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RESEARCH ARTICLE

Land Use Change Threat to Paddy Cultivation Sustainability on the Irrigated Rice Fields in Bengkulu Province, Indonesia

Muhammad Faiz Barchia[1], Dedik Budianta[2], Bambang Sulistyo[1], Dodi Hardiansyah[3], Hery Suhartoyo[4], Ridha Rizki Novanda[5]

[1]Department of Soil Science, University of Bengkulu, Bengkulu, Indonesia
[2]Department of Soil Science, Sriwijaya University, Palembang, Indonesia
[3] Agricultural Office, Mukomuko District, Bengkulu Province, Indonesia
[4] Department of Forestry, University of Bengkulu, Bengkulu Indonesia
[5] Department of Socio-economics, University of Bengkulu, Bengkulu Indonesia

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Correspondent email:
faizbarchia@unib.ac.id

Abstract. Unpredictable conditions of rice cultivation on fragile peatlands in Indonesia due to land-use changes would be an obstacle to agricultural food production and food security. This study aimed to determine the changes in land usage in Bengkulu, from prospective rice fields to oil palm plantations. The study was conducted from June to October 2020 at Air Manjuto irrigation paddy fields in Mukomuko Regency, Bengkulu Province. The analysis used satellite imagery with appropriate resolutions and multitemporal time from the United States Geological Survey's Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper + (ETM+), and Landsat 8 Operational Land Imager (OLI) collected from the years of 2000, 2008, and 2019. (USGS). The landscapes covering the Air Manjuto area were mostly marginal swampy peaty soils with ordo of Inceptisols, Histosols, and Entisols, which favor intensive rice cultivation. Oil palm plantation covers about 80% of the area, and in the last ten years, the cultivation by small-scale farmers increased sharply, about 8,219 ha or 68% from the previous decade, and no bush and bare land. In contrast, rice fields were an extraordinary loss of 6,819 ha or about 74% in the last decade, from 9,187 ha in 2008 to 2,308 ha in 2019. The loss of a huge area for rice cultivation at the Air Manjuto irrigation area threatens production in Bengkulu. The loss should be reversed through supporting infrastructure facilities and incentives, agrochemical subsidies, and agricultural insurances, and no more rice fields should be converted.

1. Introduction

Around 95% of the Indonesian society consumes rice as a staple food (Sulistyo et al., 2016), therefore, it has become one of the calculated apprehensions, and all judgments concerning the consumption impact on population growth (Arifin et al., 2021). The production should be maintained in line with the Indonesian population growth (Mariyono, 2018). In 2020, from irrigated rice fields of 10.65 Mha, farmers could produce 54.65 million paddies to feed 270 million people (BPS-Statistics Indonesia, 2021). The rice harvested from those huge areas was still insufficient to supply population needs (Mustikarini & Santi, 2020). Therefore, for almost all years, the Indonesian government has been confident in importing rice to maintain stock availability, guarantee supply flow, and stabilize rice prices (Surya, 2021). Paddy output should be raised to avoid the importation of rice.

Due to the scarcity of highly appropriate and fertile areas, agricultural development and higher productivity of marginal soils such as peatland was selected to ensure Indonesian food security (Surahman et al., 2018). Peat soil is considered marginal for agricultural purposes because of its poor nutrient content and soil fertility (Ompusunggu et al., 2020). The oligotrophic and homogenous peat soils were identified (Sahfitra et al., 2020). The features and prior growth of marginal soil types for rice fields were not accompanied by an increase in irrigation network development in terms of quality or geographical scope. A lack of water supply caused paddy lands to undergo significant land use changes in the irrigated area (Panuju et al., 2013).

