Distribution and Potential of Peatlands in Asmat Regency, Papua, Indonesia

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Abstract— *This study provides a comprehensive analysis of the distribution and potential uses of peatland in Asmat Regency, Papua, Indonesia, a region that holds significant peatland areas of global ecological and economic importance. Through a combination of field surveys, remote sensing data analysis, and laboratory soil testing, the study maps the extent, depth, and characteristics of peat soils across the Asmat Regency. The findings reveal diverse peatland ecosystems, ranging from coastal mangroves to inland freshwater swamps, with peat depths exceeding 3 meters in several areas, indicating substantial carbon storage capacity. The study evaluates the soil's physicochemical properties, such as acidity (pH), organic matter content, and nutrient availability, which are crucial for determining its suitability for agriculture, forestry, and conservation efforts. Additionally, the research addresses the challenges of sustainable management and the risks associated with peatland degradation, such as carbon emissions and biodiversity loss. It proposes strategies for utilizing peat soils that align with environmental conservation and sustainable development goals. This includes recommendations for agroforestry practices, peatland restoration, and the implementation of community-based management approaches that benefit the local population while preserving these vital ecosystems. The study underscores the importance of integrating local knowledge with scientific research to foster the sustainable use of peat soils in Asmat Regency and similar contexts globally.*

Keywords— ***Agroforestry, Carbon Storage, Peat Soil, Soil Properties, Sustainability.***

I. INTRODUCTION

Indonesia is ranked 4th in the world for its potential in extensive peat deposits. These deposits are spread across Indonesia, covering approximately 17 million hectares in 1987, or about 60% of the world's tropical peatlands. The island of Papua alone has about 8.5 million hectares of peatland, approximately 50% of Indonesia's total peatland area. With the widespread presence of peatlands in Indonesia, it represents a potential that can be developed for various purposes and can support the local economy. Otherwise, according to Harrison et al., (2019), the Indonesian government acknowledges the presence of peatlands in Papua, which account for approximately 25% to 38% of the total Indonesian peatland area. Papua holds a substantial amount of carbon within its peatlands, contributing to the vast peat carbon storage in Indonesia (Warren et al., 2017). These peatlands are part of the larger Indonesian peatland area, which is distributed across Sumatra, Kalimantan, and Papua (Graham et al., 2016). Indonesia, the country with the largest peatland area globally, has a significant portion of its peatlands located in Papua (Suwito et al., 2021).

In the last decade, there has been increasing concern over the significant loss and damage to the peatland ecosystem in Indonesia, leading to the destruction of peatland biodiversity, water management issues, and the release of millions of tons of carbon into the air. The conversion of peatlands, drainage, and over-exploitation of peatlands have been known to cause fires that have destroyed or damaged peatlands. To avoid further degradation, immediate efforts are needed to improve this condition by involving various parties. Efforts have been undertaken to restore degraded tropical peatlands in Indonesia, including those in Papua. The establishment of the Peat Restoration Agency (PRA) aimed at restoring burned peatland areas, encompassing approximately two million hectares across several provinces, including Papua (Yuwati et al., 2021). Additionally, sustainable management practices have been proposed to address climate change through the management of degraded peatlands in Central Kalimantan, Sumatra, and Papua (Surahman et al., 2019). These initiatives underscore the importance of tackling the challenges associated with peatland conservation and restoration in Papua and other regions of Indonesia.

One of the parties directly linked to the management of these peatlands is the community. Community involvement in reducing the threat and damage to peatlands is very significant, given the interaction with the utilization patterns and rate of damage. An essential action that the community can take is to guide how to manage peatlands for utilization purposes with traditional cultural patterns (local wisdom) that integrate the development of cultivation technology and agricultural cultural values. The concept of a social license to operate (SLO) has been adapted from business management literature to assess the impact of community engagement on peatland restoration in Indonesia (Wiesner & Dargusch, 2022). This underscores the importance of community participation in peatland management initiatives. Additionally, exploring community home yard innovations in utilizing degraded peatlands has the potential to restore peatlands and enhance livelihoods, showcasing the dual benefits of community-led initiatives (Sakuntaladewi et al., 2022). Efforts to engage communities in peatland restoration have been observed in various regions. For example, a study in Sungai Tohor, Indonesia, showcased the active participation of the community in peatland restoration efforts (Handoko et al., 2020). Furthermore, the Village Fund for Peatlands Restoration in the Muaro Jambi District illustrates how community engagement can address challenges and opportunities in peatland restoration (Sujai et al., 2021).

The purpose of this study is to identify the location, boundaries, extent, and allocation of peatlands in the area around Asmat Regency. The objective of this work is to guide the community and government on the management of peatland areas in connection with economic activities in Asmat Regency.

II. MATERIALS AND METHODS

2.1 Materials

The image data used in this research is the Landsat TM5 Satellite Imagery with 6 bands, namely Band 1, 2, 3, 4, 5, and 7. Band 6 was not used because it is specifically for capturing thermal data. The image preparation consisted of contrast enhancement, geometric correction of the image, and composite assembly. This image preparation process used the Dimple 3.0 image processing software, with steps including contrast enhancement, assembly of various composite images, and geometric correction using the nearest neighbor method. Land cover data was obtained using a vegetation index approach, in this case, the Normalized Difference Vegetation Index (NDVI) was chosen and calculated using the equation: NDVI = (Band 4 – Band 3) / (Band 4 + Band 3), according to Lillesand & Kiefer (1990).

