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Environmental and Social Impact Analysis Using Remote Sensing: Case Study of Food Estate Merauke, Papua

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ABSTRAK

This study aims to analyze the impact of the implementation of the Food Estate project on environmental sustainability in Merauke Regency, Papua, using remote sensing data (NDVI and MNDWI) along with spatial analysis. From 2016 to 2020, before the project was implemented, the area was largely covered by healthy vegetation and natural ecosystems that helped maintain ecological and hydrological balance. However, since the program started in 2021 up to 2024, there has been a noticeable reduction in green vegetation, suggesting extensive land conversion and environmental stress. NDVI and MNDWI results point to declining soil quality and disruptions in the natural water cycle, which raise concerns about possible droughts and seasonal floods. The spatial analysis also shows that some Food Estate areas overlap with protected zones and indigenous territories, which could lead to land use conflicts and increase social inequality. These findings suggest that the project may be threatening local ecosystems and the livelihoods of communities who depend on them. Therefore, further policy evaluation and the implementation of conservation techniques and sustainable environmental management are needed to ensure that the project meets food security goals without sacrificing ecosystem sustainability and indigenous rights.

Keywords: *Food Estate; Modified Normalized Difference Water Index; Normalized Difference Vegetation Index; Remote Sensing; Spatial Analysis*

INTRODUCTION

The term food estate refers to large-scale food crop production (more than 25 hectares) that applies an industrial agricultural system based on science and technology, capital investment, and modern organization and management (Badan Litbang Pertanian, 2011: 2). Food estates are one of the government's key strategic programs aimed at boosting food production, reducing dependence on food imports, and maintaining national food security through the development of large-scale agricultural zones (Basundoro, 2020:29; Priyantoro et al., 2024:1666). The initial development plans included 190,000 hectares in Central Kalimantan, 120,000 hectares in West Kalimantan, 10,000 hectares in East Kalimantan, 190,000 hectares in the Maluku Islands, and 1.9 million hectares in Papua (Salsabilla et al., 2022:2438). Papua, particularly Merauke, has become one of the targets for the Food Estate project due to its vast agricultural land potential. However, the implementation of this project has encountered significant challenges in various regions, including Papua, such as large-scale deforestation, social conflicts with indigenous communities, and threats to biodiversity. Land clearing in Merauke to support the project poses risks such as forest loss, higher carbon emissions, reduced water catchment areas, and increased flooding risks. Moreover, many indigenous communities have lived in these areas for generations, making the project likely to cause social conflicts over land use and resource disputes.

This study uses remote sensing technology to monitor deforestation, flood risks, and land conflicts. Remote sensing has proven to be an effective tool for providing accurate spatial data that supports sustainable development. By utilizing this approach, we can identify areas at risk of conflict and environmental damage, which will help guide more inclusive and sustainable policies for the implementation of the Food Estate project. The study aims to provide data-driven recommendations that will support the project's sustainability while minimizing negative impacts on the environment and local communities. The findings are expected to contribute to the achievement of the Sustainable Development Goals (SDGs).

METHODOLOGY

Study Area

Merauke Regency is located in South Papua Province and is the largest regency in the Papua region, with a total area of approximately 46,791.63 square kilometers. Geographically, it is positioned between 137° and 141° East Longitude and between 6°00' and 9°00' South Latitude. It shares borders with Mappi Regency to the north, the Arafura Sea to the south, Asmat Regency to the west, and Papua New Guinea to the east.

The landscape of Merauke is mostly lowland, consisting of extensive wetlands such as swamps, mangrove forests, and broad savanna areas. Its hydrological system includes major rivers such as the Bian, Kumbe, and Maro Rivers, which play important roles in the local ecosystem and irrigation system. The topography is generally flat and swampy along the coast, with slopes of 0-3% and elevations between 0-60 meters above sea level. In the northern parts including Tanah Miring, Jagebob, Elikobel, Muting, and Ulilinthe, the terrains are gently undulating, with slopes of 0-8%.

Merauke has a wet tropical climate with fairly high rainfall, making some areas prone to flooding, especially in low-lying regions with poor water absorption. The area also faces erosion risks due to land use changes and large-scale agricultural activities. Merauke's natural vegetation consists of tropical forests and savannas, home to various endemic Papua species, including birds of paradise and cassowaries. However, the conversion of land for the Food Estate project threatens large-scale deforestation, which could lead to increased carbon emissions, biodiversity loss, and reduced water catchment areas, raising the risk of future ecological disasters.

