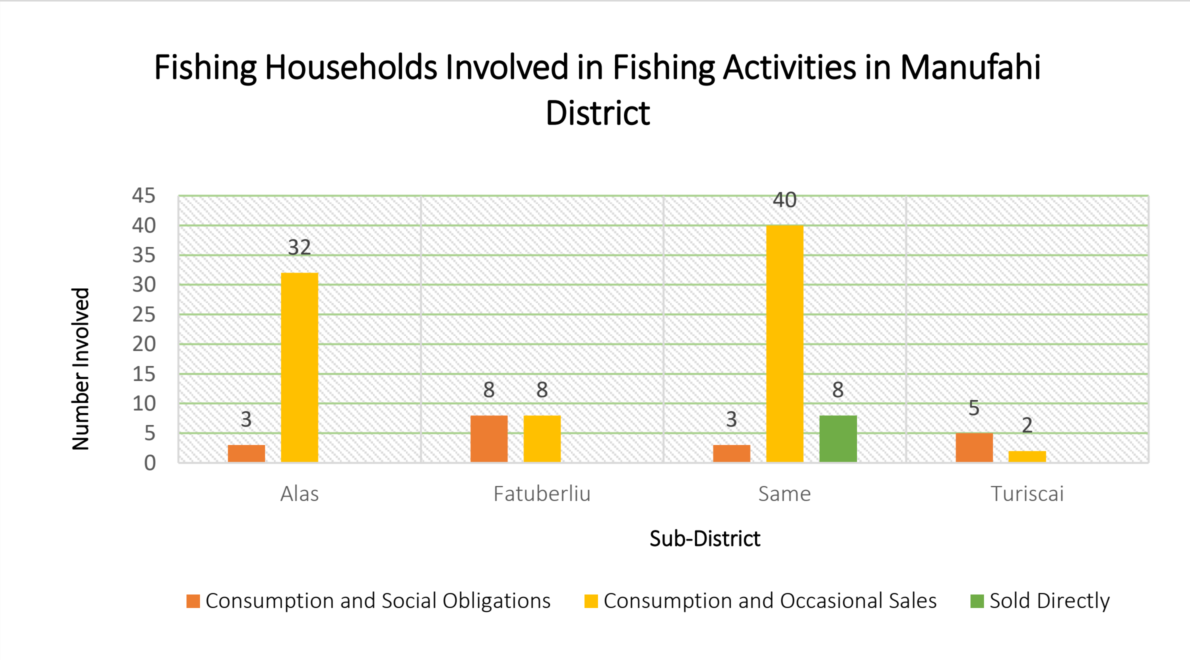


Figure 10.4 Number of Households Involved in Fishing Activities
(Source: Timor-Leste Agriculture Census, 2019)

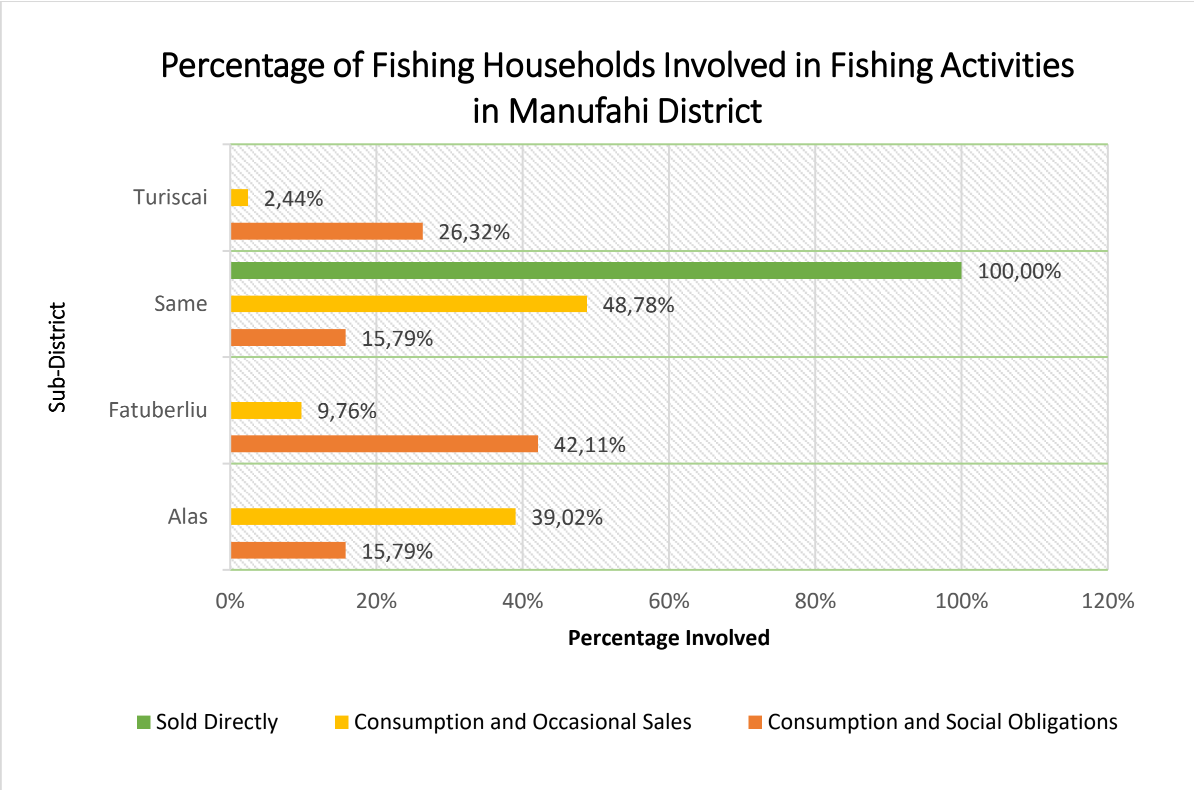


Figure 10.5 Number of Households Involved in Fishing Activities
(Source: Timor-Leste Agriculture Census, 2019)

B. Aquaculture

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

According to data from da Fonseca *et al.* (2022), aquaculture fish consumption in Manufahi District showed an increase from 0.43 kg per person per year in 2019 to 0.85 kg per person per year in 2020. Although there was a slight decrease in subsequent years, with stable values around 0.83–0.84 kg per person per year in 2021, 2022, and 2023, this consumption rate reflects consistent efforts to maintain the availability and distribution of aquaculture fish at the community level.

1. Proportion of Land for Aquaculture

The distribution of land for aquaculture in Manufahi District shows significant differences between sub-districts. Same Sub-District dominates with the largest aquaculture land area, covering 66.90 hectares (94.08%). In contrast, Fatuberliu Sub-District has only 4.15 hectares of aquaculture land, or 5.84%, indicating relatively limited potential or development for aquaculture compared to Same Sub-District. Meanwhile, Alas Sub-District has less than 1 hectare of aquaculture land. The proportion of land used for aquaculture is shown in **Figure 10.6** and **Figure 10.7**.

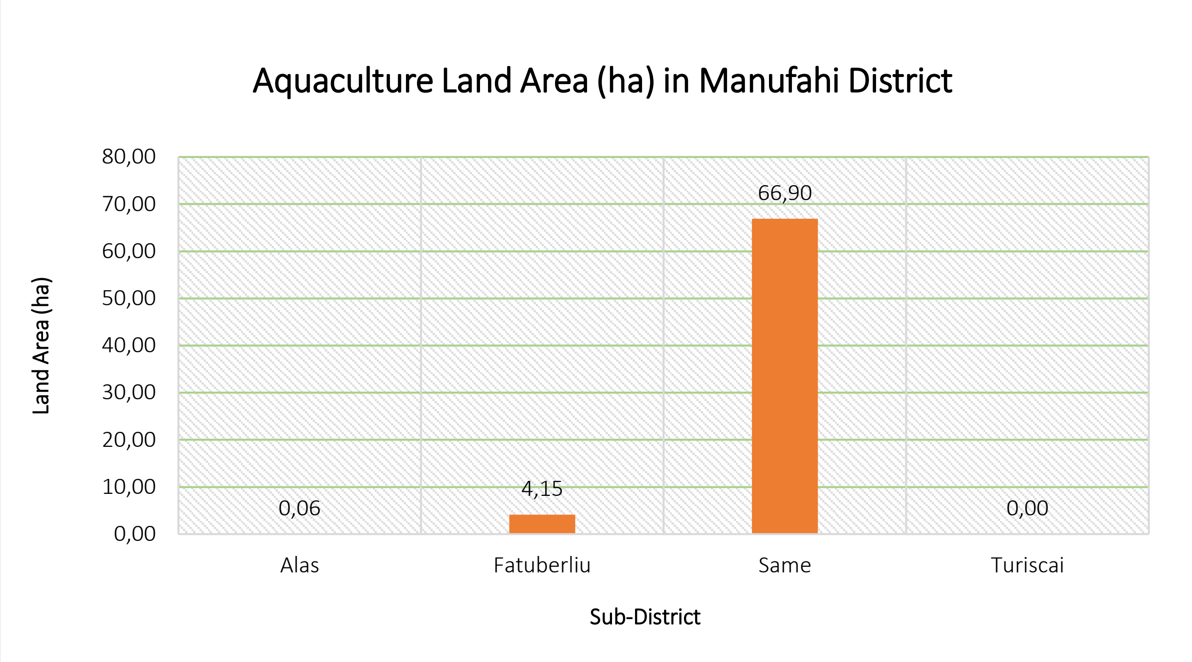


Figure 10.6 Aquaculture Land Area in Manufahi District
(Source: Timor-Leste Agriculture Census, 2019)