Land Use and Land Cover Change (LUCC) is one of the most cutting-edge and hotly debated areas of global change science. The joint interaction of LUCC and society impacts human survival and food security (Chang et al., 2018). Land use has changed from food crop areas to oil palm plantations in the last decade (Gunarso et al., 2013). Recently, the conversion rate of paddy fields has been frighteningly high, and without considerable government effort, national food security and self-sufficiency may be jeopardized (Harjanti & Hara, 2020). Rice field conversion to palm oil has come to the fore, although there is little data to back it up as a danger to the long-term viability (Wildayana, 2015). East Tanjung Jabung Regency is one of the leading rice producers in Jambi Province, with a significant rate of rice land loss (Daulay et al., 2016). The sustainability of farming in Jambi Province was investigated, and less sustainable rice production was discovered (Frimawaty et al., 2013). Ex-migrant farmers' adaptation to land conversion from rice cultivation to oil palm plantations may aggravate food deficiencies in South Sumatera Province (Zahri et al., 2019). In the communities of West Kalimantan, land conversion for oil palm plantations has resulted in significant changes in how farmers meet their fundamental household requirements, and this alteration impacts food security (Sudrajat et al., 2021).

Oil palm has been one of the most commercially appealing crops to farm in humid tropical regions in response to global markets. Indonesia, located in this region, has been the world's top producer and exporter of palm oil since 2008 (Feintrenie et al., 2010). Oil palm is a major source of revenue for Indonesia's national and regional governments (Casson, 2000). Cultivation has shown to be an effective method for strengthening rural people. It boosts growth in rural regions by increasing the economic multiplier effect. The growth of rural economic institutions is aided by palm oil operations (Syahza et al., 2020). The benefits of its adoption as a development strategy in rural regions continue to be questioned, particularly about their model, which should ensure food security (Dib et al., 2018). In the tidal lowlands of Pulau Rimau, Banyuasin Regency, oil palm plantations that previously offered cereal cropland exhibited a poor sustainability value (Muharani et al., 2020). Even though small-scale farmers' plantations have poor sustainable values, land use shift to oil palm continues to endanger rice fields. Certain sections of wetland rice cultivation in Siak District are less viable because of land use changes prompted by ecological limits (Yusuf et al., 2020).

Several studies showed land conversion to oil palm plantations threatens rice production in some areas, and this case has limited information in Bengkulu. Therefore, this study aimed to show small-scale farmers' land use change from paddy fields to oil palm plantations based on three periods of land use in the Air Manjuto irrigation area, Bengkulu Province. It was considered crucial information for the Indonesian government at the time to decide on the irrigation area as agricultural land for sustainable food crops cultivation.

2. Methods

This study was conducted from June to September 2021, covering about 28,070 ha lying on 101.03^0 – 101.33^0 long and $2,37^0$ – 2.52^0 alt. (Figure 1). Rainfall averages 3,495 mm $year^{-1}$ with several rainy days of 213 days $year^{-1}$. The maximum and minimum temperatures are 31.38°C and 24.71°C, with relative humidity levels ranging from 68.5 to 100% (Hamdan et al., 2016). Marginal peat soils cover some areas of these planted rice fields.

A land use change study is necessary to be conducted by utilizing satellite data with appropriate resolutions and multitemporal time coverage to zone and characterize the land use change (Setiawan & Yoshino, 2020). Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper + (ETM+), and Landsat 8 Operational Land Imager (OLI) images with a spatial resolution of 30 m x 30 m collected from the United States Geological Survey in the years 2000, 2008, and 2019 were utilized to show the existing of the land use conditions in each period involving the existing rice fields and oil palm plantation. Earth Resource Observation System Data Center had previously adjusted the photos geometrically (EROS). Meanwhile, all photos were orthorectified to a projection of UTM 48 S and the image analysis produced numbers of pixels for each land use. Total pixels from each land use multiply with the spatial resolution, 30 m x 30 m converted to ha by dividing 10,000 m^2. The images were categorized using the maximum likelihood technique, which was then adjusted (Utami et al., 2017) with 8 classes: thick forest, oil palm plantation, young oil palm, settlement, bare land, rice field, bush, other land uses. The ERDAS tools were used to test the land use classifications using maximum likelihood and the Kappa coefficient method (Nurwanda et al., 2016).

3. Results and Discussion

The landscapes covering the Air Manjuto area favor intensive rice cultivation (Barchia et al., 2021), however, a little bit of low productivity because of low solar radiation flux density in the year (Anwar et al., 2018) and marginal swampy peat characteristics (Siagian, 2011). The availability of peatlands was becoming increasingly appealing due to their flat geography (Hergoualc'h et al., 2018) as alternative areas for rice cultivation to ensure national food security. Based on the land unit and soil map of the Sarolangun sheet (0913), Sumatera (Wahyunto et al., 1990), ordo covering the study area involves Inceptisols, Histosols, Entisols, and Ultisols, as shown in Figure 1, and a wide area of each soil type, shown in Table 1.