Band 4 refers to the band in the near-infrared wavelength range (Near Infrared, NIR), and Band 3 refers to the band in the red wavelength range. If the resulting image is of poor contrast quality due to weather conditions, then the image classification used is by interpretation method. Based on this NDVI calculation, an NDVI image reflecting vegetation cover on the Earth's surface was obtained. To obtain spatial information about vegetation cover classes, a density slicing process was then performed, following the class boundaries used in the vegetation cover land assessment. The class boundaries in the density slicing process were determined by multiplying the NDVI value by the class boundaries used for assessment in land cover conditions (satellite image transmission flow diagram is shown in Figure 1).

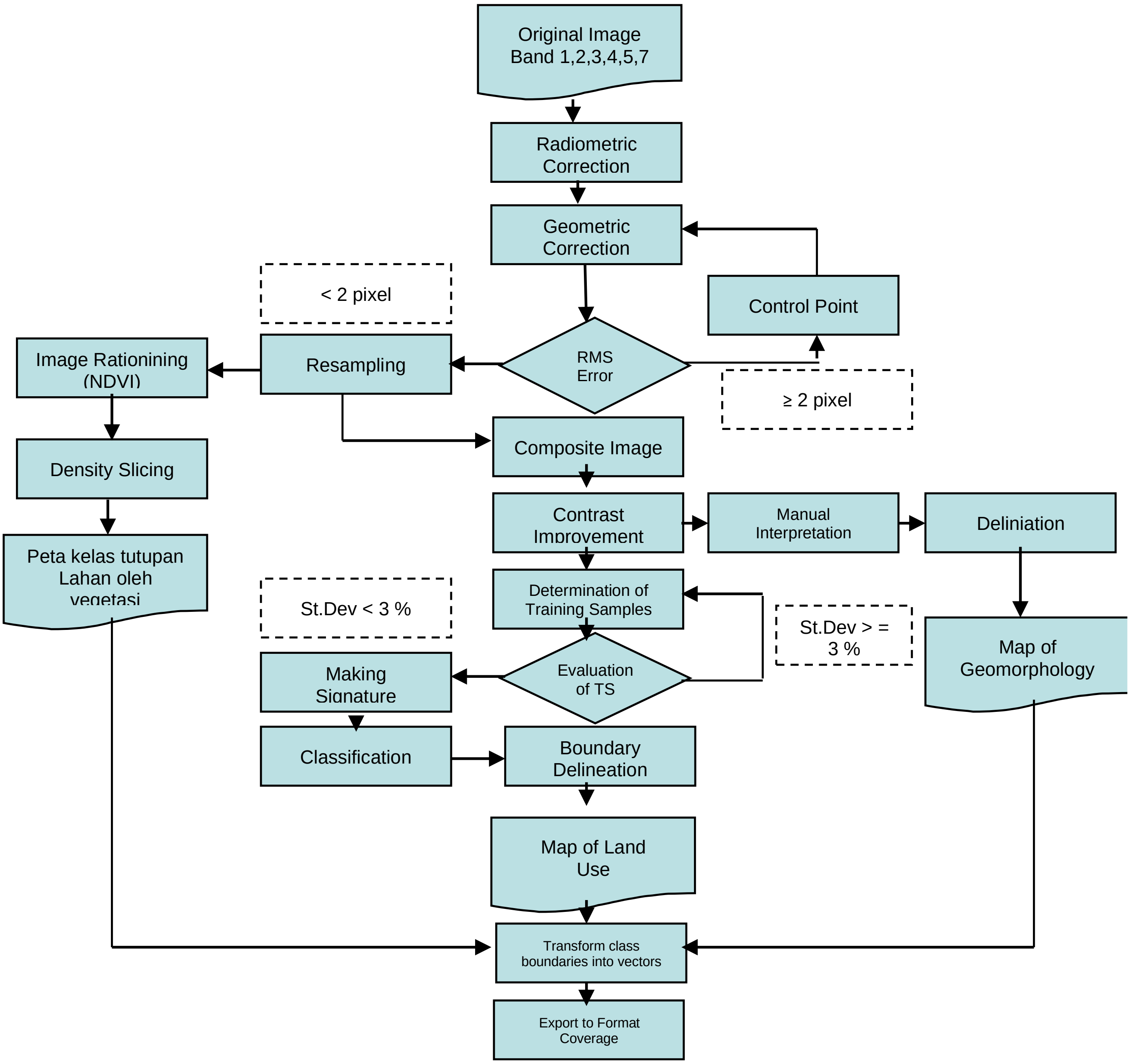

FIGURE 1: Satellite Image Transmission Flow Diagram

2.2 Methods

To thoroughly investigate the distribution and potential of peatlands in Asmat Regency, Papua, Indonesia, our research employed a multidisciplinary methodology combining remote sensing and GIS analysis, field surveys, socio-economic analyses, and environmental impact assessments. Initially, a comprehensive literature review was conducted to establish a theoretical framework and identify gaps in existing knowledge regarding the peatlands of Indonesia, with a focus on Asmat Regency. This was followed by the utilization of satellite imagery and aerial photographs, analyzed using Geographic Information System (GIS) tools, to map the extent and characteristics of peatlands accurately (Carless et al., 2019). To validate these remote sensing findings, extensive field surveys were carried out. These surveys included ground-truthing, peat depth measurements across various sites, and the collection of soil samples for laboratory analysis to determine their physicochemical properties, such as pH, organic content, and nutrient levels.

Land potential identification is carried out using the Land Evaluation method. Land evaluation is part of the land use planning process. The essence of land evaluation is to compare the requirements demanded by the type of land use to be applied with the characteristics or quality of the land that will be used (Bechtold et al., 2019). By doing so, the potential of the land or the suitability/capability class of the land for that type of land use will be known. The findings were then synthesized into a detailed report and disseminated among the scientific community, government bodies, and non-governmental organizations, offering evidence-based recommendations for policy and practice aimed at the sustainable utilization and conservation of peatlands in Asmat Regency.