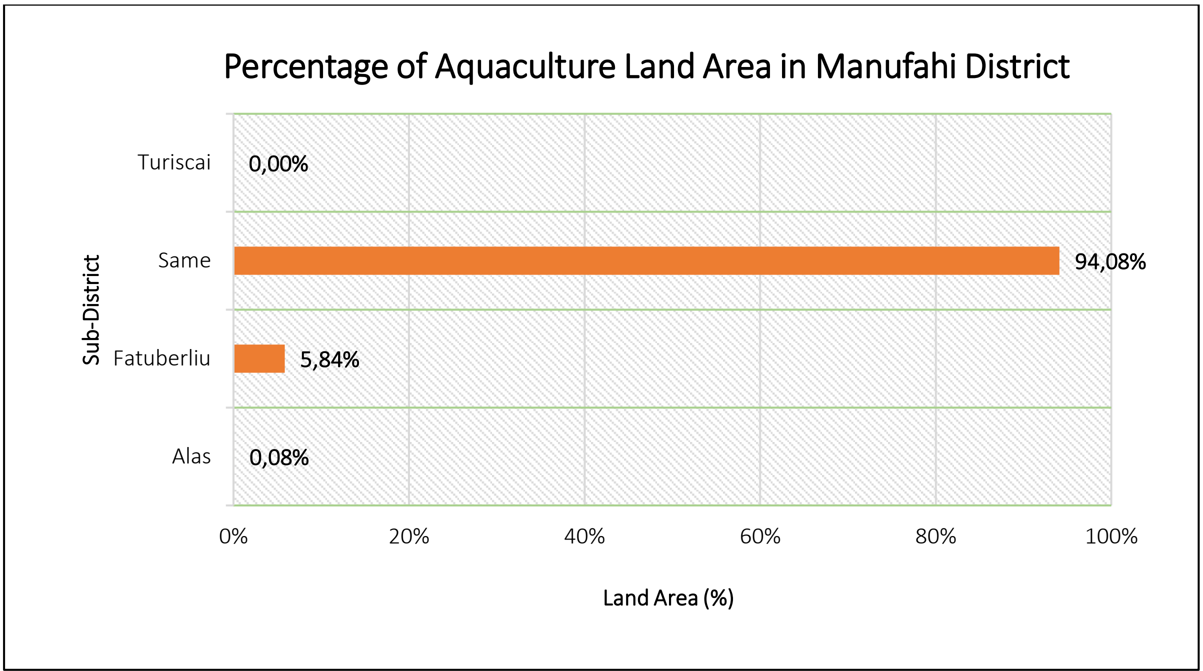


Figure 10.7 Percentage of Aquaculture Land in Manufahi District
(Source: Timor-Leste Agriculture Census, 2019)

2. Aquaculture Households

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

The number of households involved in aquaculture in Manufahi District shows considerable variation. Same Sub-District has the highest number of aquaculture households compared to others, with 185 households (82.96%), while in Fatuberliu Sub-District, only 19 households (8.52%) are engaged in aquaculture.

A strategic approach is needed to increase community participation in sub-districts with lower involvement in aquaculture. By strengthening local capacity and optimizing existing aquaculture potential in each sub-district, Manufahi District can increase the contribution of this sector to local economic growth. The number of households involved in aquaculture in Manufahi District is shown in **Figure 10.8** and **Figure 10.9.**

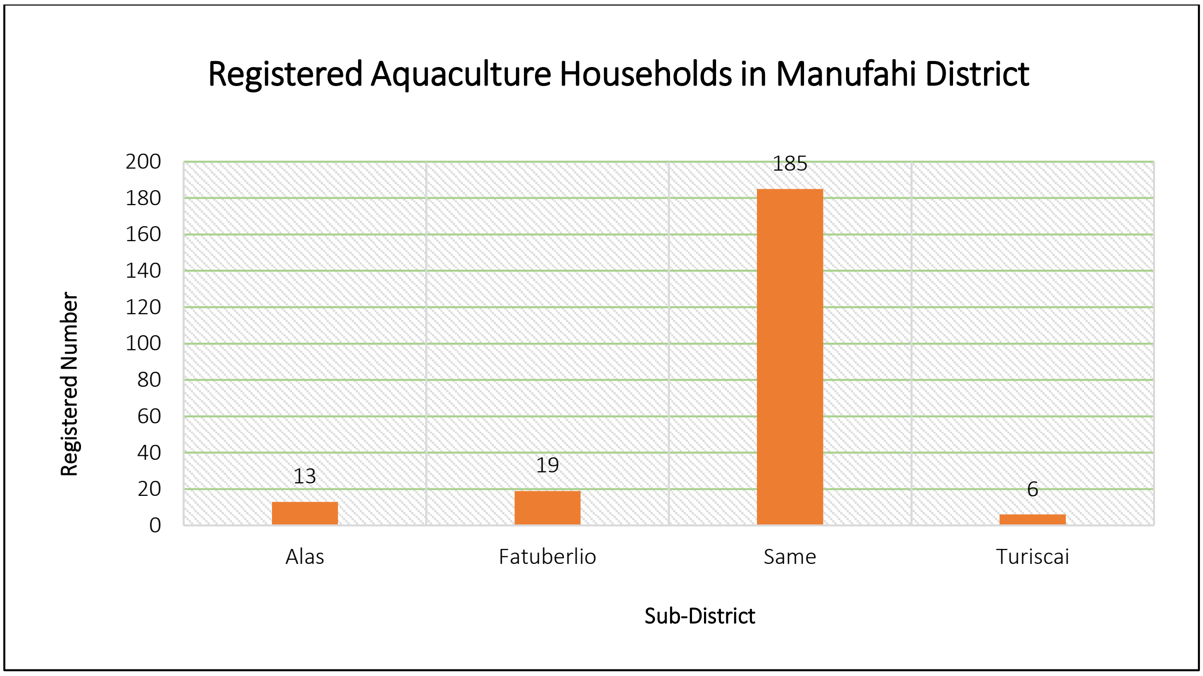


Figure 10.8 Aquaculture Households in Manufahi District
(Source: Timor-Leste Agriculture Census, 2019)

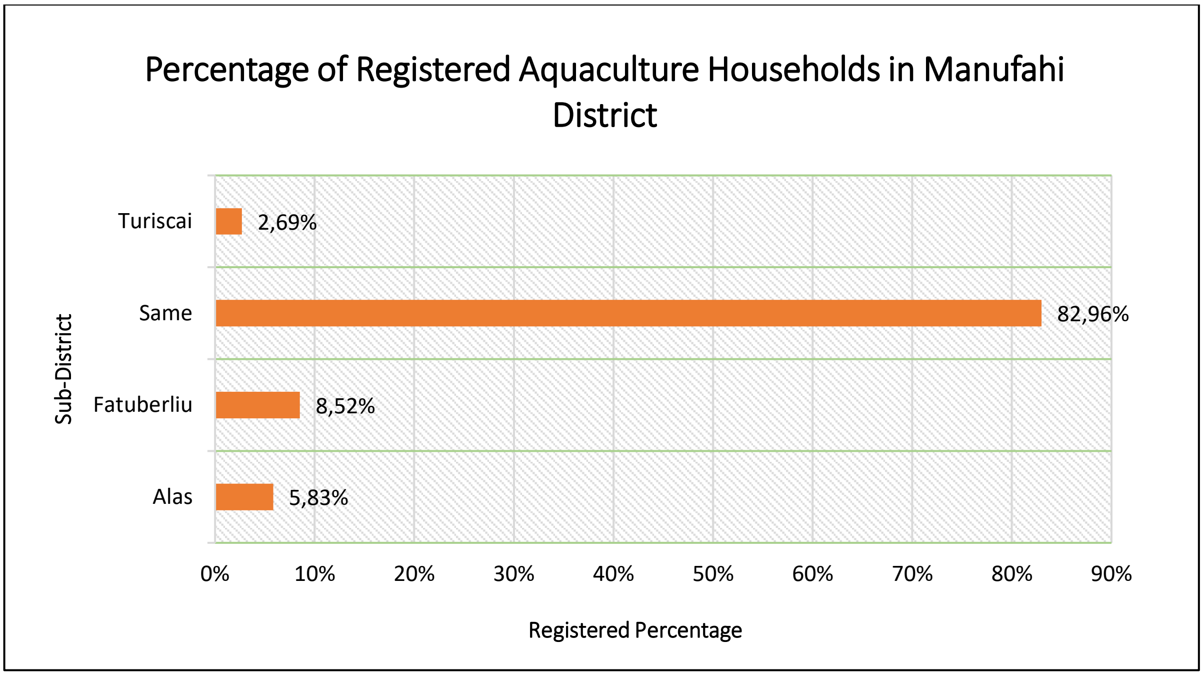


Figure 10.9 Percentage of Aquaculture Households in Manufahi District
(Source: Timor-Leste Agriculture Census, 2019)

3. Aquaculture Systems

The aquaculture systems in Manufahi District show a diverse distribution across each sub-district, with a dominance of pond-based aquaculture systems spread throughout the region. Same Sub-District has the most ponds, with 227 units or approximately 81.36%. Additionally, the rice-fish system is found in Same Sub-District, although in small numbers, with 4 units (100%). Fatuberliu Sub-District and Alas Sub-District each have 25 ponds (8.96%) used for aquaculture. Meanwhile, fish cage systems are only found in Fatuberliu Sub-District, with 1 unit, indicating diversity in farming methods, though still on a limited scale. The graph of facilities used for aquaculture in Manufahi District is shown in **Figure 10.10** and **Figure 10.11**.

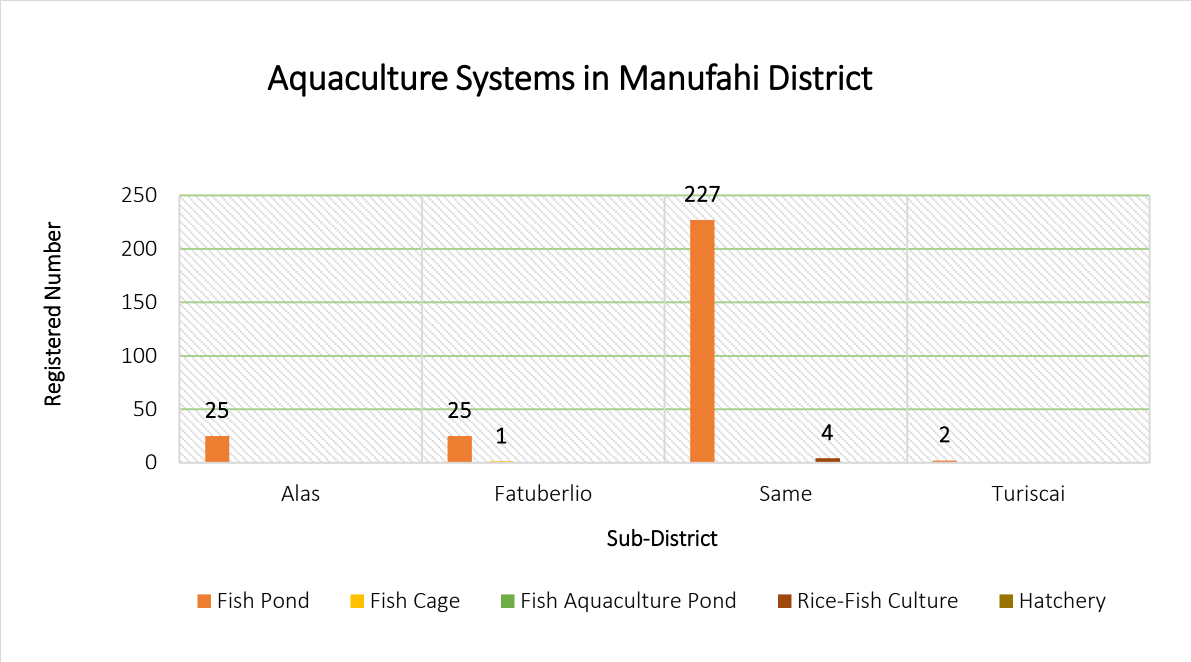


Figure 10.10 Aquaculture Systems in Manufahi District
(Source: Timor-Leste Agriculture Census, 2019)