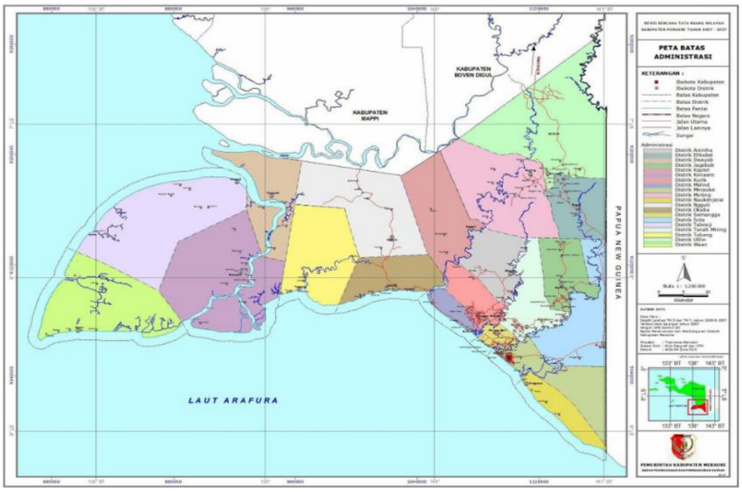

Figure 1. Map of Merauke Regency (BPS, 2015)

Satellite Data

1. MODIS (Moderate Resolution Imaging Spectroradiometer)

   MODIS can be used to calculate NDVI values in an area by utilizing spectral reflectance data captured by sensors on the Terra and Aqua satellites. MODIS records various light wavelengths, including the red channel (Band 1) and near-infrared (NIR, Band 2). The MODIS data used in this study has a spatial resolution of 250 meters with a temporal resolution of 16 days.

2. Sentinel-2

   Sentinel-2 is a high-resolution multispectral imaging satellite that captures data every 5 days worldwide. Its Multispectral Instrument (MSI) contains 13 spectral bands with varying resolutions: visible and NIR bands at 10 meters, red edge and SWIR bands at 20 meters, and atmospheric bands at 60 meters. Sentinel-2 data is often used for environmental change analysis, such as vegetation, soil, and water monitoring.

3. Supporting Data

   a. Food Production Center Area Map (KSPP)

      The KSPP map from the Merauke Integrated Food and Energy Estate (MIFEE) project was used as the main reference to identify areas included in the large-scale agricultural development plan.

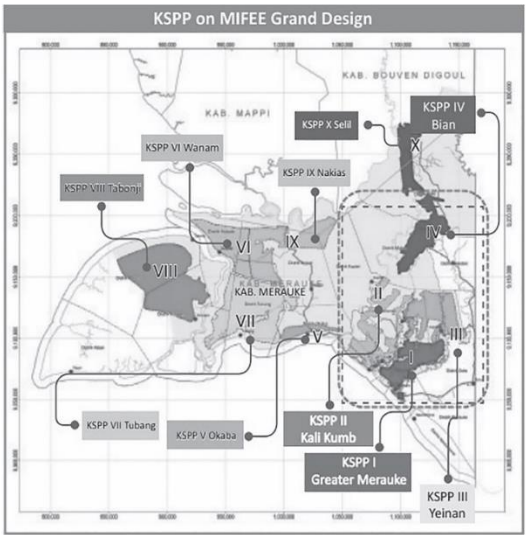

Figure 2. Food Production Center Area (KSPP) map from the 2015 to 2019 National Medium-Term Development Plan (Chao, 2017:22)

b. OpenStreetMap (OSM)

OpenStreetMap (OSM) data was used to map protected areas and indigenous territories, which are important aspects in assessing the potential for overlapping land uses.