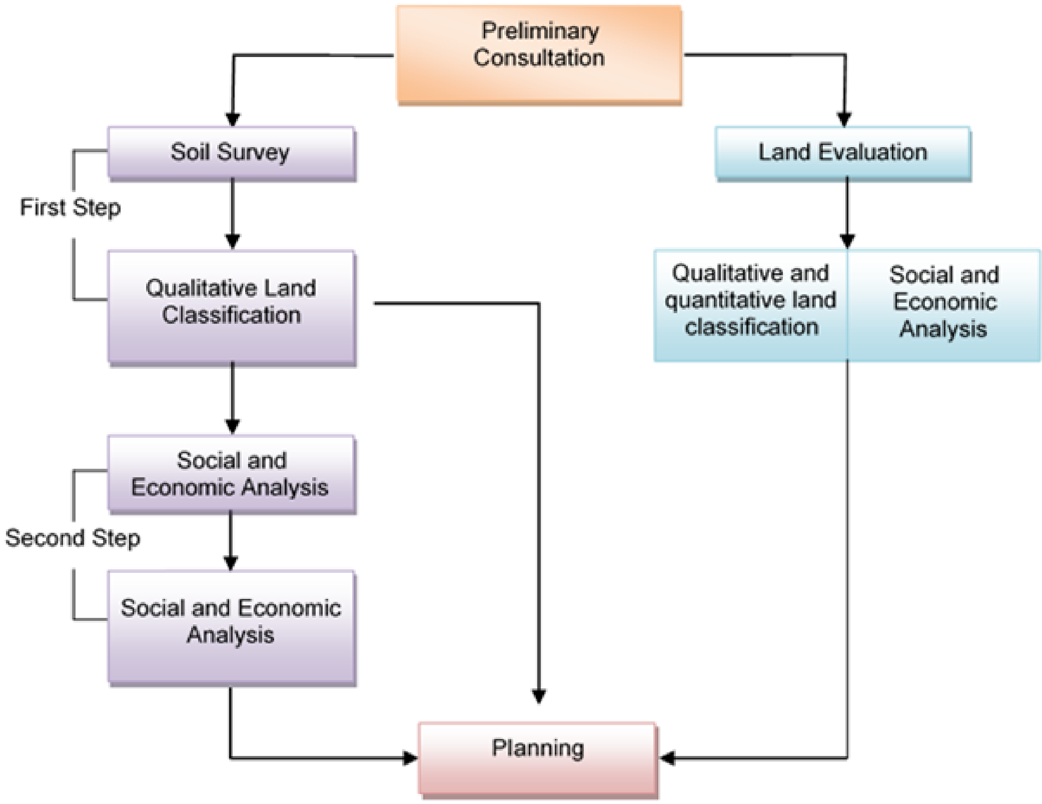

FIGURE 2: Two-Stage and Parallel Approaches to Land Evaluation (FAO, 1976)

Simultaneously, a socio-economic analysis was undertaken through surveys and interviews with local communities and stakeholders to gauge the socio-economic context, including land use practices and the potential for sustainable management of peatlands (Lestari et al., 2023). This also involved evaluating the economic activities related to peatlands, like agriculture, forestry, and eco-tourism, to assess their viability and sustainability. An environmental impact assessment was integral to understanding the biodiversity, hydrology, and carbon sequestration capacities of these ecosystems, alongside identifying potential threats such as land conversion, drainage, and fires.

III. RESULT AND DISCUSSION

3.1 Physical and Spatial Analysis

3.1.1 Soil Map Units (SMUs)

SMUs are arranged based on survey level with a review or reconnaissance level map scale. The SPT boundaries are prepared following the boundaries of physiographic units or landforms by also taking into account the shape of the area or relief and the size of the slopes. Information regarding physiography and landforms is obtained through the interpretation of Landsat satellite images, then the results of this landform interpretation are classified based on a landform classification system with a physiographic or geomorphic approach.

Through this classification system, landforms are grouped into 10 main landform groups, namely: (1) alluvial, (2) marine, (3) fluvio-marine, (4) peat, (5) eolian, (6) karst/karstic, (7) volcanic, (8) uplift, (9) folds and faults, and (10) miscellaneous (influence of human activities, such as mining and others). Furthermore, the division of these main landforms is based on differences in relief and slopes, lithology, and level of incision.

Based on homogeneity in geological/lithological conditions, soil, slopes, climate, and land use in Asmat Regency there are around 28 SMUs, which are shown in Figure 3.