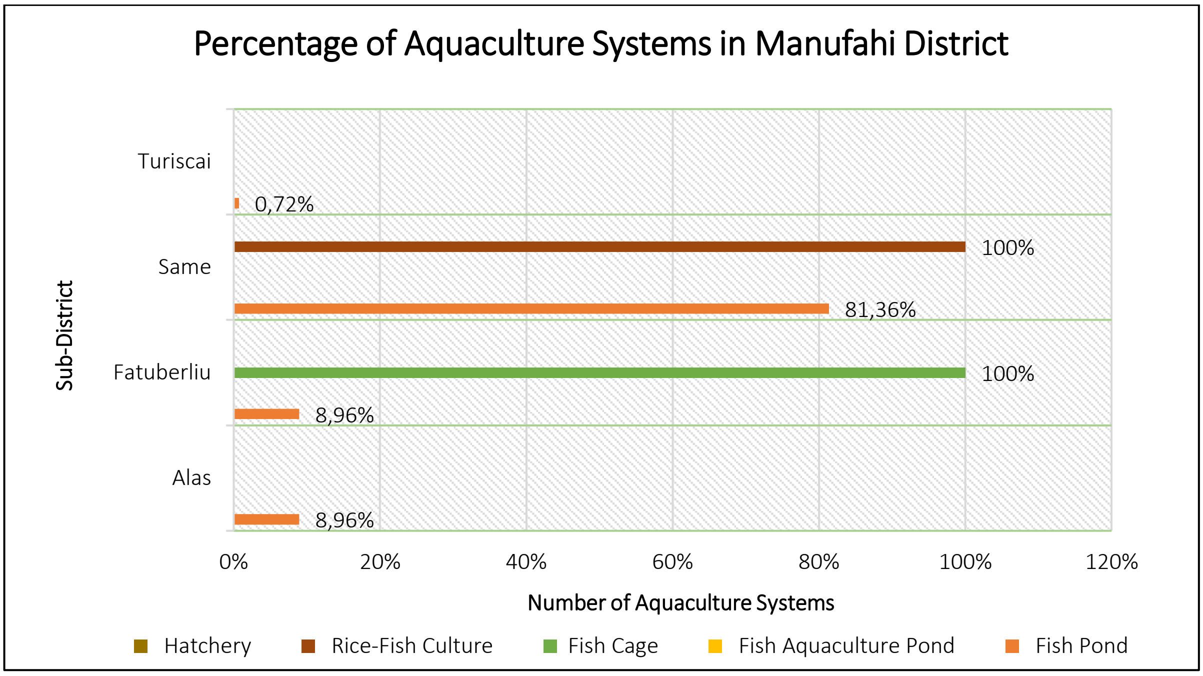


Figure 10.11 Percentage of Aquaculture Systems in Manufahi District
(Source: Timor-Leste Agriculture Census, 2019)

C. Field Observation Results

Manufahi District has various fish farming systems managed by both the government and private entities. In Fatuberliu Village, there is the Centru Clacuc Fish Farming Center, which focuses on the management of tilapia, covering breeding, nursery, and grow-out stages. This location is situated in a coastal area near a lagoon and mangrove vegetation, with the farming system using conventional earthen ponds covering an area of 20 hectares.

Figure 10.12 Breeding Facility at Centru Clacuc
(Source: Research Documentation, 2025)

Figure 10.13 Fish Farming Ponds at Centru Clacuc
(Source: Research Documentation, 2025)

Figure 10.14 Water Source and Irrigation at Centru Clacuc
(Source: Research Documentation, 2025)

The water source comes from springs channeled through ditches, and both irrigation and aeration systems have been applied to support the feasibility of farming. However, supporting facilities such as laboratories remain limited, presenting challenges in fish health monitoring. Mass fish deaths have occurred at this location with undetermined causes, compounded by limited feed availability, which hampers production. Additionally, as this facility functions as a non-commercial center, its production orientation is not focused on sustainability or expansion.

In Uma Berloic Village, there is the Sentru Fini Ikan, a private facility engaged in tilapia farming, covering all stages from breeding to grow-out. The farming system at this location is privately managed, with three staff members holding high school-level education to support operations. There are nine ponds measuring 30×20 meters, and the water source is from natural springs. Unlike the previous location, Sentru Fini Ikan has implemented additional aeration systems to improve the farming environment's feasibility.

Figure 10.15 Sentru Fini Ikan in Uma Berloic Village
(Source: Research Documentation, 2025)

Meanwhile, in Letefoho Village, there is a government-run freshwater fish farming facility that manages tilapia and carp. Currently, there are 25 active ponds, with two additional ponds under construction. These ponds are divided into three main sizes: one unit measuring 16×30 meters, eight units measuring 5×10 meters, and sixteen units measuring 10×20 meters.

Figure 10.16 Freshwater Fish Farming Facility in Letefoho Village
(Source: Research Documentation, 2025)

The water source is from mountain springs channeled through ditches, providing ample supply for farming needs. However, no aeration system has been applied at this location, which presents a challenge for water quality management. Additionally, the temperature at this location is relatively low, especially at night, reaching 16°C, although it tends to increase from July to September. This relatively cold temperature affects fish survival rates, which are recorded at only around 40%. Moreover, feed availability remains a primary constraint for production.

Overall, fisheries in Manufahi District demonstrate variations in management methods, challenges faced, and potential for future development. Improving supporting facilities, optimizing aeration systems, and strategies to address feed limitations are crucial steps in supporting the sustainability of fish production in this region.

10.4 COMPREHENSIVE LAND SUITABILITY ANALYSIS FOR AQUACULTURE

A. Aquaculture Land Suitability in Manufahi District

Land suitability refers to the degree to which an area is appropriate for a specific use, particularly for aquaculture development. This evaluation focuses on the physical, chemical, and climatic characteristics that support the optimal and sustainable cultivation of aquatic commodities. The assessment is conducted through two approaches: actual conditions (as they are) and potential conditions (after improvements have been made).

The actual land suitability is obtained from field survey results that represent the land's capacity in its natural state, without additional interventions. This evaluation does not consider improvement or management efforts to address limiting factors. The process includes identifying limiting factors, scoring, and determining the final value, which reflects the suitability of the land for aquaculture commodities.

On the other hand, potential land suitability shows the degree of suitability after improvements are made. Land that was initially only marginally suitable (S3) can be improved to moderately suitable (S2) or highly suitable (S1) if limiting factors, such as topography and water quality, are addressed. This assessment focuses on efforts to improve land quality so that suitability increases.

The application of technology and management strategies allows land with a low suitability class (actual) to be improved to a higher class (potential). However, not all land characteristics can be improved, or sometimes the improvements require a very high level of management. Therefore, land use planning for aquaculture places more emphasis on potential suitability, as it reflects the maximum capacity of the land after improvements. Thus, this assessment serves as a reference in formulating strategies for effective and sustainable land utilization and in determining the technical steps necessary to achieve optimal results.

B. Results of Aquaculture Land Suitability Evaluation

Land suitability analysis is a crucial step in planning the sustainable management of land resources to support aquaculture development. The evaluation is conducted using an integrated approach that utilizes geospatial data, field surveys, and laboratory analysis of soil and water physical and chemical properties. This approach allows for the identification of both the potential and limitations of the land's bio-physical characteristics in supporting the cultivation of various aquatic commodities.

The data from the analysis are then compared to the growth requirements of each commodity, both under actual conditions and potential suitability after land improvements such as topography modification, water quality management, or the application of adaptive farming techniques. This process provides comprehensive information to determine the priority of commodity development, identify limiting factors, and design relevant technical solutions. This scientific approach serves as the basis for the land suitability evaluation in Manufahi District, while also providing strategic guidance to optimize land productivity while maintaining the sustainability of aquatic resources. All supporting data, both from the field and laboratory, are presented in the relevant supporting documents. The land distribution map for aquaculture in Manufahi District is shown in **Figure 10.17.**