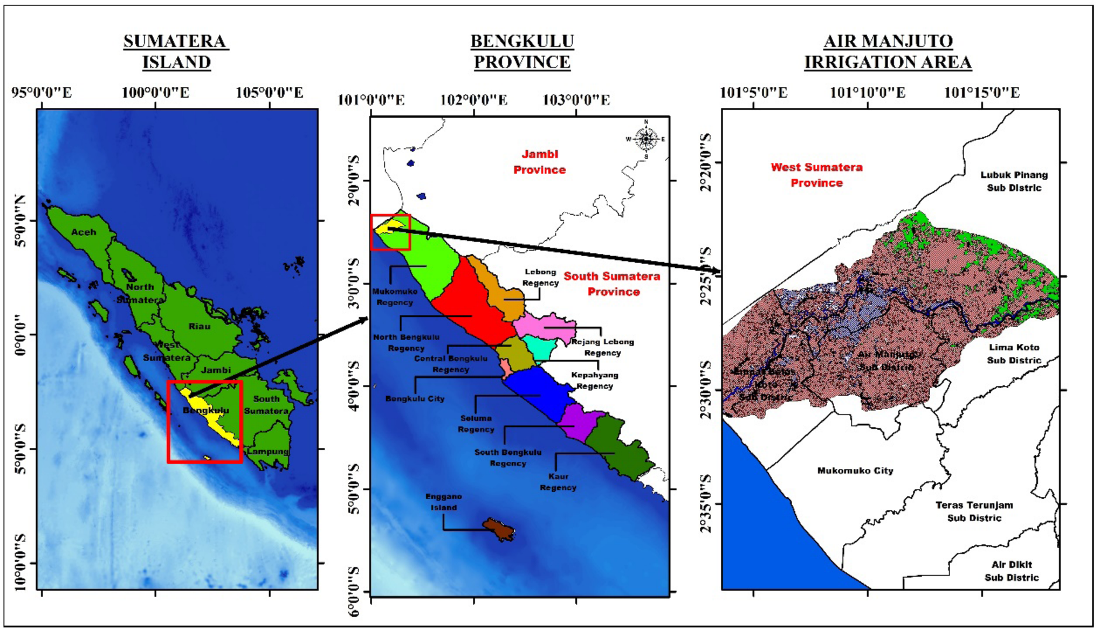

Figure 1. Study location in Air Manjuto irrigation area, Bengkulu

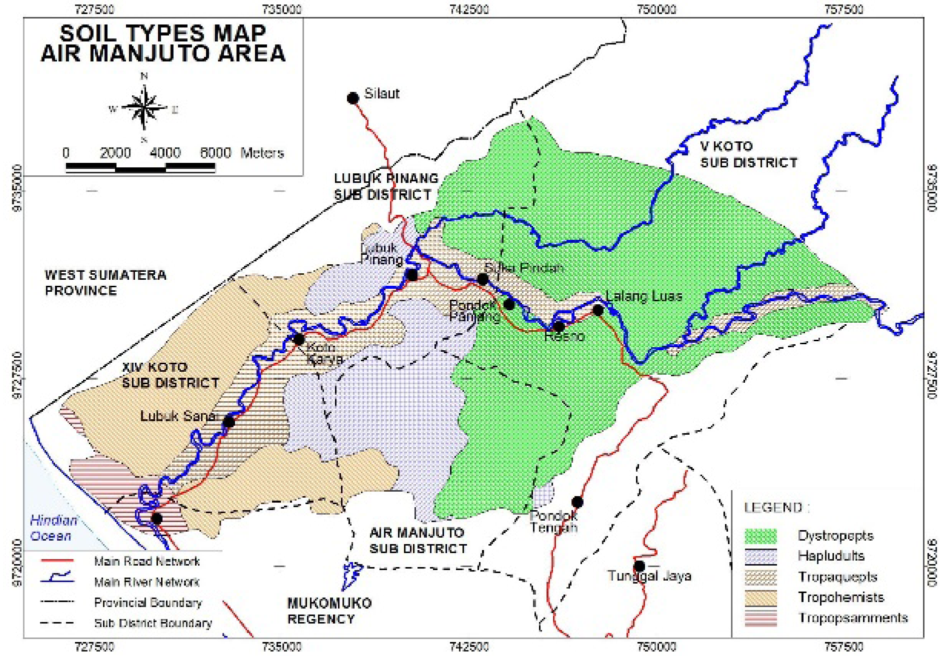

Figure 2. Soil types in the Manjuto area

Table 1. Soil ordo and a great group in the Air Manjuto irrigation area

Ordo	Great Group	Physiographic	Ha	%
Ultisols	Hapludults	Acid tuff plain	4,520	16.1
Inceptisols	Dystropepts	Alluvial	13,110	46.7
	Tropaquepts	Alluvial	4,558	16.2
Entisols	Tropopsamments	Marine deposits	891	3.2
Histosols	Tropohemists	Peat dome	4,991	17.8
			28,070	100.0

The Inceptisols are Dystropepts, and Tropaquepts soil types found in alluvial plains created from diverse materials deposited at a flat to the nearly flat slope by fluvial and colluvial processes were reasonably appropriate for wetland rice (Hikmatullah & Al-Jabri, 2007). However, with the soil pH in acid condition and nutrient availability limited, Inceptisols were less suitable for rice crops (Syamsiyah et al., 2018). The application of ameliorants and fertilizers could improve soil fertility for intensive rice cultivation (Harahap et al., 2021).

From Table 1, peat soil covered this area of about 4,991 ha, and some were classified as shallow to deep peat, < 200 cm. Many reasons restrict peatland use for agricultural growth, including acidity, poor base saturation, organic acid toxicity, and nutrient insufficiency (Septiyana et al., 2017) (Maftu'ah & Nursyamsi, 2019). However, peat with organic layer thickness at a depth smaller than 200 cm was marginal suitable for paddy cultivation (Allamah et al., 2018).