4. Environmental and Social Indicators

a. Normalized Difference Vegetation Index (NDVI)

NDVI was used to identify changes in vegetation caused by land conversion in Merauke Regency, Papua, which was affected by the Food Estate project. The analysis used MODIS satellite data that captures different light wavelengths, including the red and near-infrared (NIR) bands, which are needed to calculate NDVI. The NDVI was calculated using the formula:

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

NIR : Near Infraread Band

RED : Red Band

The analysis reviewed two time periods, before the project (2016 to 2020) and after it began (2021 to 2024), using Google Earth Engine (GEE) to observe vegetation change patterns. These results provide data-based insights into how the Food Estate project has affected vegetation.

b. Modified Normalized Difference Water Index (MNDWI)

MNDWI was used to identify flood-prone areas in Merauke Regency, Papua, which were affected by the Food Estate project. The analysis used Sentinel-2 satellite imagery and calculated using the formula:

$$MNDWI = \frac{GREEN - SWIR}{GREEN + SWIR}$$

GREEN : Green Band

SWIR : Shortwave Infrared Band

The study covered two periods, before (2016 to 2020) and after (2021 to 2024), using GEE to extract changes in water inundation patterns. The mapping results were compared with land use maps to assess environmental and social impacts, including the potential for conflict with indigenous communities. This study provides data-driven insights into hydrological changes linked to the Food Estate project.

c. Spatial Overlay

Spatial analysis refers to a series of techniques used to process Geographic Information System (GIS) data. It involves exploring and studying data from a spatial perspective. Overlay is an important part of spatial analysis because it combines several spatial elements into a new spatial layer. Overlay can be applied to both vector and raster data (Larasati et al., 2017:91).

RESULTS AND DISCUSSION

Normalized Difference Vegetation Index (NDVI)

Before the start of the Food Estate project (2016-2020), the NDVI map of Merauke Regency showed that vegetation cover was well-preserved, with high NDVI values across most areas. Dense vegetation, such as forests and wetlands, was scattered throughout, particularly in the outer regions of the analyzed area. This indicates that the natural ecosystem was still dominant and had not yet been significantly disturbed by large-scale human activity. Healthy vegetation plays a crucial role in maintaining ecosystem stability, including preserving soil moisture and reducing the risk of erosion and land degradation. Additionally, the relatively even distribution of vegetation reflects an environment that supports optimal photosynthesis, while also helping to maintain the balance of the carbon and hydrological cycles before the Food Estate project began its operations.