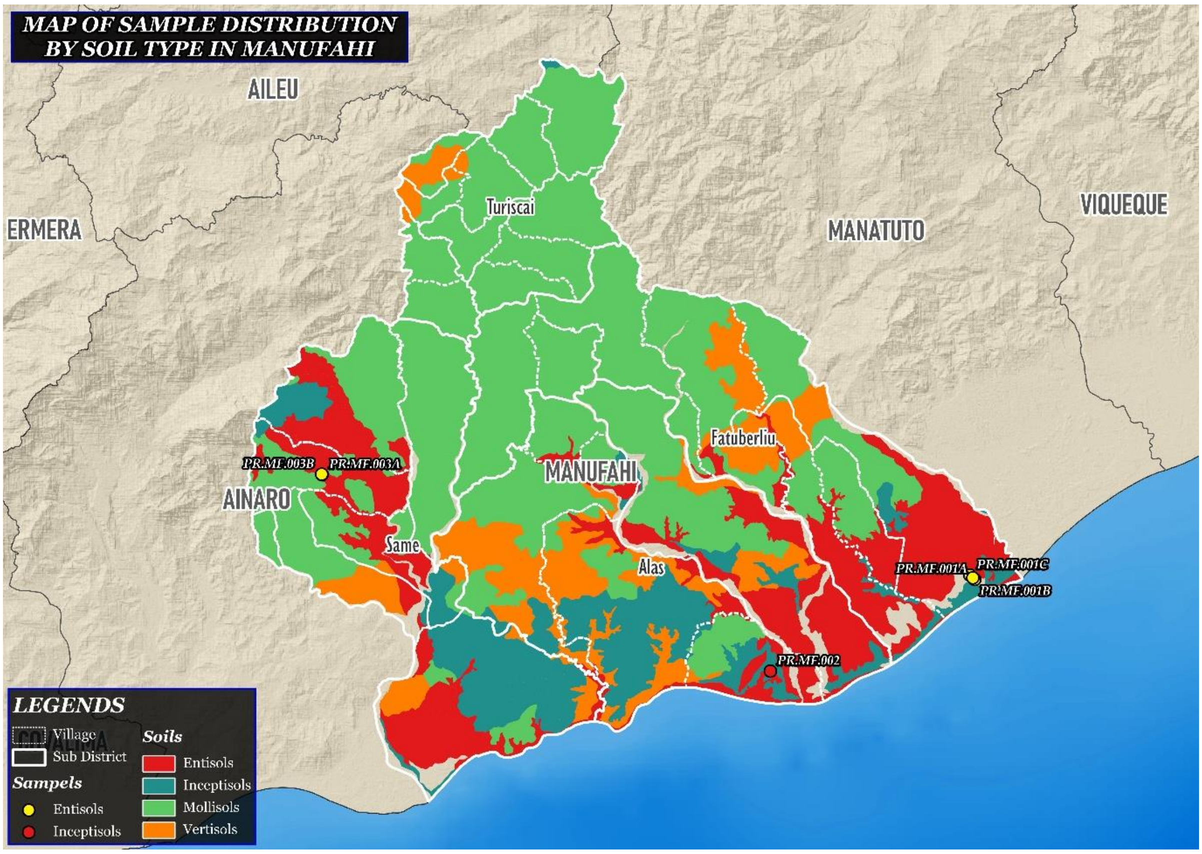


Figure 10.17 Map of Soil Distribution on Aquaculture Land in Manufahi District

A. Land Suitability Evaluation in Alas Sub-District

The land suitability evaluation in Alas Sub-District shows that all aquaculture commodities, both freshwater and brackish water, face significant limiting factors. For freshwater commodities such as gourami, catfish, carp, and tilapia, the main constraints are steep slopes (N), which are unsuitable for conventional ponds, and climate factors such as dry months and extreme rainfall (S3), which affect water availability. Some species are also affected by acidic pH (gurami) and high temperatures (mas, gurami), as shown in **Table 10.9.**

Brackish water commodities such as milkfish, mangrove crab, and vannamei shrimp face even greater challenges. In addition to slopes, the most critical constraint is low salinity due to the inland location with no seawater influence. This low salinity is rated as N for mangrove crab and S3 for bandeng and vannamei. Dry months and high rainfall are also additional constraints (**Table 10.9**).

Some of the constraints are irreparable (as seen **in Table 10.9**), such as steep slopes, dry climates, and low salinity. However, technical interventions can improve land suitability to S3 potential, including: terracing/stepped ponds to reduce slope, liming to raise pH, water management (ponds, irrigation, drainage) to address dry seasons and flooding, and mineral supplementation to support low-salinity aquaculture (vannamei shrimp).

The results of improvements show an increase in the suitability index from ±3.0 to ±3.4–3.6, although it remains in the S3 class because climate and topography constraints are not fully addressed. The focus of development should be directed towards adaptive freshwater fish such as tilapia and catfish, which are resistant to suboptimal water quality, high temperatures, and limited water availability. Carp and gurami can be considered as additional species with specific technical conditions. Brackish water commodities are generally not recommended, except for vannamei with intensive technology, due to low salinity and high costs. Alas Sub-District still holds potential for small- to medium-scale aquaculture development to enhance local food security.

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

Commodity	Current Land Suitability Limiting Factors	Current Final Evaluation	Potential Land Suitability Limiting Factors	Potential Final Evaluation
Gourami (*Ospronemus gouramy*)	N: pH, slope gradient S3: High temperature, rainfall, dry months S2: pH	3,01	S3: Dry months, rainfall, slope gradient	3,44
Catfish (*Clarias batrachus*)	N: Slope gradient S3: Rainfall, dry months S2: High temperature, pH	3,20	S3: Dry months, rainfall, slope gradient	3,44
Carp (*Cyprinus carpio*)	N: Slope gradient S3: Rainfall, dry months, High temperature S2: pH	3,20	S3: Dry months, rainfall, slope gradient	3,44
Tilapia (*Oreochromis niloticus*)	N: Slope gradient S3: Low salinity, rainfall, dry months S2: pH, high temperature	3,00	S3: Dry months, rainfall, slope gradient	3,44
Milkfish (*Chanos chanos*)	N: Slope gradient S3: Dry months, Low salinity S2: pH, rainfall, High temperature	3,01	S3: Dry months, slope gradient S2: Rainfall	3,50
Mangrove crab (*Scylla serrata*)	N: Low salinity S3: Slope gradient, dry months S2: High temperature, pH, rainfall	3,08	S3: Dry months S2: Rainfall, slope gradient	3,62
Vannamei (*Litopenaeus vannamei*)	N: Slope gradient S3: Low salinity, rainfall, dry months S2: High temperature, pH	3,00	S3: Dry months, rainfall, slope gradient	3,56

B. Land Suitability Evaluation in Fatuberliu Sub-District

The land suitability evaluation in Fatuberliu Sub-District shows that all aquaculture commodities, both freshwater and brackish water, are currently categorized as unsuitable (S3) with different limiting factors for each group. The comparison of AFE–PFE shows the greatest improvement in suitability for mangrove crab (from 3.26 to 3.68), followed by bandeng (from 3.18 to 3.50). All freshwater commodities and vannamei shrimp reached EAP 3.44, indicating moderate improvement potential (**Table 10.10**).

For freshwater commodities (gourami, catfish, carp, tilapia), the biggest barriers are steep slopes (unsuitable, N) and low rainfall during the dry season (S3). Gurami is also affected by pH (S2), while mas faces high temperatures (S2). The Actual Final Evaluation Value (AFE) range from 3.25 to 3.32. With technical interventions such as pH neutralization, aeration, adjustment of seed stocking times, or pond modification, the Potential Final Evaluation value (PFE) can increase to 3.44. However, slopes and dry season constraints remain challenging (**Table 10.10).**

Brackish water commodities face more severe challenges, especially low salinity. Milkfish and vannamei shrimp recorded EAK values of 3.18 and 3.12, respectively, while mangrove crab had 3.26. The salinity, which is much lower than optimal needs, reduces productivity; slopes and dry seasons are also limiting factors. After interventions such as adding seawater or salt and improving pond layout, salinity can be addressed, and the EAP value increases: milkfish 3.50, mangrove crab 3.68 (the highest among all commodities), and vannamei shrimp 3.44, as shown in **Table 10.10.**

Development should focus on mangrove crab as the flagship commodity due to its highest technical suitability after improvements and high economic value. Bandeng becomes a strategic alternative due to its salinity tolerance and relatively simple farming techniques. Tilapia can be considered as a supporting species due to its adaptability in both freshwater and brackish water. Vannamei shrimp, though valuable, requires expensive interventions and is thus less recommended. A focus on mangrove crab, bandeng, and tilapia is expected to provide optimal technical and economic outcomes for Fatuberliu Sub-District.

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

Commodity	Current Land Suitability Limiting Factors	Current Final Evaluation	Potential Land Suitability Limiting Factors	Potential Final Evaluation
Gourami (*Ospronemus gouramy*)	N: Slope gradient S3: Rainfall, dry months S2: pH	3,25	S3: Rainfall, dry months, slope gradient	3,44
Catfish (*Clarias batrachus*)	N: Slope gradient S3: Rainfall, dry months	3,32	S3: Rainfall, dry months, slope gradient	3,44
Carp (*Cyprinus carpio*)	N: Slope gradient S3: Rainfall, dry months S2: High temperature	3,27	S3: Rainfall, dry months, slope gradient	3,44
Tilapia (*Oreochromis niloticus*)	N: Slope gradient S3: Rainfall, dry months	3,32	S3: Rainfall, dry months, slope gradient	3,44
Milkfish (*Chanos chanos*)	N: Slope gradient S3: Low salinity, dry months S2: Rainfall	3,18	S3: Rainfall, slope gradient S2: Dry months	3,50
Mangrove crab (*Scylla serrata*)	N: Low salinity S3: Slope gradient, dry months	3,26	S3: Dry months S2: Slope gradient	3,68
Vannamei (*Litopenaeus vannamei*)	N: Slope gradient S3: Low salinity, rainfall, dry months	3,12	S3: Rainfall, dry months, slope gradient	3,44

C. Land Suitability Evaluation in Same Sub-District

The land suitability evaluation in Same Sub-District indicates moderate aquaculture potential despite facing significant constraints. The main universal limiting factor is the steep slope (N), consistently rated as unsuitable, showing that the steep topography is a fundamental physical barrier for conventional pond construction for all commodities. Climate conditions such as dry months (S2) and low temperatures (S2) are also limiting factors, affecting water availability and optimal growth (**Table 10.11**).

For freshwater commodities such as gourami, catfish, carp, and tilapia, improvement efforts can increase land suitability. A stepped pond system can address slope issues, improving suitability to S3 (marginally suitable). pH and low temperature problems can also be mitigated. However, dry months remain a S2 constraint, indicating the need for strong water management, as shown in Table 10.11.

Brackish water commodities like milkfish, mangrove crab, and vannamei shrimp face greater challenges. In addition to slopes (N), low salinity (N or S3) is the most critical constraint due to Same Sub-District's tendency towards freshwater. Although salinity can be addressed, this requires significant and potentially expensive interventions. Mangrove crab shows the highest potential score (3.78) if salinity can be resolved, with slope improvement to S2, as shown in Table 10.11.

Overall, all commodities show potential improvement scores after interventions, but slopes and dry months often remain persistent limiting factors. Therefore, the development focus should be directed towards freshwater commodities with investments in topographic engineering and integrated water resource management. For brackish water commodities, the economic feasibility of salinity management must be carefully evaluated. Same Sub-District holds potential to become a productive aquaculture center with appropriate planning and investment.

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

Commodity	Current Land Suitability Limiting Factors	Current Final Evaluation	Potential Land Suitability Limiting Factors	Potential Final Evaluation
Gourami (*Ospronemus gouramy*)	N: Slope gradient S3: pH S2: Low temperature, dry months	3,35	S3: Slope gradient S2: Dry months	3,66
Catfish (*Clarias batrachus*)	N: Slope gradient S2: Dry months	3,54	S3: Slope gradient S2: Dry months	3,66
Carp (*Cyprinus carpio*)	N: Slope gradient S2: Dry months	3,54	S3: Slope gradient S2: Dry months	3,66
Tilapia (*Oreochromis niloticus*)	N: Slope gradient S2: Dry months, Low temperature	3,49	S3: Slope gradient S2: Dry months	3,66
Milkfish (*Chanos chanos*)	N: Slope gradient S3: Low salinity S2: Low temperature, dry months	3,29	S3: Slope gradient S2: Dry months	3,66
Mangrove crab (*Scylla serrata*)	N: Low salinity S3: Slope gradient S2: Low temperature, rainfall	3,35	S2: Rainfall, slope gradient	3,78
Vannamei (*Litopenaeus vannamei*)	N: Slope gradient S3: Low salinity S2: Low temperature, dry months	3,39	S3: Slope gradient S2: Dry months	3,66

C. Aquaculture Land Improvement Efforts

The results of the actual land suitability evaluation in Manufahi District show various limiting factors that make most areas unsuitable or only marginally suitable for aquaculture. To improve the land suitability class, efforts to correct or improve these limiting factors are necessary, as far as possible. Land improvement efforts in the context of aquaculture include all 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 the cultivated commodities. These improvements can include habitat modifications (such as physically improving pond conditions), water quality manipulation, and the provision of supporting infrastructure.