The soil groups of Tropopsamments cover a small portion of the Air Manjuto irrigation area's landscape due to the siliceous sedimentary formations. Due to high permeability, soil acidity, and low nutrient status, these soil characteristics have been identified as significant constraints for crop cultivation on sandy soils (Huang & Hartemink, 2020). However, the sandy soils at Air Manjuto are mostly planted by the local farmers with oil palms.

Based on land suitability and water supply from Air Manjuto Dam built-in years of 1983 – 1986 and its canals, this area could be developed with paddy fields of 9,493 ha (Zulkarnain, 2016). Therefore, in 2000, the rice field covered 9,063 ha or closed to potential paddy fields in Air Manjuto, and the land use is shown in Figure 3. In the same year, oil palm plantations had only covered 23.0 % consisting of 12.1 % mature and 10.9 % young oil palm.

In 2008, wide areas of oil palm plantations closed surrounding the Air Manjuto irrigation area increased sharply to 50.2%. The areas of rice fields also slightly increased to 32.7% or 0.4% from the previous decade. In this case, oil palm plantation expansion used unproductive lands such as bush areas, bare land, and thick forest. During this period, arable dry lands surrounding the irrigation areas were unproductive. Therefore, local farmers could expand oil palm plantations on these lands. Land uses covered the Air Manjuto and surrounding areas, and the changes are shown in Figure 4. Detailed land use and changes in 2000, 2008, and 2019 at areas are reported in Table 2.

In the last decade, oil palm plantations by local farmers expanded drastically, covering about 80 % of the Air Manjuto irrigation area and its surrounding without bush and bare land. The land use covered the irrigation area in 2019, as seen in Figure 5.