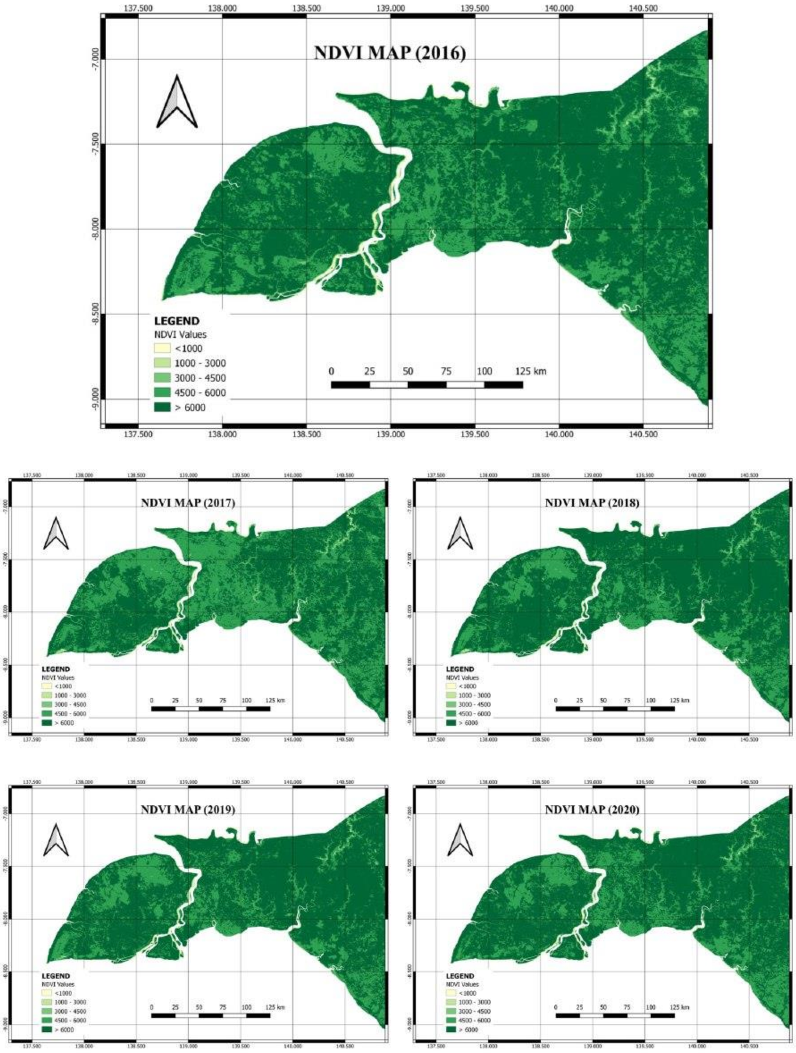

Figure 3. NDVI Map of Merauke Regency Before the Food Estate Project

After the Food Estate project began (2021-2024), significant changes occurred in the vegetation cover of Merauke Regency. The NDVI map shows a reduction in the green areas, particularly in regions that previously had dense vegetation. This reflects large-scale land clearing for agricultural activities, which led to the loss of natural ecosystems. Vegetation, which once played a key role in maintaining soil moisture and preventing erosion, has deteriorated, making the land more vulnerable to drought and a decline in fertility. The gradual loss of vegetation also has the potential to reduce the area's capacity to absorb carbon, which could impact the ecosystem balance in the long term.

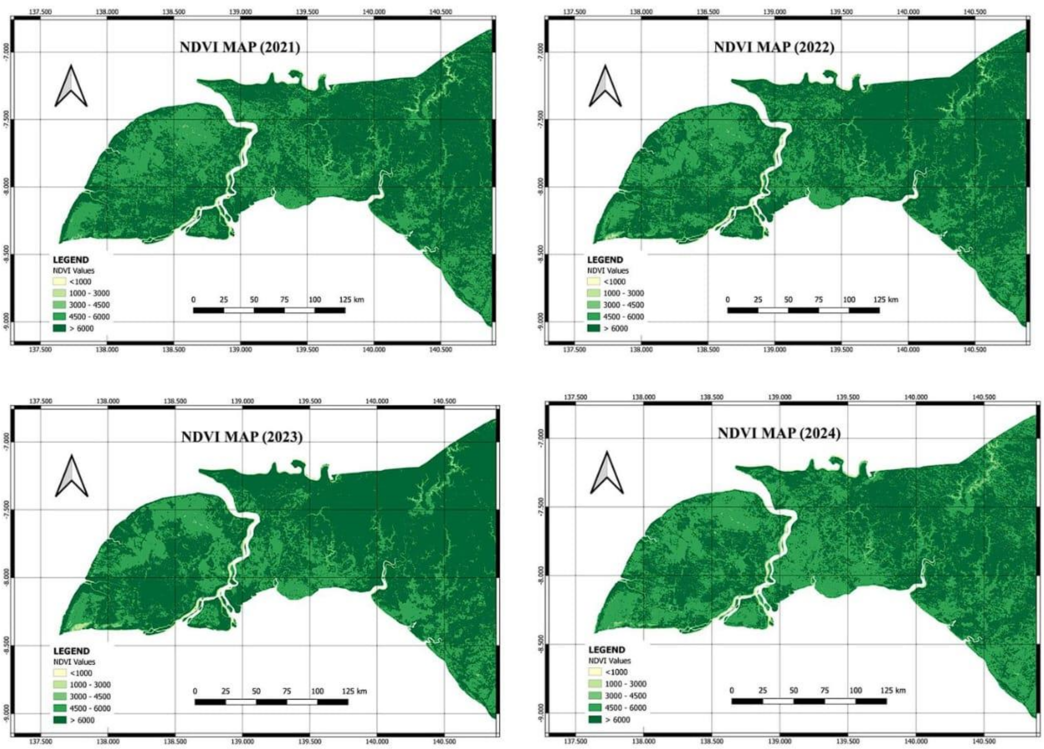

Figure 4**.** NDVI Map of Merauke Regency After the Food Estate Project

The comparison before and after the project shows that the Food Estate has had a significant impact on vegetation preservation. The decrease in green cover has disrupted the ecosystem and accelerates land degradation. While the project aims to improve food security, continuous evaluation is needed to ensure it remains environmentally friendly. Regular monitoring using remote sensing is crucial to maintaining ecosystem balance and ensuring the well-being of local communities.