Based on **Table 10.12**, there are types of improvement efforts with varying management difficulty levels. The management difficulty levels are divided into three categories: low, medium, and high. These levels then have assessment assumptions for improving actual land quality to potential quality, as shown in **Table 10.13**.

Table 10.12 Recommended Improvement Measures for Limiting Parameters

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

Description :

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

Table 10.13 Assumptions for Improving Actual Land Quality to Potential, Based on Management Difficulty Levels

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

Description :

- *Not feasible for improvement*

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

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

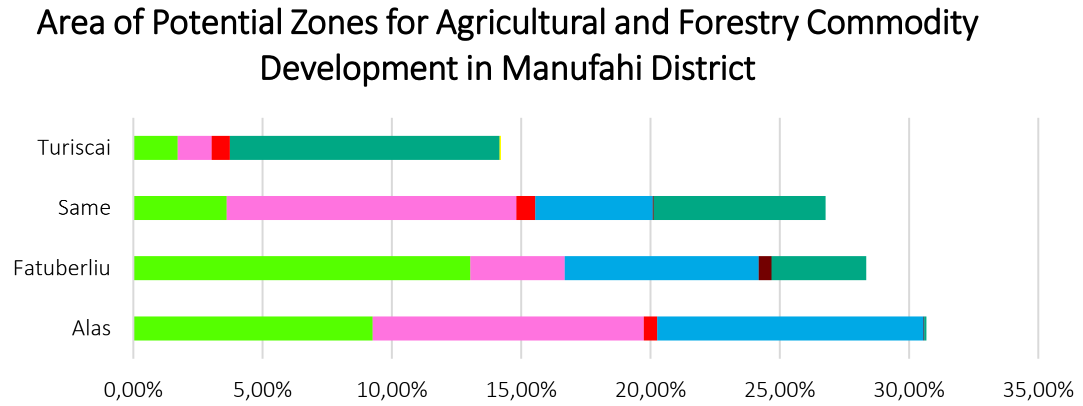
+++ *Improvement will increase the suitability class by three levels (N to S1)*

XI. AGRICULTURAL COMMODITIES DEVELOPMENT ZONING

11.1 AGRICULTURAL COMMODITIES DEVELOPMENT ZONING

Manufahi District has significant land resource potential to support the development of the agriculture, forestry, and livestock sectors. To maximize this potential, a comprehensive scientific approach to land suitability evaluation was conducted, which included field observations, laboratory testing of soil samples, and matching the growth requirements of crops with the agroclimatic map of the region. The results of this evaluation produced a systematic, science-based zoning to identify the potential for developing various strategic commodities such as rice, corn, horticultural crops, industrial crops, and forestry areas. This zoning is expected to support the efficient and sustainable management of land resources, thereby contributing to national food security and improving community welfare.

Manufahi District has land development potential divided into several main categories, including irrigated rice fields covering 280.76 km² (21.22%), rainfed rice fields covering 0.25 km² (0.02%), dryland agriculture or mixed plantations covering 359.11 km² (27.14%), agroforestry covering 340.00 km² (25.70%), protected forests and conservation areas covering 335.68 km² (25.37%), and mangroves covering 7.35 km² (0.56%). The data on the land development potential for agricultural commodities in Manufahi District is shown in **Figure 11.1**, and its spatial distribution is presented in **Figure 11.2**. This zoning reflects the diverse potential land uses to support the agriculture, forestry, and livestock sectors sustainably, contributing to food security, environmental protection, and improved community welfare.



	Alas	Fatuberliu	Same	Turiscai
Agroforestry	9,26%	13,03%	3,61%	1,71%
Dryland Farming	10,48%	3,65%	11,20%	1,31%
Grazing Area	0,52%	0,00%	0,73%	0,71%
Irrigated Rice Fields	10,30%	7,50%	4,54%	0,00%
Mangrove Forest	0,02%	0,49%	0,04%	0,00%
Protected Forest	0,10%	3,66%	6,65%	10,42%
Rainfed Rice Fields	0,00%	0,00%	0,00%	0,05%

Figure 11.1 Area of Agricultural Commodity Development in Manufahi District

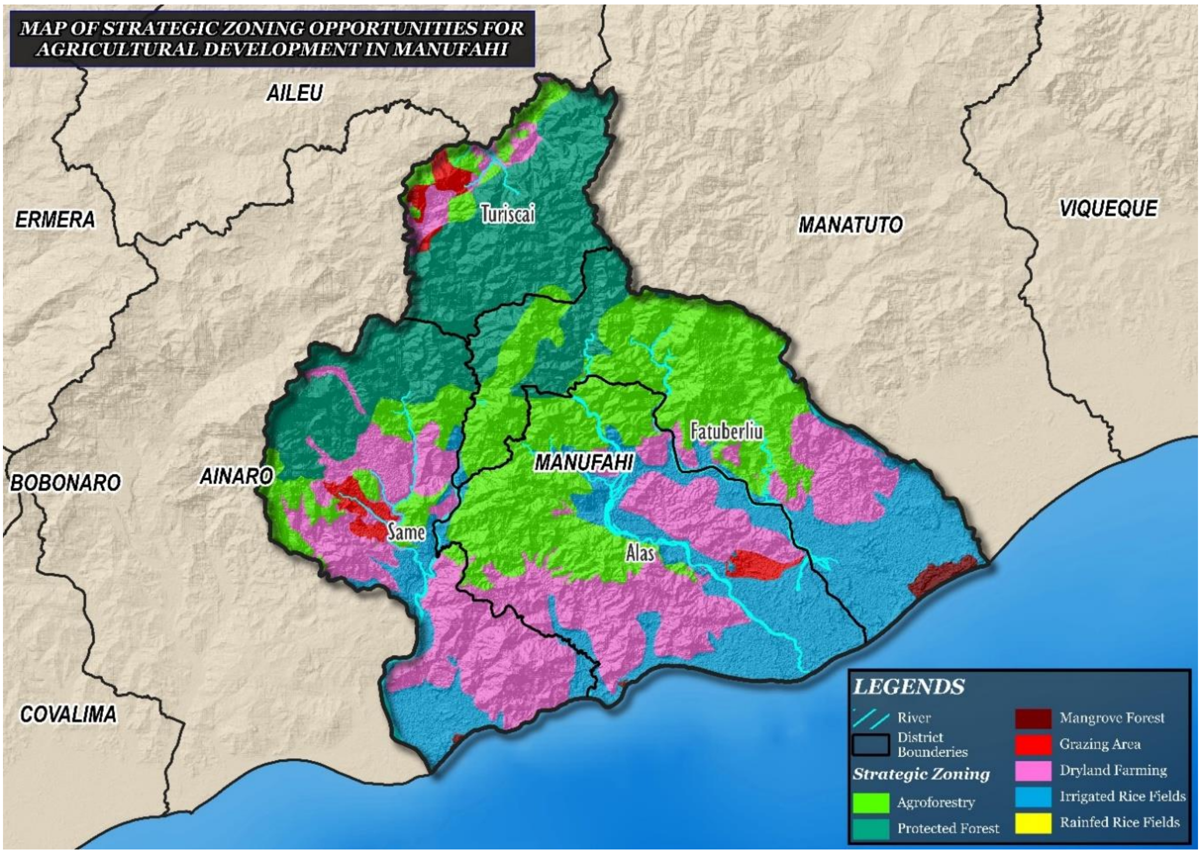


Figure 11.2 Map of Agricultural and Forestry Commodity Development Potential in Manufahi District

A. Irrigated Rice Fields

The zoning for irrigated rice fields in Manufahi District covers an area of 280.76 km², or about 21.22% of the total area. This zoning is located in low-elevation areas, ranging from 0 to 100 meters above sea level, with a slope gradient of 0-8%. Based on agroclimatic characteristics, this region falls within Zone F, characterized by a wet season lasting 7 to 8 months each year. The presence of river networks in this area supports efficient irrigation, thereby enhancing the potential for high rice productivity. The distribution of irrigated rice fields in Manufahi District is spread across several Sub-Districts. Alas Sub-District has the largest irrigated rice field area, accounting for 10.07% of the total area, followed by Fatuberliu Sub-District with 6.95%, and Same Sub-District with only 4.20%. This shows the variation in the distribution of irrigated rice fields across Sub-Districts, which plays a role in supporting rice production in Manufahi District.

B. Rainfed Rice Fields

Rainfed rice fields in Manufahi District cover only a small area, measuring 0.25 km², or 0.02% of the total area of Manufahi. These fields are located in Turiscai Sub-District, which is dominated by the characteristics of agroclimatic zone C. This zone has a monomodal rainfall pattern, with a wet season lasting 6 to 7 months each year. The location is situated at an elevation of more than 500 meters above sea level. The productivity of rainfed rice fields is highly dependent on seasonal rainfall, making them vulnerable to climate fluctuations. Therefore, the recommended management strategies to improve harvest yields include the construction of water reservoirs, the use of drought-resistant rice varieties, and water management practices to enhance productivity.

C. Dryland Agriculture (Mixed Plantations and Upland Fields)

Dryland agriculture is the largest sector in Manufahi District, covering an area of 359.11 km², or 27.14% of the total area. This zoning is spread across all Sub-Districts, with varying distributions. Same Sub-District has the largest coverage, at 11.69%, while Alas Sub-District covers 10.48%. Fatuberliu Sub-District covers 3.65%, and Turiscai Sub-District has the smallest coverage at 1.31%. This zoning is located at an elevation of 100-500 meters above sea level with a slope gradient of 8-25%. This area supports a diverse range of agricultural commodities, including food crops such as corn, cassava, peanuts, as well as horticultural commodities such as vegetables, fruits, and flowers. Additionally, industrial crops like coffee, cocoa, and spices also thrive in this area. The agricultural potential is supported by the implementation of a mixed cropping system, which has proven effective in increasing land productivity. This system not only provides harvest diversification but also contributes to increased farmer income. To mitigate the risk of erosion in areas with moderate slopes, the adoption of soil conservation strategies, such as strip cropping and crop rotation, is recommended.