Traditional farmers' growth of oil palm plantations used the marginal paddy soils developed about 40 years ago because no more arable dry land is closed to the irrigation area. In 2019, the remaining rice field in the irrigation area was about 2,368 ha. The fields were an extraordinary loss of 6,819 ha or about 74 % in the last decade. Traditional farmers' choice to switch from paddy fields to oil palm plantations was groundbreaking (Barchia et al., 2020). Various drivers led the land-use shift from rice fields to oil palm plantations, with 85% of respondents

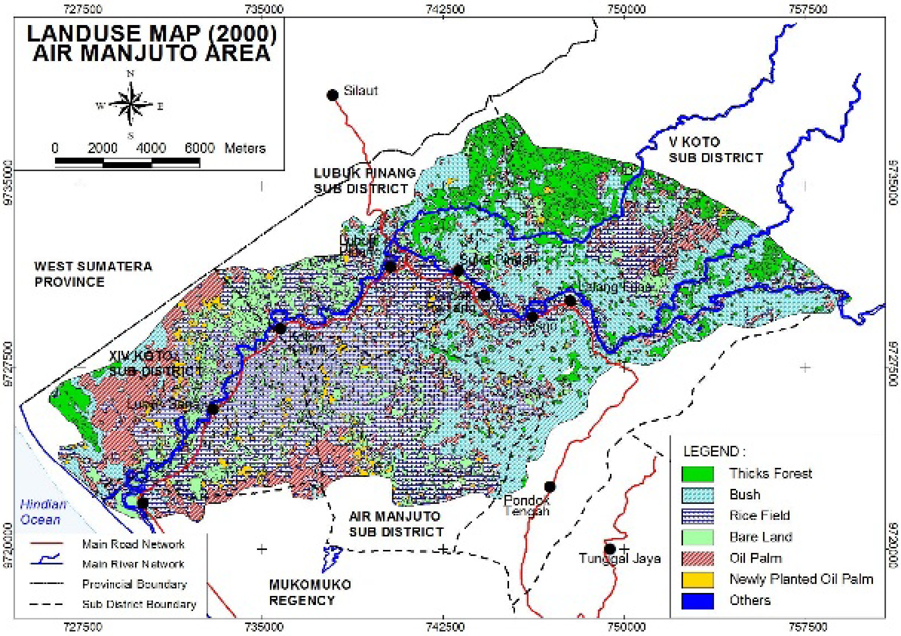

Figure 3. Land uses covered the Air Manjuto irrigation area in 2000

Table 2. Land use and its changes in the Manjuto irrigation area

Land uses	2000		2008		2019	
	Ha	%	Ha	%	Ha	%
Thick Forest	3,425	12.2	2,273	7.4	2,126	7.6
Oil Palm	3,391	12.1	14,096	50.2	22,315	79.5
Bare Land	242	0.9	0	0	0	0
Young Oil Palm	3,055	10.9	671	2.4	0	0
Settlement	833	3.0	833	3.0	833	3.0
Rice Field	9,063	32.3	9,187	32.7	2,368	8.4
Bush	7,970	28.4	0	0	0	0
Others	91	0.3	1,010	4.3	428	1.5

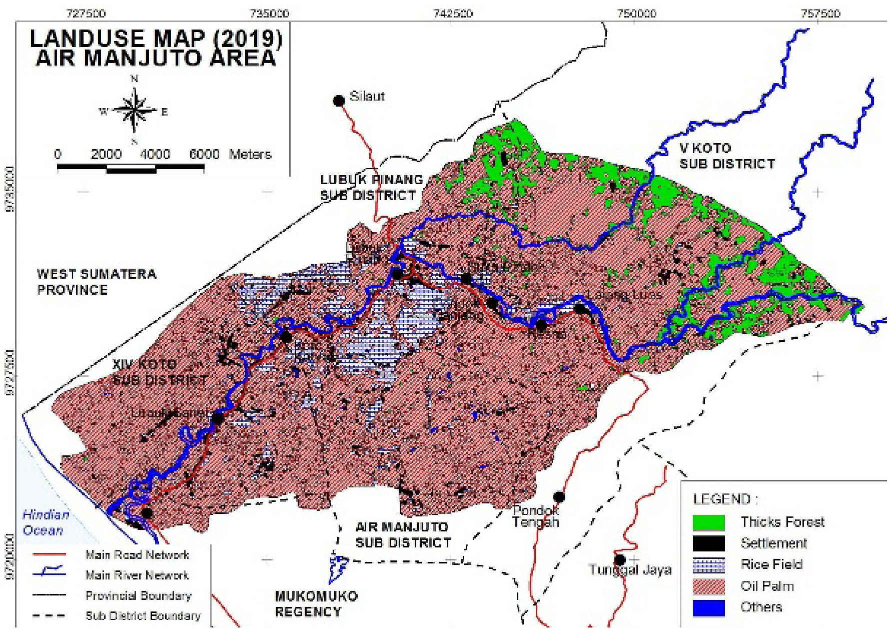

Figure 4. Land uses covered the Air Manjuto irrigation area in 2008

expressing a willingness to convert their farm, including cost considerations (58.4%), technical issues (19.4%), and environmental limits (22.2%) (Astuti et al., 2011).