Modified Normalized Difference Water Index (MNDWI)

Before the Food Estate project began (2016-2020), the MNDWI map of Merauke Regency showed that most areas had relatively high water content, indicated by the dominance of blue on the map. Vegetation was still scattered in parts of the region's edges, reflecting the presence of natural ecosystems that help balance the water cycle. The vegetation played a crucial role in maintaining soil moisture and reducing evaporation rates at the surface. Additionally, the natural drainage patterns were still intact, allowing a balance between water supply and evaporation within the local hydrological system.

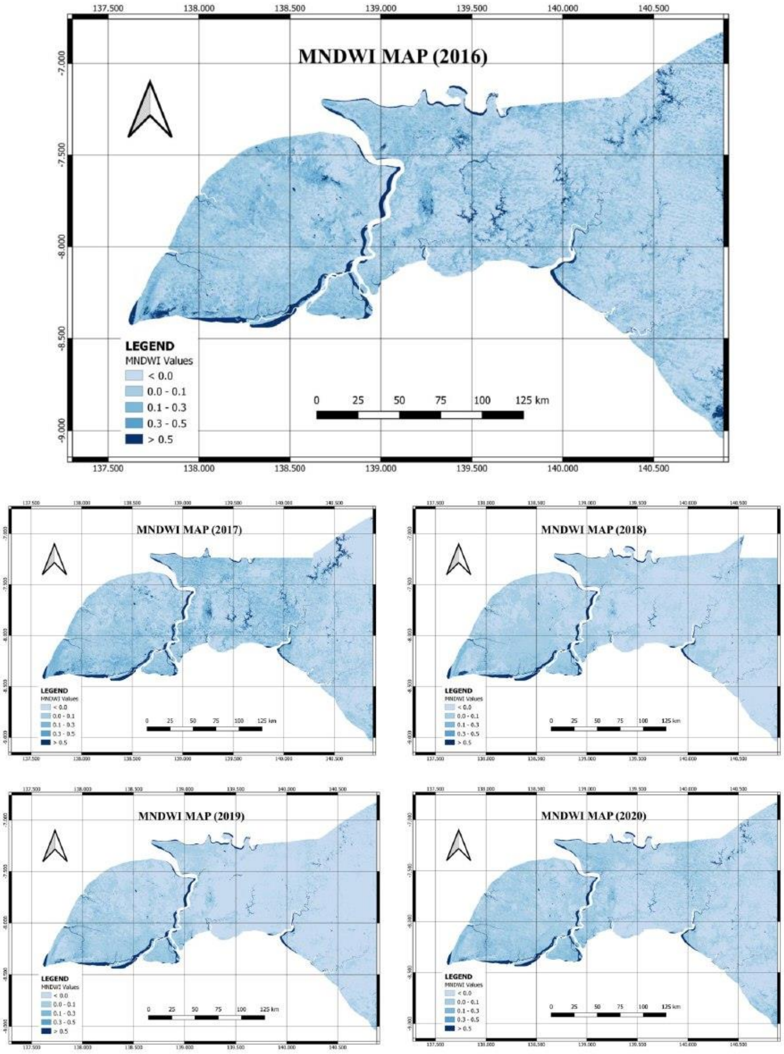

Figure 5. MNDWI Map of Merauke Regency Before the Food Estate Project

After the project began (2021-2024), significant changes occurred in both water distribution and vegetation. The map showed a gradual reduction in vegetated areas, especially in regions that previously had extensive green cover. This indicates large-scale land clearing for agriculture. As a result, some areas experienced changes in water levels. Some showed an increase in water due to disruptions in natural drainage systems, while others experienced a decrease, likely caused by increased evaporation and changes in soil structure due to intensive farming. If this trend continues, the region may face environmental degradation, including declining soil quality and risks of seasonal drought or flooding.