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

NO	SUB-DISTRICT	FOOD CROPS	DRYLAND AGRICULTURE (MIXED PLANTATIONS & HORTICULTURE)	FORESTRY
1	Alas	WETLAND FOOD S2: Irrigated Rice DRYLAND FOOD S2 : PUpland Rice, Corn, Peanut, Cowpea, Taro S3 : Sorghum, Soybean, Mung Beans, Cassava, Sweet Potato	INDUSTRIAL CROPS S2 : Coconut, Oil Palm, Robusta Coffee, Tobacco, Sugarcane S3 : Cocoa, Clove, Cashew, Melinjo, Cotton, Kapok, Quinine FRUITS S2 : Papaya, Rambutan, Guava, Starfruit, Durian, Watermelon, Cantaloupe, Melon, Pineapple, Banana, Duku, Jackfruit, Soursop, Custard Apple, Breadfruit, Snakefruit, Sapodilla, Longan, Mangosteen, Kepayang, Persimmon, Orange, Avocado S3 : Apple, Mango, Passion Fruit VEGETABLES S2 : Spinach, Mustard, Eggplant, Tomato Vegetable, Red Chili, Shallot, Bell Pepper, Cabbage, Green Beans, Long Beans, Cucumber, Bitter Melon, Broccoli, Asparagus, Beetroot, Petai, Lettuce, Petsai, Grape FLOWERS S2 : Sunflower, Jasmine, Hairbrass, Gladiolus, Aster S3 : Rose, Ylang Ylang SPICES & MEDICINAL PLANTS S2 : Pepper, Vanilla, Ginger, Aromatic Ginger, Turmeric, Galangal, Cardamom, Jatropha S3 : Candlenut, Lemongrass, Vetiver Root	S3 : Teak, Mahogany, Acacia, Leucaena, Eucalyptus, Melaleuca

2	Fatuberliu	**WETLAND FOOD** **S2**: Irrigated Rice **DRYLAND FOOD** **S2** : Upland Rice, Corn, Peanut, Cowpea, Taro, Sorghum, Soybean, Mung Beans, Cassava, Sweet Potato, Hui, Iles-iles **S3** : Chickpeas	**INDUSTRIAL CROPS** **S2** : Rubber, Coconut, Oil Palm, Robusta Coffee, Tobacco, Sugarcane, Cocoa, Clove, Cashew, Melinjo, Cotton, Kapok **S3** : Quinine **FRUITS** **S2** : Papaya, Rambutan, Guava, Starfruit, Durian, Watermelon, Cantaloupe, Melon, Pineapple, Banana, Duku, Jackfruit, Soursop, Custard Apple, Breadfruit, Snakefruit, Sapodilla, Longan, Mangosteen, Kepayang, Persimmon, Orange, Avocado **S3** : Apple, Mango, Passion Fruit **VEGETABLES** **S2** : Spinach, Mustard, Eggplant, Tomato Vegetable, Red Chili, Bell Pepper, Cabbage, Green Beans, Long Beans, Cucumber, Bitter Melon, Broccoli, Asparagus, Beetroot, Petai, Lettuce, Petsai, Grape, Spinach **FLOWERS** **S2** : Rose, Ylang Ylang, Sunflower, Jasmine, Hairbrass, Gladiolus, Aster **SPICES & MEDICINAL PLANTS** **S2** : Pepper, Nutmeg, Candlenut, Vanilla, Ginger, Aromatic Ginger, Turmeric, Galangal, Cardamom, Jatropha, Lemongrass, Vetiver Root	**S3** : Teak, Mahogany, Acacia, Leucaena, Eucalyptus, Melaleuca
3	Same	**WETLAND FOOD** **S2**: Irrigated Rice **DRYLAND FOOD** **S2** : Upland Rice, Sorghum, Corn, Peanut, Cowpea, Cassava,	**INDUSTRIAL CROPS** **S2** : Coconut, Robusta Coffee, Tobacco, Sugarcane, Oil Palm, Cashew, Clove, Melinjo, Cotton **INDUSTRIAL CROPS** **INDUSTRIAL CROPS** **S3** : Cocoa, Tea, Kapok, Quinine	**S3** : Agathis, Eucalyptus, Acacia

		Soybean, Mung Beans, Sweet Potato, Taro, Iles-iles, Hui **S3** : Chickpeas	FRUITS **S2** : Papaya, Starfruit, Banana, Soursop, Custard Apple, Sapodilla, Longan, Orange, Avocado **S3** : Apple, Mango, Passion Fruit, Strawberry, Persimmon VEGETABLES **S2** : Eggplant, Beetroot, Kailan, Tomato Vegetable, Shallot, Cabbage, Green Beans, Long Beans, Bitter Melon, Broccoli, Petai, Lettuce, Petsai, Mustard, Spinach FLOWERS **S2** : Rose, Ylang Ylang, Jasmine, Hairbrass, Aster, Sunflower, Gladiolus SPICES & MEDICINAL PLANTS **S2** : Pepper, Nutmeg, Candlenut, Vanilla, Lemongrass, Vetiver Root, Ginger, Aromatic Ginger, Turmeric, Galangal, Cardamom, Jatropha	
4	Turiscai	DRYLAND FOOD **S2** : Corn, Wheat, Mung Beans **S3** : Upland Rice, Sorghum, Peanut, Cowpea, Cassava	INDUSTRIAL CROPS **S2** : Arabica Coffee, Quinine **S3** : Tea, Tobacco FRUITS **S2** : Papaya, Apple, Mango, Banana, Breadfruit, Snakefruit, Mangosteen, Orange, Avocado **S3** : Starfruit, Soursop, Custard Apple, Sapodilla, Longan, Strawberry, Persimmon, Passion Fruit, Grapes VEGETABLES **S2** : Spinach, Mustard, Tomato Vegetable, Cabbage, Green Beans, Long Beans, Broccoli, Asparagus, Beetroot, Lettuce, Petsai, Grapes, Spinach, Kailan, Radish, caissim **S3** : Eggplant, Bitter Melon, Petai FLOWERS	**S3** : Agathis, Altingia, Albizia, Leucaena, Eucalyptus, Pine

			S2 : Rose, Jasmine, Hairbrass, Gladiolus, Aster **S3** : Ylang Ylang, Sunflower SPICES & MEDICINAL PLANTS **S2** : Vanilla, Aromatic Ginger, Turmeric, Galangal **S3** : Candlenut, Lemongrass, Vetiver Root, Cardamom, Jatropha	

Description: S2: Suitable, S3: Marginally Suitable, N: Not Suitable

11.2 POTENTIAL ZONING FOR FOOD CROPS

Agricultural production analysis in Manufahi District, according to the report from the Crop and Food Security Assessment Mission (CFSAM), indicates that the agriculture sector in Manufahi District made a significant contribution to food security in 2021. During the planting season, corn was planted on an area of 1,550 ha, with a productivity rate of 3.3 tons per ha, resulting in a total production of 5,150 tons. Secondary production added 300 tons, bringing the total corn production to 5,450 tons. Rice was planted on an area of 500 ha, with a harvested yield of 3.5 tons per ha, equivalent to 2.1 tons of rice per ha. The primary production yielded a total of 1,050 tons, while secondary production contributed 300 tons, resulting in a total rice production of 1,350 tons. Additionally, tubers contributed to food production, with a total output of 5,400 tons. Overall, total food production in Manufahi District in 2021, when converted to cereal equivalents, reached 8,530 tons.

Cereal equivalents is a conversion method used to standardize the production output of various agricultural commodities into one unit. This process is necessary because each commodity, such as corn, rice, tubers, and others, has different nutritional and caloric content. To facilitate analysis and comparison, the production output of various commodities is converted into uniform values based on their calorie or energy content equivalent to cereals, such as rice or wheat.

Manufahi District has significant potential for the development of food crops to support national food security and reduce dependence on imports. Based on agroclimatic zoning, this region covers large areas suitable for rice cultivation, as well as other commodities such as corn, soybeans, peanuts, cassava, sweet potatoes, and potatoes. The development of food crops, especially rice, is a key component in achieving food self-sufficiency. The irrigated rice area of 280.76 km² has ideal agroclimatic characteristics for agricultural intensification. The presence of a strategic river network supports efficient irrigation systems, enabling consistent rice production year-round. In addition to irrigated rice, rainfed rice also contributes, although its coverage is smaller, only 0.25 km² or 0.02% of the total area. The monomodal rainfall pattern supports rainfed rice cultivation, but its sustainability requires drought-resistant varieties and planned water management.

Dryland farming, which dominates an area of 359.11 km², opens opportunities for diversification, with large-scale production of crops such as corn, soybeans, peanuts, and horticultural crops. This sector is a main pillar in supporting national food security while also strengthening the local economy. With integrated management, Manufahi District has great potential to support food self-sufficiency. The synergy between the development of both irrigated and rainfed rice, as well as dryland farming diversification, can become a key foundation for the national agriculture sector. Support from collaboration between the government, local communities, and modern technology will strengthen efforts to enhance sustainable food production.

Figure 11.3 Potential for Food Crop Development in Manufahi District
(Source: Researcher Documentation 2024)

XII. RECOMMENDATION

12.1 LAND MANAGEMENT RECOMMENDATION

These recommendations are based on comprehensive scientific research that maps the potential of regions in the Democratic Republic of Timor-Leste for the development of various commodities, including food/horticulture, plantations, forestry, and grazing areas. Land zoning, determined through land suitability evaluation, serves as the primary basis for designing land management strategies that support food security, economic sustainability, and environmental protection. The analysis resulted in six main zoning categories with the following areas: irrigated rice fields covering 21.22% of the total area, rainfed rice fields covering 0.02%, dryland farming/mixed farming covering 27.14%, agroforestry covering 25.70%, protected/conservation forests covering 25.37%, and mangroves covering 0.56%. This proportion reflects the diversity of biophysical potential and the urgency of implementing specific management approaches for each zone.

The food zone plays a strategic role in supporting national food security. Manufahi District, particularly Alas Sub-District, has been identified as a major food production center, expected to become a primary rice granary through the optimization of irrigation networks, soil management focused on fertility enhancement, and the application of sustainable agricultural technologies. The success of this zone is expected to directly contribute to achieving SDGs related to eradicating hunger and improving rural community livelihoods.

The agroforestry and protected forest zones, which cover 51.07% of the total area, play a vital role in economic diversification through the development of high-value commodities. Manufahi District has significant potential for industrial crops such as Robusta coffee, Arabica coffee, cacao, and coconut, as well as horticultural crops like avocado, mango, tomato, and chili. Integrated agroforestry systems that combine horticultural crops not only support land productivity but also contribute to soil and water conservation, erosion mitigation, and climate change adaptation.

The forestry zone, which includes protected forest areas, plays an essential role in protecting biodiversity, water resources, and mitigating climate change.