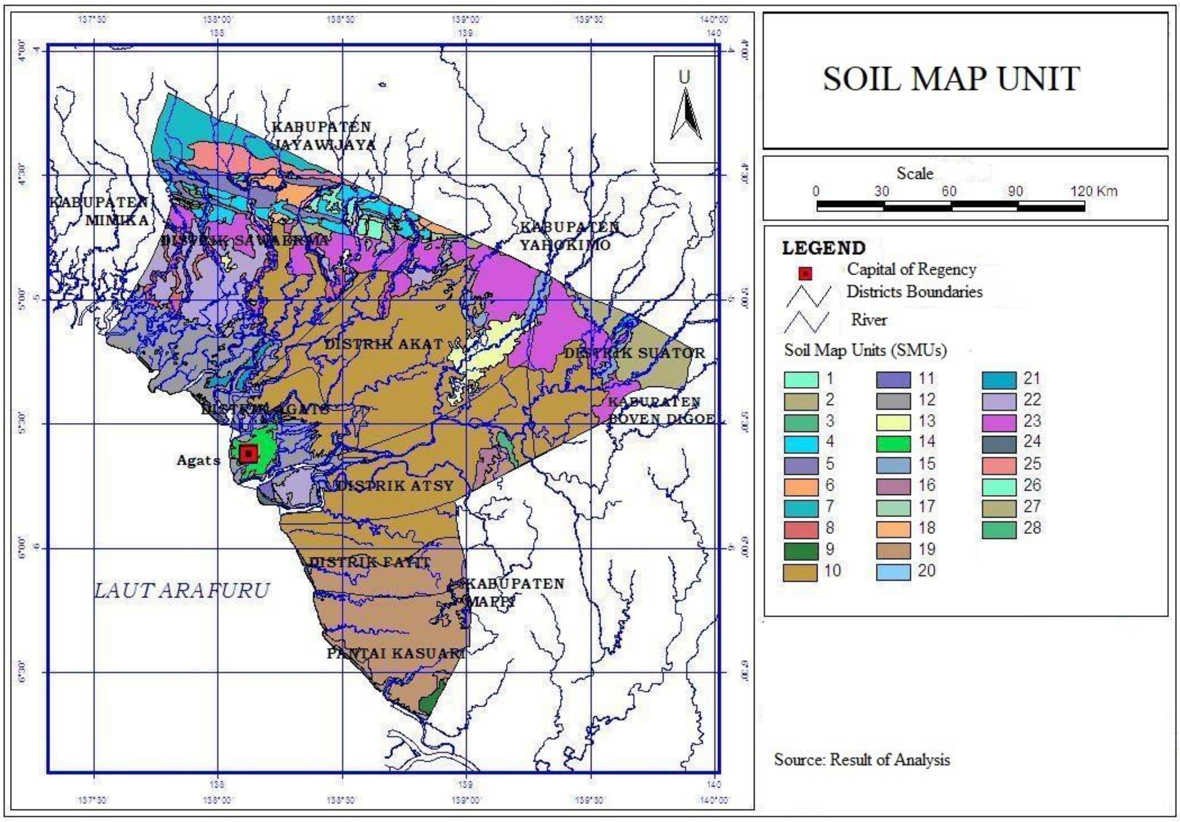

FIGURE 3: Soil Map Units of Asmat Regency

TABLE 1
SMUs DESCRIPTION OF ASMAT REGENCY

SMUs	Soil Type	Landform
1	Dystropepts, tropaquepts, tropohemists	Terrace and remaining terraces; slope 2-8%; height difference < 10 m
2	Dystropepts, eutropepts, tropofluvents	Alluvial Fan Plains; slope: 2-8%; height difference < 10 m
3	Dystropepts, tropofluvents	Alluvial fan ridges, colluvial fans; slopes 9 - 15; height difference 11 - 50 m
4	Dystropepts, tropudalfs/tropudults	Fans & terraces are strongly incised; slope 16-40%; height difference 50-300 m
5	Dystropepts, Tropudults, Tropofluvents	Parallel ridges; slope: 26-60%; height difference 51-300 m
6	Dystropepts, Tropudults, Tropudalfs,	Hilly terrain; slope 41-60%; height difference 51-300 m
7	Dystropepts; humitropepts; tropaquods	Steep mountain ridges; slope: > 60%; height difference > 300 m
8	Eutropepts; Tropaquepts; Tropofluvents	River meanders; slope < 2 % (flat)
9	Paleustults	Coastal plains with erosion residue; slope 9-15%; height difference 11-50 m
10	Paleustults, haplustults	Undulating coastal plains; slope 2-8%; height difference < 10 m
11	Rock; Troporthents; tropohemists	Hill/mountain peaks with exposed rock; slope > 60%; height difference >300 m
12	Sulfaquents; Sulfaquepts; Sulfihemists	Tidal Area with mangrove associations; slope < 2%
13	Tropaquents; Hydraquents; Tropohemists	Peat swamp lake, flooded all year round; slope < 2%
14	Tropaquents; Sulfaquents	New coastal plain with parallel drainage pattern; slope < 2%
15	Tropaquents; Tropaquepts; Tropohemists	River back swamp; slope < 2 %
16	Tropaquepts, paleustults, tropohemists	New alluvial plain with remains of old plain; slope < 2%
17	Tropaquepts, tropaquods, tropohemists	Old alluvial fan; slope 2 - 15 %
18	Tropofluvents, tropaquepts, eutropepts	Terraced river basin, slope < 2%
19	Tropohemists; Tropaquents	Swamp with short terraces; slope < 2%
20	Tropohemists; Tropaquents; Hydraquents	Swamp behind the river, periodically flooded; slope < 2 %
21	Tropohemists; Tropaquepts; Tropaquents	Swamps on the coastal plain, flooded all year round; slope < 2 %
22	Tropohemists; Troposaprists; Tropaquents	Marshes on the coastal plain, seasonally inundated; slope < 2 %
23	Tropohemists; Tropaquepts; Tropofluvents	Swamp with lower terraces; slope < 2 %
24	Tropopsamments; Tropaquepts; Eutropepts	Sandbars, coastal areas; slope < 2 %
25	Troporthents, Tropudults, Dystropepts	Parallel mountain ridge; slope > 60 %; height difference > 300 m
26	Tropudalfs, tropaquepts	Wavy - undulating plains; slope 2-8%; height difference 11-50 m
27	Tropudalfs, troporthents	Steep ridge; slope 41-60%; height difference 11-50 m
28	Tropudalfs, tropudults, dystropepts, eutropepts	Low hilly terrain; slope 16-25; height difference 11-50 m

From the description above, it can be seen that almost 80% of the soil map units have peat soil types (Histosol/Organosol) which are formed in the swamp areas of coastal basins. The wide distribution of peatlands is the basis for considering the need for a comprehensive study regarding its utilization considering that this type of land has unique characteristics. Mismanagement of land like this can result in environmental damage both locally and globally.