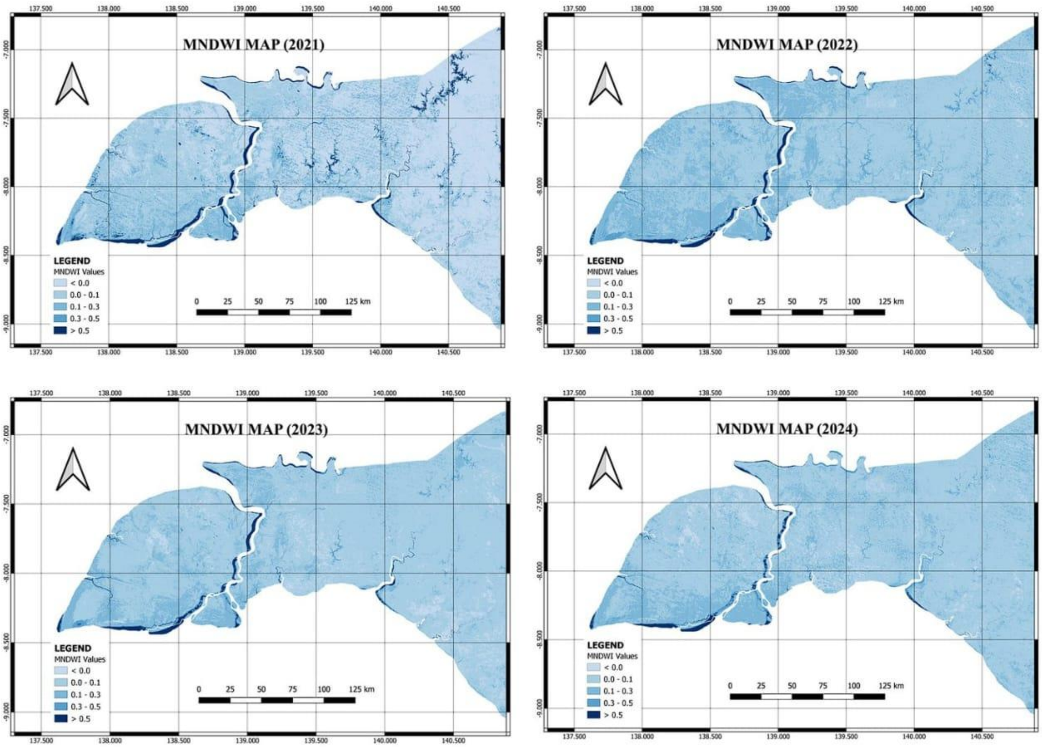

Figure 6. MNDWI Map of Merauke Regency After the Food Estate Project

The comparison between the pre-project and post-project maps shows that the Food Estate's implementation has significantly impacted the ecological balance in Merauke Regency. The considerable reduction in vegetation cover may disrupt natural hydrological cycles, increasing the risks of erosion and changes in water flow patterns. Although the main goal of the project is to boost food production and support national food security, further evaluations are needed to ensure its sustainability aligns with the Sustainable Development Goals (SDG 2 - Zero Hunger, SDG 13 - Climate Action, and SDG 15 - Life on Land). Regular monitoring using remote sensing technology is crucial to ensure the project not only provides economic benefits but also considers ecological and social balance for local communities.

Spatial Overlay

Based on the spatial overlay analysis, overlapping areas were identified between the KSPP, protected areas, and customary lands in Merauke Regency. The analysis showed that about 53,437.835 hectares (2.8%) of the total KSPP area overlapped with protected zones, while 290,534.945 hectares (15.29%) of customary lands were included in the planned Food Estate development area. In terms of spatial distribution, the largest overlap between indigenous territories and KSPP is found in the southern and southeastern parts of Merauke Regency, particularly around the coastal areas and lowland forests. The most impacted protected areas from KSPP expansion are located in the southwest and central regions, which are known for their rich biodiversity. The pattern of conflict zones is clearly visible, especially where indigenous territories and KSPP overlap, creating clusters at specific points. Additionally, protected areas overlapping with KSPP tend to follow the paths of rivers and coastal ecosystems, suggesting potential impacts on water resources and natural habitats. This mapping provides a clear picture of the scale and distribution of the possible environmental and social consequences of the Food Estate development. The data can serve as a foundation for further analysis of policy impacts and strategies to reduce land-use conflicts in Merauke Regency.