The development of production forests with high-value trees such as teak, mahogany, and Albizia is also recommended to provide added economic value while involving local communities in sustainable forest management.

The strategy designed here aims to support the achievement of SDGs related to food security, climate change, and water resource conservation. Through a zonal approach and solutions to limiting factors such as poor drainage, erosion risks, and surface rocks, these recommendations aim to promote sustainable development that balances both economic and ecological aspects. Recommendations for improving each limiting factor, as the basis for enhancing land suitability for the development of agricultural and forestry commodities, are presented in **Table 12.1.**

Tabel 12. 1 Recommendations for Improvement on Each Limiting Factor

No	Land Quality/Characteristic	Improvement Measures	Management Level
1.	**Temperature (tc)** - Average annual temperature	- No improvements possible - Replacement of suitable crops/varieties	- Cannot be improved
2.	**Water Availability (wa)** - Annual rainfall - Rainfall during growth period	- Irrigation/creating reservoirs/drip irrigation - Crop rotation/planting calendar	- Moderate, high
3.	- **Root Media (rc)** - Drainage - Texture - Effective depth - Coarse fragments	- Improve drainage system, such as creating drainage channels, ridges/beds - Cannot be improved, can be managed by adding organic matter - Generally cannot be improved, except in shallow, soft, and thin layers by tilling during land preparation \ - Depends on the amount and distribution in the profile (if <35%, it is called an obstructing layer and can be managed by adding organic matter and minimum tillage; if >90%, it is a restricting layer, difficult to improve)	- Moderate, high - High - Moderate, high - High
4.	**Nutrient Retention (nr)** - Soil CEC (Cation Exchange Capacity) - Base Saturation - pH - Organic Carbon (C-organic)	- Add organic matter - Lime application, add organic matter - Lime if soil pH is low, while high pH can be treated with sulfur or ZA fertilizer	- Moderate, high - Moderate, high, - Moderate, high - Moderate, high,

		- Add organic fertilizer, and return litter to the soil	
5.	**Nutrient Availability (na)** - Total N - Available P - Available K	- Apply N fertilizers (urea and ZA) - Apply P fertilizers (SP36 and TSP) - Apply K fertilizers (KCl) - Compound fertilizers (NPK)	- Low, moderate, high - Low, moderate, high - Low, moderate, high
6.	**rosion Risk (eh)** - Slope (%) - Erosion Risk	- Erosion reduction, terracing, contour planting, planting cover crops, applying mulch/plant litter, agroforestry implementation.	- Moderate, high
7.	**Flood Risk (fh)** - High - Duration	- Construct flood barriers, create drainage channels to expedite water disposal, build infiltration wells	- High
8.	**Land Preparation (lp)** - Surface rocks (%) - Rock outcrops (%)	- If the amount is small (remove rocks), if large/very large, use TOT (No-Till), create planting holes, add organic matter	- Moderate, high
9.	**Technical Cultural Improvements**	- Establish orchards, pruning, maintenance	- Moderate, high

Description :

1) *Low management level: Management can be carried out by farmers with relatively low costs.*
2) *Moderate management level: Management can be carried out by medium-level farmers, requiring medium capital and moderate agricultural techniques*
3) *High management level: Management can only be carried out with relatively large capital, typically done by the government or large or medium-sized companies.*

12.2 GLOBAL RECOMMENDATION

These recommendations provide strategic guidance based on data for policymakers in each Sub-District in Manufahi District. The main focus is on the management of the conservation sector integrated with the sustainable utilization of weeds. The strategies formulated aim to address complex ecological challenges while implementing management approaches that support food security, environmental sustainability, and improved community welfare.

One of the main challenges in Manufahi District is the presence of the invasive weed *Chromolaena odorata* (C. odorata), which has a high regeneration capacity. Conventional approaches like eradication are often considered ineffective due to the high costs and the potential to trigger further ecosystem degradation. As an alternative, a sustainable utilization-based approach is proposed to turn this challenge into an opportunity. This effort involves utilizing the economic, social, and ecological value of *C. odorata* through an integrated approach that includes soil conservation, agroforestry, and innovative weed management. This strategy offers a holistic solution to optimize natural resource potential and create long-term positive impacts for both the environment and community welfare.

A. New Paradigm: Utilization of *Chromolaena odorata*

1. Weaknesses of Eradication Approaches

Eradication methods previously implemented often fail due to the rapid regeneration of remaining roots and stems, as well as the high seed production, making complete eradication difficult. Furthermore, the use of herbicides poses serious risks to ecosystem health.

Destructive methods, such as the widespread practice of slash-and-burn, can also accelerate land degradation. Therefore, a paradigm shift towards a sustainable weed utilization strategy is needed to optimize its ecological potential without damaging the environment.

2. Sustainable Utilization for Economic Value

a) Biomass for Agriculture

C. odorata biomass has the potential to be processed into fermented organic fertilizer or vermicompost, which can improve soil fertility, especially in marginal lands. This innovative approach can be implemented in Manufahi District to support the sustainable and environmentally friendly enhancement of agricultural productivity.

b) Pharmaceutical and Health Products

Extracts from *C. odorata* have proven antimicrobial, anti-inflammatory, and anticancer properties. Further research is required to develop this plant as a raw material for pharmaceuticals and local cosmetics, which can increase its economic value.

c) Bioenergy

The biomass of this plant can also be utilized as biochar or plant-based fuel. Bioenergy production from *C. odorata* not only reduces dependency on fossil fuels but also creates business opportunities in rural areas.

d) Community Empowerment

The success of this strategy depends on three key elements:

- Community Training and Education

Enhance skills in processing biomass into high-value products such as organic fertilizer, biochar, or herbal materials.

- Collaboration between Government and Academia
  Develop simple, multidisciplinary research-based technologies to support the efficient utilization of *C. odorata*.
- Partnerships with the Private Sector
  The role of the fertilizer, pharmaceutical, and energy industries in supporting production and marketing of *C. odorata*-based products. This approach is designed to create synergy between environmental, technological, and economic aspects to support sustainability and the welfare of local communities.

3. Policy and Regulations

The sustainable weed management approach includes three strategic steps:

a.) **Inventory and Mapping:** Identify priority areas that require weed management intervention.
b.) **Economic Incentives:** Encourage farmer and business participation in the sustainable utilization of resources.
c.) **Socialization and Education:** Increase public understanding of the potential and benefits of *Chromolaena odorata.*

B. Soil and Water Conservation

Soil and water conservation recommendations are based on efficiency and ease of implementation.

1. Agroforestry Systems for Conservation

The agroforestry approach offers sustainable solutions by integrating environmental conservation with economic production. Three main systems recommended include:

a.) **Agrisilviculture,** which combines food crops with timber trees in one area.
b.) **Silvopastoral,** combining trees with grazing land as a source of animal feed.
c.) **Agrosilvopastoral,** integrating crops, trees, and livestock in one land area. This strategy is designed to enhance productivity while supporting environmental preservation.

2. **Biopore Holes and Drainage Channels**

This technology supports water infiltration and prevents waterlogging in horticultural and rocky lands. It also helps improve groundwater storage.

3. **Erosion Risk and Slope Conservation**

Manufahi District has a landscape dominated by steep lands, thus facing high erosion risk. Recommended conservation solutions include:

a.) **Terracing:** Control water flow, enhance water absorption into the soil, and support farming practices on slopes.

b.) **Cover Vegetation:** Use plants such as legumes and grasses to protect the soil surface and prevent erosion.

These steps support environmental sustainability and improve land productivity.

4. **Check Dam Technology**

A check dam is a structure designed to reduce erosion in water channels. Three main types are recommended based on the characteristics of their use locations:

a.) **Brushwood**: Made from wood or twigs, effective for small water channels.

b.) **Loose Stone**: Uses loose stones, suitable for rocky areas.

c.) **Gabion**: Consists of wire baskets filled with stones, ideal for retaining water flow in large channels.

Each type of check dam is designed to meet the specific needs of the location to optimize water resource management.

5. **Regulations**

Government policy plays a crucial role in supporting conservation efforts, especially on land with slopes exceeding 45%. Additionally, the presence of customary law in each village is also important as a tool for regulating conservation actions.

C. Addition of Organic Matter and Fertilization

Most of Manufahi's areas have low organic matter content, which impacts soil fertility, water retention capacity, and microorganism activity. The following steps are recommended to address this:

1. **Utilization of Local Organic Waste**

Manure, compost, and biochar made from organic waste can be used to improve soil structure, detoxify the soil, and enhance biological activity to increase soil resilience. This improvement is highly effective for supporting crops like upland rice, sorghum, chili, and tomato.

2. Addition of Plant Litter

   Applying organic litter on the soil surface as mulch helps retain moisture, improve water retention, and prevent erosion. This technique is suitable for both flat and sloping lands at risk of drought.

3. Location-Specific Fertilization

   Applying macro fertilizers at doses of 200 kg NPK ha^{-1}, 175 kg Urea ha^{-1}, 40 kg SP-36 ha^{-1}, and 100 kg KCl ha^{-1} is recommended to improve nitrogen, phosphorus, and potassium availability. These fertilizers support rice paddy development according to local soil fertility characteristics.

D. Drainage Management and Shallow Soil Depth

Poor drainage and shallow soil depth are significant challenges in rocky and sloped areas. The recommended technical solutions include:

1. Improving Drainage Channels with Ridges/Beds

   Drainage channels, such as ridges or beds, are designed to prevent waterlogging and support efficient water management, particularly in horticultural lands. This system can improve water use efficiency, reduce water loss, and increase soil aeration.

2. Biopore Holes/Rorak and Infiltration Wells

   This technique helps improve water infiltration in rocky soil, where organic matter from plant residues or other organic fertilizers can be stored, improving drainage quality. Biopores can also enhance water storage capacity during the dry season.

3. Creating Deep Planting Holes

   Deep planting holes allow plants to root strongly, especially industrial crops like coconut and timber trees, which are often planted in soils with shallow effective depth.

E. Alternative Crop Development on Rocky Lands

Rocky lands require adaptive strategies that optimize plant capacity to thrive under challenging conditions. Recommended alternatives include:

1. Spice and Medicinal Plants

Commodities such as turmeric, ginger, galangal, and Aromatic Ginger are suitable for rocky lands. Planting under the canopy of forestry trees provides additional protection and improves land use efficiency.

2. Cover Crops

Legume plants and Setaria grass are recommended to reduce erosion, improve organic matter, and enhance soil structure.

3. Deep-Rooted Industrial Plants

Coconut and timber trees are the main options due to their tolerance to shallow soil depth and ability to grow in rocky soils.