Peatlands are unique ecosystems characterized by the accumulation of dead organic matter, primarily plant material, in waterlogged conditions where decomposition rates are slower than the rate of organic matter production. The formation of peatlands is a complex process influenced by various factors. Studies such as those by Yu et al. (2010) and Yin et al. (2022) suggest that peatland expansion and carbon accumulation are controlled by different factors in different regions, with nitrogen supply playing a crucial role in supporting peatland formation. The slow decomposition of plant litter, as highlighted in research by Silvianingsih et al. (2022), is a key aspect shaping peatland development. Additionally, the role of roots in peatland formation, as discussed by Hoyos-Santillan et al. (2015), underscores the importance of vegetation in the accumulation of peat. Overall, the formation of peatlands is a dynamic process influenced by hydrology, plant productivity, decomposition rates, and environmental conditions, leading to the gradual accumulation of peat over time.

3.2 Description of Peat Soils

Peat soils in Indonesia, particularly in Papua and Asmat Regency, are characterized by their high organic content, low shear strength, and high compressibility. Studies such as those by Mohamad et al. (2021) and Wahab et al. (2022) highlight the unstable nature of peat soils due to their poor engineering properties, making them unsuitable for construction and agriculture. The physical properties of peat soils, including high moisture content and organic content, are key indicators of their occurrence, as emphasized by Al-Ani (2013). Peat soils in Indonesia, which encompass a significant portion of the world's tropical peatlands, are predominantly found in regions like Papua and Sumatra, as noted by Wang et al. (2021). The irreversible drying of peat soils, as discussed by Lestari (2023), poses a significant challenge, further emphasizing the unique characteristics and challenges associated with peat soils in Indonesia, Papua, and Asmat Regency.

3.2.1 Peat Soils Distribution Based on Maturity

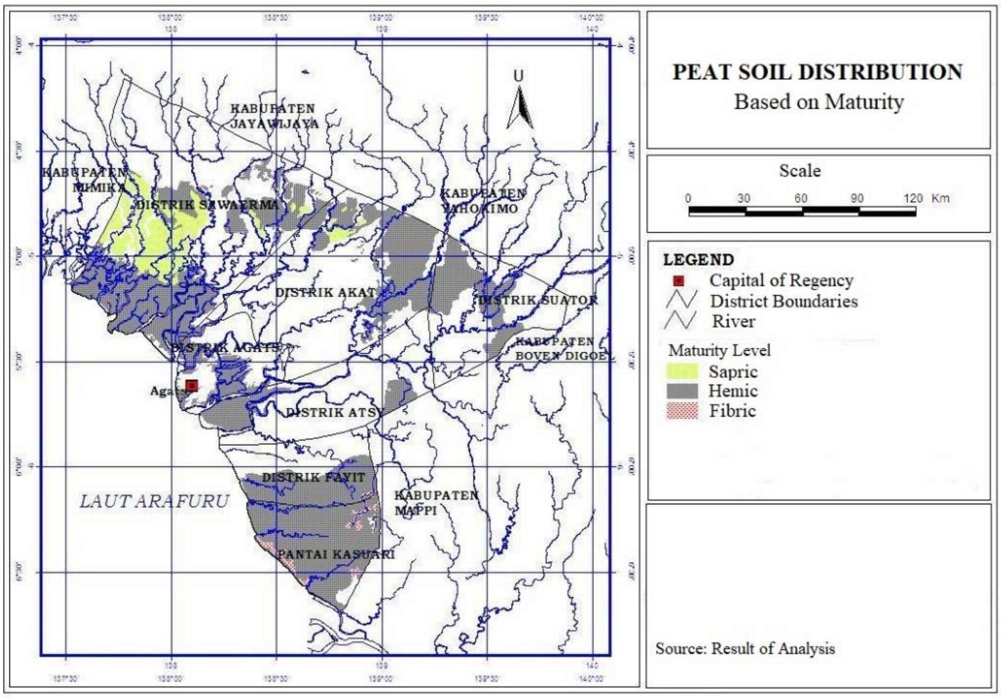

FIGURE 4: Peat Soil Maturity Distribution of Asmat Regency

Based on observations in the peat field at the study location, it is classified based on the level of maturity, depth, fertility, and position of formation. Based on the level of maturity, peat is divided into:

a) Sapric (mature) peat is peat that has been further decayed and the source material is unknown, dark brown to black, and when crushed the fiber content is <15%.

b) Hemic (moderately mature) peat is semi-rotted peat, some of the original material can still be recognized, is brown, and when crushed the fiber content is 15 – 75%.

c) Fibric (raw) peat (Figure 4, top) is peat that has not yet rotted, the original material can still be identified, is brown, and when crushed >75% of the fiber remains.

The maturity of peat soil in Indonesia, Papua, and Asmat Regency is influenced by various factors that contribute to the development and characteristics of these peatlands. Studies such as those by Imanudin et al. (2022). Additionally, the analysis of FTIR spectroscopic data by Siregar et al. (2022) reveals distinctions in hydrophilic and hydrophobic levels of peat at different maturity stages. The influence of drainage on peat organic matter, as discussed by Fulazzaky et al. (2022), highlights the role of decomposition intensity in peat maturity.