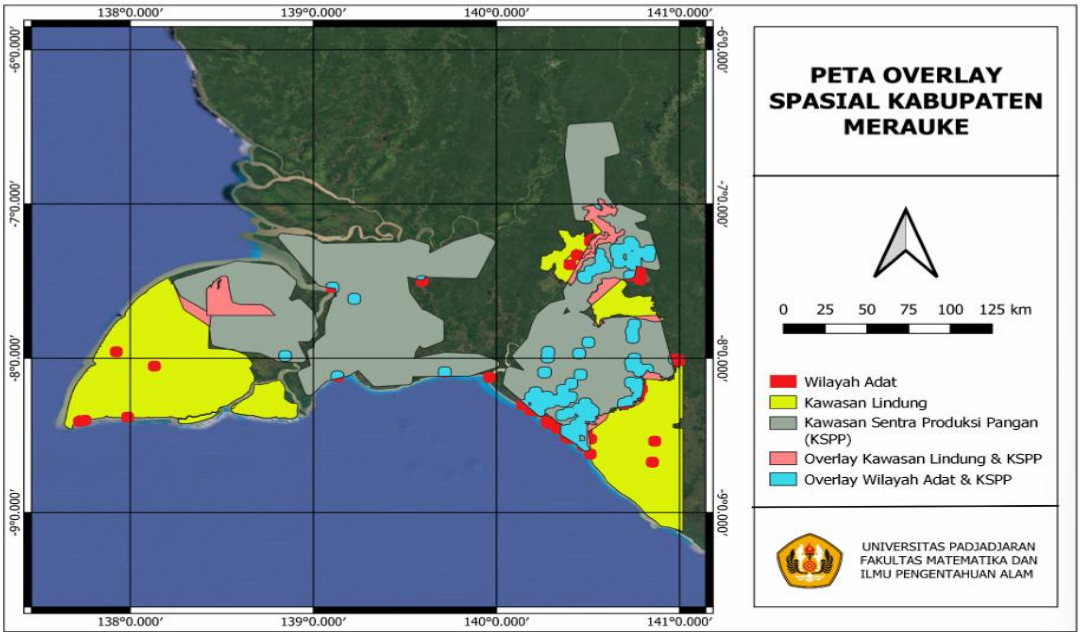

Figure 7. Spatial Overlay Map of Merauke Regency

The analysis of NDVI (Normalized Difference Vegetation Index) reveals that the implementation of the Food Estate project has impacted vegetation sustainability in Merauke Regency. The reduction of green space, caused by vegetation shifts from dense forests to shrubs or dry land, indicates an acceleration of land degradation. NDVI data suggest that the Food Estate program in Merauke may lack long-term sustainability. This poses risks to ecological balance, reduces land productivity, and threatens both ecosystem integrity and the livelihoods of local communities who depend on natural resources. These findings are consistent with a previous study by WALHI (2021), which stated that the Food Estate projects in various regions of Indonesia have led to deforestation and land degradation. Significant changes in forested areas have lowered ecosystem quality, with many lands experiencing a decline in soil fertility. If land degradation continues without effective mitigation, the Food Estate zone in Merauke could face declining soil productivity within the next 5 to 10 years, contradicting the program's goal of achieving food security.

According to the MNDWI analysis, the implementation of the Food Estate project in Merauke Regency has significantly impacted the region's ecological balance. A decrease in water content in several areas indicates a disruption of the natural water cycle, suggesting that the land is no longer able to retain water effectively. The widespread reduction of vegetation has increased the risk of erosion due to the loss of root systems that stabilize the soil, altered water flow patterns, and reduced the land's capacity to store water. This shows that water management in the Food Estate program has not adequately considered hydrological sustainability. These conditions may lead to droughts during the dry season as the land loses its water storage capacity and increase the risk of flooding during the rainy season due to disrupted watershed functions. The irrigation system used in the project must also be efficient. If it relies only on rainfall, it could cause extreme fluctuations in soil moisture. Without effective mitigation, the area may experience a decline in soil fertility in the coming years as water shortages and rising surface temperatures intensify drought conditions in the dry season.

Spatial analysis shows an overlap between the KSPP under the Food Estate project and protected areas and customary lands. This distribution pattern points to a risk of land-use conflict, especially in the southern and southeastern lowland forest and coastal areas of Merauke. Additionally, the impacted protected areas often follow river flow patterns and coastal ecosystems, highlighting further risks to water resources and biodiversity. If not properly managed, this overlap could accelerate environmental damage and worsen social inequality among Indigenous communities who rely on local land and natural resources.

The study challenges the assumption that the Food Estate project can be carried out sustainably without sacrificing environmental and social aspects. The large-scale farming model used in this project does not appear to fully consider the land's carrying capacity and local ecological balance. Therefore, further research is needed to assess the impacts in greater depth, including hydrological modeling to understand changes in water flow patterns, high-resolution satellite image analysis to monitor land degradation more accurately, and socio-economic studies to evaluate the impacts on local livelihoods.