F. Implementation Strategy

The implementation strategy designed based on land zoning aims to optimize land management in Manufahi District. This land zoning includes several categories such as irrigated rice fields (21.22%), rainfed rice fields (0.02%), dryland farming/mixed farming (27.14%), agroforestry (25.70%), protected/conservation forests (25.37%), and mangroves (0.56%). This zoning serves as the foundation for planning management that focuses on improving food security, economic sustainability, and environmental preservation. This zonal approach requires relevant implementation steps, such as:

1. Optimization of Food Zone Production

The food zone, which includes irrigated rice fields and rainfed rice fields, plays a strategic role in supporting national food security:

a.) Expansion of Irrigation Networks:

- Prioritize the expansion of irrigation networks in Manufahi District, particularly in Alas, Fatuberliu, and Same Sub-Districts.
- Develop micro-irrigation systems and reservoirs to support intensified cropping patterns.

b.) Management of Rainfed Rice Fields:

- Increase productivity in Turiscai Sub-District by using drought-tolerant rice varieties.
- Provide training for farmers in using simple water management systems, such as rainwater harvesting.

c.) Diversification of Commodities:

Optimize the use of food zones for other commodities, such as corn, soybeans, and cassava, as part of food diversification efforts.

2. Utilization of Agroforestry and Protected Forest Potential

The agroforestry and protected forest zones, covering 46.83% of the total area, provide significant opportunities for economic diversification while conserving ecosystems:

a.) **Development of Agroforestry Systems:**

- **Industrial Crops:** Focus on high-value commodities such as Robusta coffee, Arabica coffee, cacao, and coconut.
- **Horticulture:** Integrate fruit trees (avocado, mango) and vegetables (tomato, chili) with forestry trees on sloped land to support soil conservation.

b.) **Protected Forest Management:**

- Prioritize biodiversity protection, climate change mitigation, and land resource management.
- **Utilize production forests,** such as planting teak, mahogany, and Albizia to add economic value while involving local communities in sustainable forest management.

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

3. **Infrastructure and Technology Development**

a.) **Supporting Infrastructure Development:**

- **Build reservoirs and rainwater harvesting** systems to support water needs in rainfed rice fields and drylands.
- **Provide drainage channels** to control water runoff in sloping areas, particularly in agroforestry zones.

b.) **Use of GIS and Remote Sensing Technologies:**

- Map land potential to support accurate spatial planning.
- Monitor land cover changes to evaluate the success of conservation strategies

4. **Community Capacity Building**

a.) **Training and Education:**

- Provide training in soil conservation and water management for farmers in each zone.
- Educate on commodity diversification in agroforestry zones to improve income.

b.) **Community Empowerment:** Establish farmer groups based on zoning to support the implementation of participatory strategies.

c.) **Empowerment of Women:** Train in agroforestry and weed biomass management to support social inclusion and improve household income.

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

a.) **Utilization of Biomass:**

- Process biomass into organic fertilizer to improve soil fertility.
- Produce biochar and briquettes as local bioenergy.

b.) **Development of Herbal Products**: Research the potential of *C. odorata* as a traditional medicine raw material through cooperation between government and the pharmaceutical sector.

c.) **Multistakeholder Collaboration:** Develop weed utilization technologies involving government, academia, and the private sector.

6. **Integrated Spatial Planning Zoning**

The spatial planning zoning approach allows for more effective land use:

a.) **Protected and Conservation Forests** for land with slopes >45%.

b.) **Agroforestry Zone** for land with slopes of 15-45% (timber and horticultural crops).

c.) **Intensive Farming Zone** on flat land to 15% slope (main food crops).

7. **Policies and Incentives**

The sustainable management approach includes two main steps:

a.) **Economic Incentives:**

- Subsidies for farmers adopting conservation technologies.
- Microcredit for agroforestry-based businesses or weed utilization.

b.) **Zoning Regulations:** Regulate land use based on suitability zoning to ensure sustainable management.

8. **Monitoring and Evaluation**

This strategic approach involves two main steps:

a.) **Data-Based Monitoring**: Use GIS to assess the effectiveness of strategies and detect changes in land conditions.

b.) **Participatory Evaluation**: Involve local communities, stakeholders, and the government in evaluating the relevance and sustainability of the strategy.

This implementation strategy integrates scientific approaches, modern technology, and community participation. With zoning as the basis, this strategy not only addresses conservation and food security challenges but also promotes sustainable local economic development in Manufahi District.

12.3 LIVESTOCK SECTOR

The KTS Dotik Center aligns with the national-scale plan for the development of Timor buffalo to meet the community's milk needs. The short-term recommendation starts with preparing high-nutrient livestock forage land for milk productivity. The government can introduce additional varieties of livestock forage such as Setaria grass and legumes such as Gamel, Kaliandra, and Indigofera.

Technically, it is important to consider the forage composition, with a combination of 60% grass and 40% legume. Additionally, the use of supplementary feed such as bran, concentrate, or flushing feed in specific buffalo conditions is recommended. The long-term recommendation involves enhancing reproductive technology and training and educating workforce resources. There needs to be significant attention to the reproductive aspect, which directly impacts milk production through workforce training.

A potential challenge in the future could be silent heat or quiet estrus, which can occur in buffalo livestock. This can be addressed if workers have sufficient education and expertise in reproduction, allowing them to detect estrus accurately. Furthermore, training can be enhanced through certified artificial insemination (AI) training, with the expectation that the KTS Dotik Center can adapt to livestock technologies that will increase milk production efficiency. Once facilities are adequate, the KTS Dotik Center can implement sexing methods for livestock breeding as a step to increase the chances of female births for seed production and milk production.

12.4 FRESHWATER FISHERIES SECTOR

Manufahi District shows great potential for aquaculture development, both in the highland and coastal areas. Three main Sub-Districts evaluated, Same, Fatuberliu, and Alas, have different ecological and social characteristics, but each provides specific opportunities for freshwater and coastal fish farming development.

The evaluation shows that freshwater species such as catfish, tilapia, gourami, and Nile tilapia have a relatively high land suitability in most of Manufahi District, with actual values ranging from 3.20 to 3.54, and the potential suitability can be increased to 3.66 after environmental improvements and production input management.

The main limiting factors are land slope, prolonged dry seasons, and temperature fluctuations, especially in highland areas such as Suco Letefoho. In coastal areas such as Fatuberliu and Alas Sub-Districts, additional constraints such as low salinity and limited infrastructure access hinder the development of certain species, especially brackish water commodities.

Although brackish water species such as milkfish, vannamei shrimp, and mangrove crabs have been tested for suitability, their actual suitability values are still relatively low due to limiting factors such as low salinity and slope. However, there is still potential for improving the suitability of these species, especially in areas with access to lagoons or mangrove ecosystems such as around Fatuberliu and the coast of Alas, where the potential value could increase to 3.66–3.78 after technical interventions.

Thus, the development of freshwater species remains the primary priority in all Sub-Districts, especially in Same and Fatuberliu. For brackish water species farming, limited-scale development may be considered in certain coastal areas, provided there is infrastructure investment and adequate water quality management.

1. Specific Location Technical Recommendations

Tabel 12. 2 Specific Location Technical Recommendations

Location	Main Issues	Technical Recommendations
Same Sub-District (Letefoho Village)	- Low temperature (16°C at night) - Low survival rate (±40%) - No aeration in some units	- Apply passive heating technology (mini greenhouse or insulating tarpaulin) - Implement aeration system in all units - Focus on species tolerant to cold temperatures (e.g., tilapia)
Fatuberliu (Balai Centru Clacuc)	- Limited household participation in business	- Extension and technical training programs to encourage community participation
Alas (Uma Berloic Village)	- Limited land and low accessibility	- Rehabilitate marginal land with vertical farming technology

2. Pilot Project Location Determination

Based on the integration of field observations, secondary agrisensus data, actual-potential land suitability, and local institutional capacity, the Centru Clacuc Aquaculture Center in Fatuberliu Sub-District is recommended as the pilot project location. The location is situated in a semi-coastal area, with infrastructure support of 20 ha, and the recommended commodities are tilapia, carp, catfish, as well as the potential use of lagoons for developing mangrove crab commodities.

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

a.) Budget allocation for the development and renovation of aeration systems, mini-laboratories, and self-sustaining feed units.

b.) Collaboration with research institutions and donor agencies to enhance the technical capacity of aquaculture farmers.

c.) Placement of technical staff in each Sub-District to assist with the pilot project and monitor water quality and fish health.

d.) Involve women and youth in aquaculture activities through community-based training programs.

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Manufahi Municipality

Manufahi Municipality occupies a strategically important geographic position as part of the main corridor of the national rice granary area in the southern zone of Timor-Leste, extending from Municipality Viqueque to Covalima, Ainaro, and Hatu Udo. The Municipality demonstrates strong capacity for integrated and sustainable agricultural development, supported by a proportional land use pattern. The land use structure consists of irrigated rice fields covering 21.22 %, rainfed rice fields covering 0.02 %, dryland agriculture covering 27.14 %, and forest areas comprising protected forest (25.37 %) and mangrove forest (0.56 %) of the total Municipality area.

Based on land suitability analysis, Municipality Manufahi has potential for leading commodities across multiple subsectors that support integrated agricultural development. These include irrigated lowland rice in wetland areas; rainfed rice and corn in dryland areas; fruit horticulture such as mango and watermelon; and vegetable horticulture including chili and cucumber. The Municipality is also suitable for the development of spice crops such as cinnamon and candlenut, as well as industrial crops including Robusta Coffee and Arabica Coffee, particularly in Administrative Post Turiscai. In addition, the area is suitable for forage-based grazing systems dominated by elephantgrass and for the development of forestry species such as mahogany and teak. Furthermore, Municipality Manufahi has strong potential for the development of Bali cattle and buffalo livestock, supported by the availability of forage resources such as Gliricidia (gamal) and Leucaena (lamtoro), and by the presence of KTS Dotik in Village Alas, which has potential to serve as a national dairy development center. The Municipality also shows potential for fisheries, specifically gourami and catfish aquaculture in Administrative Post Fatuberliu, implemented through sustainable aquaculture systems.

These potentials can be optimized through the implementation of planned, integrated, and policy-oriented multisectoral management, including the development of integrated farming systems based on the five key farming practices, integration with livestock systems, and the intensification of sustainable aquaculture. In this context, Villages Clacuc, Dotic, Betano, Babulu, and Letefoho are recommended as pilot project locations for integrated agricultural development. The implementation of these policy measures is expected to strengthen national food security, increase productivity and competitiveness in the agricultural sector, and support Timor-Leste's readiness to respond to regional dynamics, including within the context of ASEAN membership.