3.2.2 Peat Soils Distribution Based on The Depth

The results of identification using satellite imagery showed that the area of peat swamp land in Asmat Regency reached 80% of the total area which is divided based on depth into (Figure 5):

a) shallow peat (0 – 60 cm)

b) medium peat (60 – 300 cm)

c) deep peat (> 300 cm)

The depth of peat soil in Indonesia, particularly in Papua and Asmat, is influenced by various factors that shape the unique characteristics of these peatlands. Studies such as those by Farida (2024) and Nizam et al. (2023) highlight the impact of improper drainage on peat depth, with activities like drainage leading to a decrease in peat depth. The depth of peat soil in different regions varies, as indicated by Wahid et al. (2022), who reported depths ranging from 293 to 310 cm in natural forests in Aceh Barat Daya District. Factors such as agricultural practices, as discussed by Imanudin et al. (2022), can also influence peat depth, with limiting factors like peat depth affecting land suitability classes. Additionally, the composition and characteristics of peat soil can vary with depth, as shown by Khakim et al. (2022), who observed spatiotemporal variations in soil moisture and groundwater levels in South Sumatra peatlands.

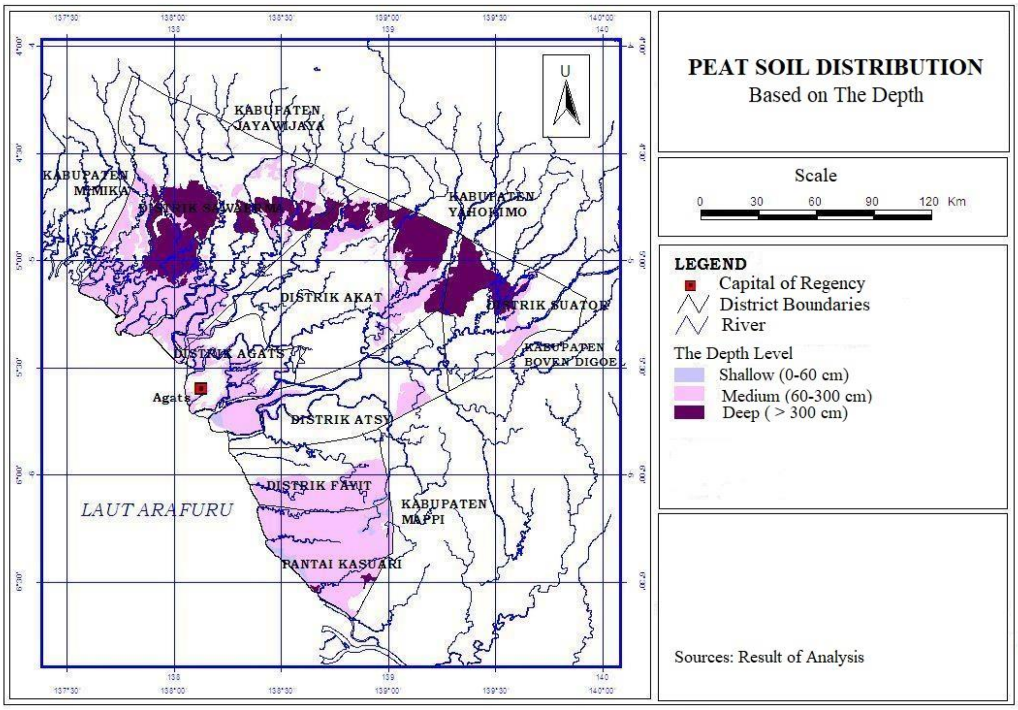

FIGURE 5: Peat Soil Depth Distribution of Asmat Regency

3.2.3 Chemical Characteristics of Peat Soils in Asmat Regency

The chemical characteristics of peatlands are generally determined by the mineral content, thickness, type of minerals in the substratum (at the bottom of the peat), and the level of peat decomposition. The mineral content of peat in Indonesia is generally less than 5% and the rest is organic material. The organic fraction consists of humic compounds around 10 to 20% and most of the others are lignin, cellulose, hemicellulose, wax, tannin, resin, suberin, protein, and other compounds. Peat soils in Asmat Regency have a relatively high level of acidity with a pH range of 3 - 5. Oligotrophic peat is often found in Asmat Regency and has a very low content of basic cations such as Ca, Mg, K, and Na, especially in thick peat. On the other hand, the cation exchange capacity (CEC) of peat is relatively high, so base saturation (KB) is very low. The negative charge (which determines the CEC) on peat soil is an entirely pH-dependent charge, where the CEC will increase if the peat pH is increased. The negative charge formed is the result of the dissociation of the hydroxyl in the carboxylate or phenol group. Therefore, determining the CEC using an ammonium acetate extractor at pH 7 will produce a high CEC value, while determining the CEC using an ammonium chloride extractor (at the actual pH) will produce a lower value. A high CEC indicates that the sorption capacity of the peat is high, but the sorption power is weak so K, Ca, Mg, and Na cations that do not form coordination bonds will be easily leached.

The chemical characteristics of peat soil in Indonesia, Papua, and Asmat Regency are influenced by various factors that shape the composition and properties of these unique ecosystems. Studies such as those by Treat et al. (2014) and Hodgkins et al. (2018) emphasize the importance of soil chemistry measurements, including lignin, lipids, polysaccharides, proteins, and nitrogen-bearing compounds, in understanding the chemical composition of peat soil. The chemical composition of plant inputs, as highlighted by Hodgkins et al. (2018), plays a fundamental role in determining the recalcitrance of peat, influencing its stability and carbon storage capacity. Changes in stream water chemistry, as discussed by Buffam et al. (2007), are attributed to rising water tables intersecting upper organic soil layers high in dissolved organic carbon (DOC). Additionally, variations in microbial community composition, as studied by Jurasinski et al. (2020), can affect soil chemical data, vegetation composition, and greenhouse gas exchange in peatlands.