If land conversion is not managed more carefully, the Food Estate project in Merauke risks long-term failure due to environmental degradation and increasing social instability. Policy evaluation is crucial to ensure that agricultural expansion takes ecological balance and Indigenous rights into account. One possible strategy is to revise spatial planning based on sustainability principles, provide stronger protection for conservation areas, and develop farming methods that are better adapted to local ecological conditions. With a broader, data-driven approach that considers environmental and social aspects, there is still an opportunity to make the project more sustainable without sacrificing ecosystem balance and the rights of local communities.

If this land conversion is not managed more carefully, the Food Estate project in Merauke is likely to fail in the long term due to increasing environmental degradation and social instability. Policy evaluation is a crucial step to ensure that the expansion of agricultural land takes into account ecological balance and the rights of indigenous communities. One strategy that can be implemented is revising spatial planning based on sustainability, providing stronger protection for conservation areas, and developing farming methods that are more adaptive to local ecological conditions. With a broader, data-driven approach that considers both environmental and social aspects, there is still an opportunity to make this project more sustainable without sacrificing ecosystem balance and the rights of local communities.

CONCLUSION

Based on the results of NDVI and MNDWI analyses, there are clear differences before and after the implementation of the Food Estate project. These changes indicate that after development began, there was a shift in vegetation and an increase in flood-prone areas, both of which suggest the environmental impacts of land clearing. Spatial analysis also revealed not only environmental effects but also social and economic impacts, as evidenced by overlapping zones between food production areas and indigenous protected forests. These findings indicate that the Food Estate project in Merauke Regency does not yet align with the principles of the Sustainable Development Goals (SDG 2 - Zero Hunger, SDG 13 - Climate Action, and SDG 15 - Life on Land). In light of this, further research is needed to explore strategies for minimizing environmental impacts, such as implementing sustainable farming systems, land rehabilitation, and the protection of ecologically valuable areas. Future studies may also focus on long-term monitoring of land cover dynamics and water availability to evaluate the effectiveness of environmental management policies in the Merauke Food Estate project. The government should also review the Environmental Impact Assessment (AMDAL) documents and revise mitigation strategies and project locations to avoid damaging critical ecosystems.

REFERENCES

Badan Penelitian dan Pengembangan Pertanian. 2011. *Buku Pintar Food Estate*. Jakarta: Badan Litbang Pertanian.

Basundoro, A.F., dan F.H. Sulaeman. 2020. “Meninjau Pengembangan Food Estate sebagai Strategi Ketahanan Nasional pada Era Pandemi Covid-19.” *Jurnal Lemhannas RI* 8(2): 27–41.

BPS. 2015. Merauke Dalam Angka 2015. Badan Pusat Statistik Kabupaten Merauke, Merauke.

Chao, Sophie. 2017. “There Are No Straight Lines in Nature: Making Living Maps in West Papua.” *Anthropology Now* 9(1): 16–33.

Larasati, N.M., S. Subiyanto, dan A. Sukmono. 2017. “Analisis Penggunaan dan Pemanfaatan Tanah (P2T) Menggunakan Sistem Informasi Geografis Kecamatan Banyumanik Tahun 2016.” *Jurnal Geodesi Undip* 6(4).

Pemerintah Provinsi Papua. t.t. “Gambaran Umum Kabupaten Merauke.” https://papua.go.id/view-detail-kabupaten-121/gambaran-umum.html, diakses 13 Februari 2025.

Priyantoro, A.E., F.L. Pakpahan, dan S.P. Simangunsong. 2024. “Identifikasi Faktor Kunci pada Penentuan Lahan Tidur sebagai Kawasan Food Estate dalam Mendukung Ketahanan Pangan.” *Jurnal Penelitian Inovatif* 4(3): 1665–1674.

Salsabilla, S., G.R. Deksino, dan D.T.T. Dewi. 2022. “Pengelolaan Sumber Daya Air dan Food Estate sebagai Faktor Pendukung Penyediaan Logistik Wilayah untuk Pertahanan Negara.” *Jurnal Kewarganegaraan* 6(2): 2436–2444.

WALHI. 2020. *Hentikan Proyek Cetak Sawah/Food Estate di Lahan Gambut di Kalimantan Tengah*. Jakarta: Wahana Lingkungan Hidup Indonesia.