3.3 Land Suitability Evaluation

Considering the importance of the agricultural sector in the economic growth of Asmat Regency, efforts need to be made to advance the agricultural sector. One effort is the regionalization of agricultural commodities based on agro-ecological zones (ZAE) to develop agriculture on a regional scale. Regionalization of agricultural development is expected to increase farmers' income, while also contributing to the regional economy through the creation of investment and trade flows between islands.

3.3.1 Food Plant

Based on the results of the land suitability analysis above, it can be seen that the dominant suitability class for rice commodities reaches class S3 with the dominant limiting factors being the availability of nutrients (n) and root conditions (r). This can be overcome through input of fertilizer technology and management of irrigation and drainage techniques.

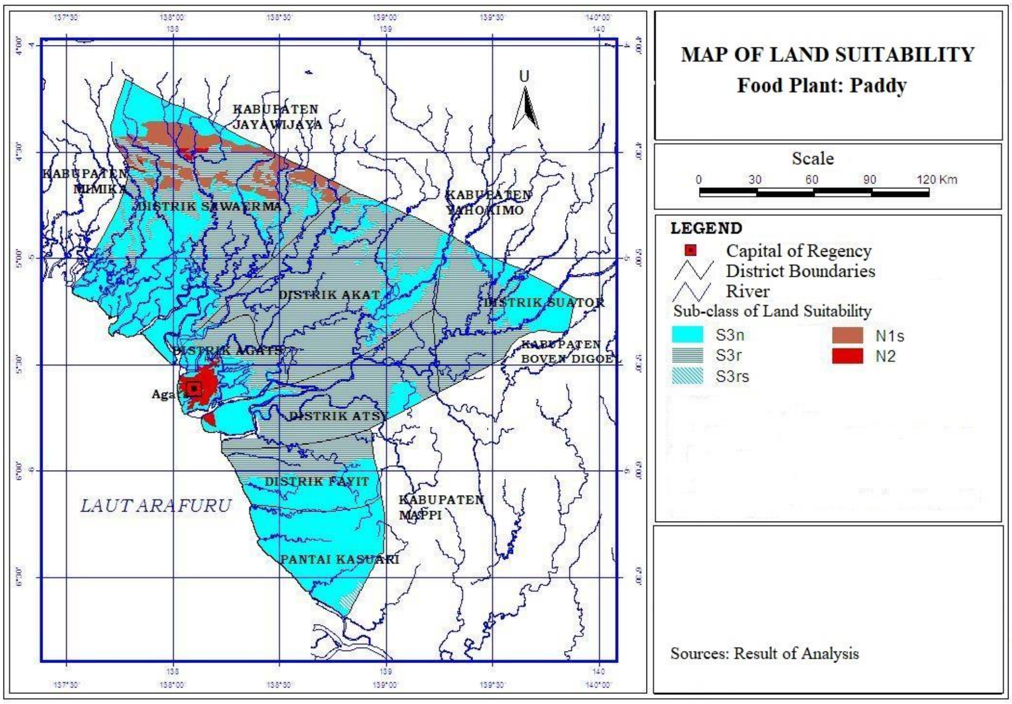

FIGURE 5: Land Suitability of Paddy in Asmat Regency

The results of the oil palm land suitability analysis showed that the dominant suitability class for oil palm commodities is class S2 with the dominant limiting factors being nutrient availability (n), land slope (s) and root conditions (r).

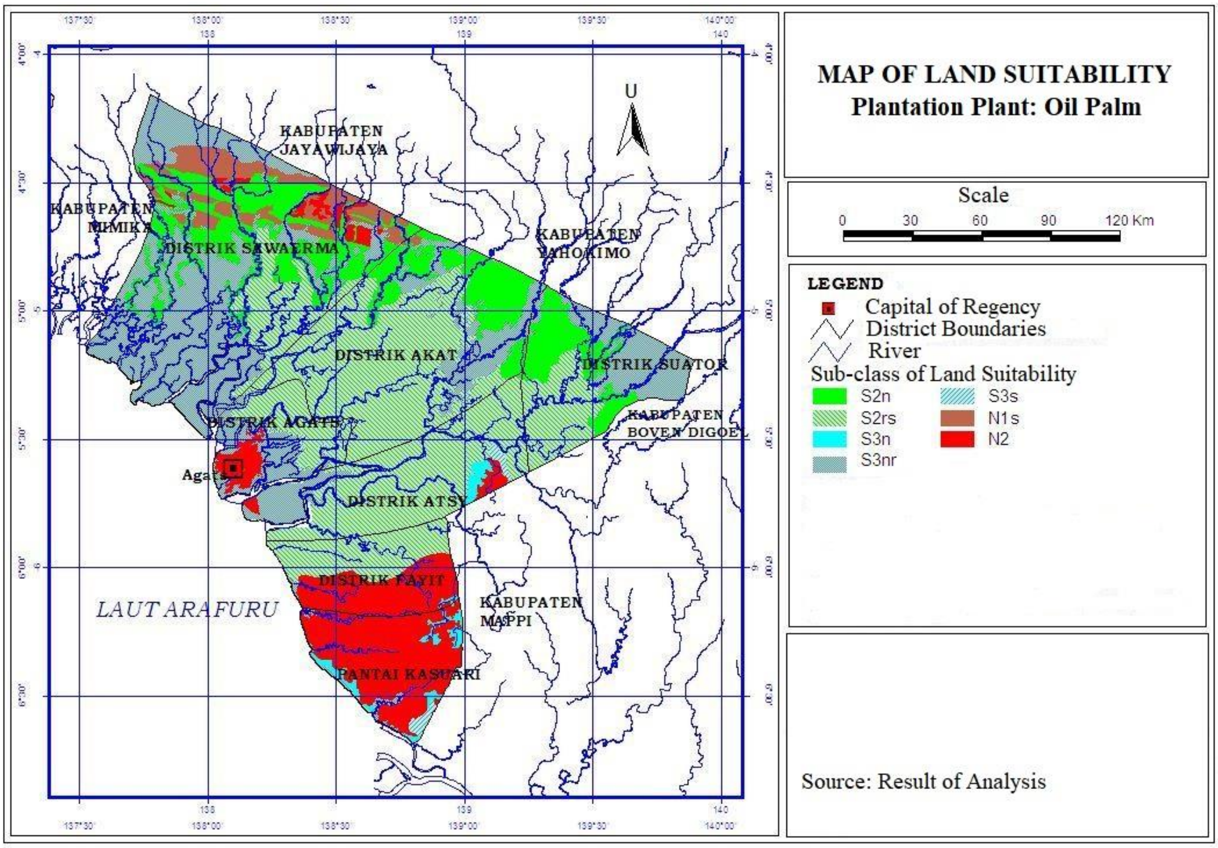

FIGURE 6: Land Suitability of Oil Palm in Asmat Regency

Land suitability evaluation involves assessing various factors to determine the appropriateness of land for specific land uses, such as agriculture. Studies like those by Bandyopadhyay et al. (2009) and Marull et al. (2007) have utilized remote sensing, GIS, and spatial analysis techniques to evaluate land suitability potentials for agriculture, emphasizing the importance of integrated indices and holistic views of environmental factors. Factors such as geology, biology, climate, and topography are considered in land suitability assessments, as demonstrated by Qing et al. (2015) in their post-earthquake reconstruction evaluation in China. The assessment of potential land suitability for specific crops, like tea in Sri Lanka by Jayasinghe et al. (2019), involves integrating multiple factors to generate suitability maps. Biophysical factors, socio-economic conditions, and environmental considerations are crucial in land suitability evaluations, as highlighted by Keshavarzi et al. (2010). Understanding these factors and their interactions is essential for optimizing land use planning, sustainable agriculture, and environmental management practices.

3.4 Social and Cultural Analysis

The characteristics of society in Asmat Regency are broadly divided into two categories, agricultural society (forestry-based) and maritime society. The ethnic background of the population of an area has quite an influence on their orientation towards the economic centers they visit. This happens especially in border areas between provinces. In everyday life, informal leaders are an important part of society along the western corridor of Sumatra. Informal religious leaders are still role models for people in this area. Despite these characteristics, society does not differentiate between immigrant communities of different ethnicities and religions. This can be seen from their accommodating attitude towards immigrants from outside.

Developments in Asmat district have an influence on the work orientation of residents in this area. This change in orientation especially occurs among young people. Among young people, the desire to pursue work in the agricultural sector is starting to decrease. However, because the level of education possessed by young people in this area is still relatively low, the service and trade sectors that are more popular with residents in this area are the informal sectors. The Asmat people are divided into several ethnic subgroups which emerged due to the existence of village federations during the era of war between villages and groups in ancient times. Adaptive federations are sometimes also characterized by similarities in dialect and symbols of mythological social unity. These subgroups include: unisirau, bismam, Simai, Emari-ducur, Betch-mBup, Kaimo, Kaigir, Safan, Brazza and Joerat.

The social and cultural life of the Asmat people in Papua, Indonesia, is deeply intertwined with their traditional practices, beliefs, and community structures. Research by Visnu (2020) highlights the patriarchal culture that influences social dynamics within the Asmat community. The Asmat people have a strong connection to their land, which shapes their cultural, spiritual, and social lives. The relationship that the Asmat people have with their environment is central to their identity and influences various aspects of their lives, as discussed by Wambrauw & Morgan (2014). The Asmat culture focuses on sustaining balance in the universe, emphasizing the interconnectedness between humans, the environment, and spiritual beliefs. The social and cultural resilience of the Asmat people is a key aspect of their identity, as explored by Vilkelienė & Kulikauskienė (2014). The communal cultural context in which the Asmat people live plays a significant role in shaping their well-being, resilience, and social interactions. Understanding the social and cultural life of the Asmat people is essential for appreciating their traditions, values, and community dynamics within the context of Papua, Indonesia.

IV. CONCLUSION

The comprehensive study conducted on the distribution and potential of peatlands in Asmat Regency, Papua, Indonesia, has provided invaluable insights into the ecological and economic importance of these ecosystems. Through meticulous field surveys, remote sensing data analysis, and laboratory soil testing, the research has unveiled the extensive and diverse peatland ecosystems within the region, highlighting their significant carbon storage capacity and the role they play in global climate regulation. The study's findings emphasize the varied physicochemical properties of peat soils, underlining their potential for sustainable agriculture, forestry, and conservation efforts, while also drawing attention to the challenges of peatland degradation.

The study proposes a set of strategies for the sustainable management of peatlands that include agroforestry practices, peatland restoration, and the adoption of community-based management approaches. These recommendations aim to balance environmental conservation with the economic development needs of the local population, thereby ensuring the long-term preservation of these vital ecosystems. Moreover, the research stresses the importance of integrating local knowledge with scientific research, advocating for a collaborative approach to the sustainable use of peat soils in Asmat Regency and beyond.

Furthermore, the socioeconomic and cultural analyses reveal the dynamic relationship between the community and its environment, highlighting the significance of adapting agricultural practices to local conditions and the potential impact of community engagement in peatland management. The study's comprehensive approach, combining physical, chemical, and socio-economic analyses, offers a robust foundation for informing policy and practice, aiming to foster the sustainable utilization and conservation of peatlands not only in Asmat Regency but also in similar contexts worldwide.

ACKNOWLEDGMENTS

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