Political economy and structure are the primary drivers of land-use change (Hubacek & Vazquez, 2002). Agricultural land use changes have been expedited by structural and economic transformations, with structural transformations in economic activities reliant on conventional agricultural systems shifting to agro-industrial operations (Ashari, 2003). Land values have risen dramatically, which acted as a land-use reform catalyst

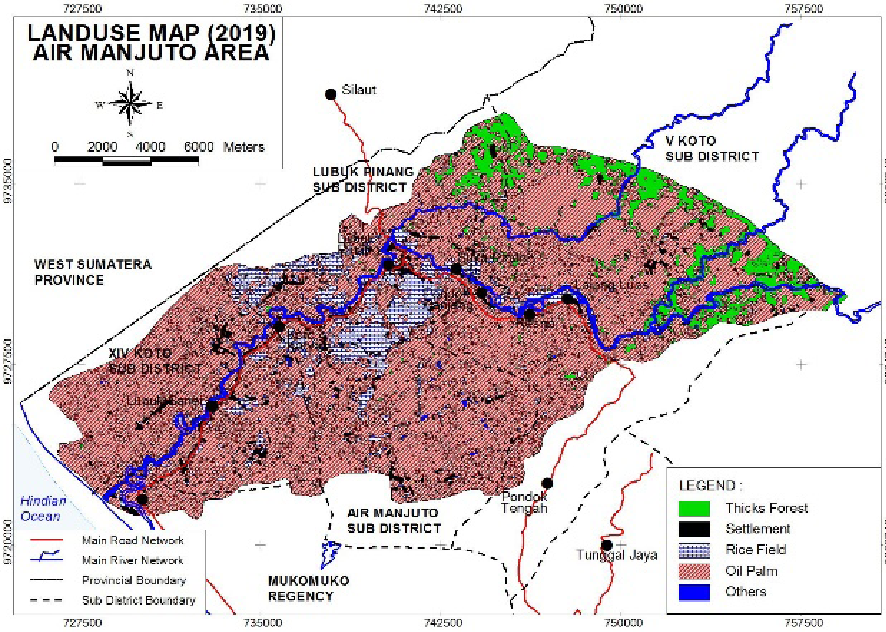

Figure 5. Land uses covered the Air Manjuto irrigation area in 2019

(Střeleček et al., 2010). The main cause for the transition in land usage from paddy fields to oil palm plantations was the reduced economic value (Fahri, 2016). According to farmer perfectives, economic land values heavily influenced rice field conversion.

The rising expenses of rice farming were determining factors in converting rice fields to oil palm plantations. The conversion was influenced by the cost of agricultural inputs such as fertilizers, insecticides, and seeds. Furthermore, rice cultivation was thought to take a long time and be fraught with natural adversity, resulting in crop failures, while plated rice was generally associated with lower profits. Oil palm production appears to be less time-consuming, easier to handle, has no ecological barriers, and yields a larger profit.

Water scarcity, insect and disease infestations, and barren soils were the key ecological variables that drove land use change from paddy fields to rubber and oil palm plantations. Irrigation water availability was restricted, specifically during dry seasons, and increased assaults from numerous pests and diseases such as brown planthopper, stem borer, and rodents pushed the conversion of rice fields to other uses (Suharyanto et al., 2015). Lack of water supply for paddy agriculture frequently resulted in rice harvest failure, necessitating year-round water supply for ongoing cultivation. The lack of water supply from irrigation canals was one of the key reasons farmers in Seluma Regency changed rice fields to oil palm plantations (Ishak et al., 2017). However, the land use changes in Bengkulu, specifically in the Air Manjuto irrigation area, have not been quantified by previous studies.

Rice production and food security in Bengkulu Province were threatened by the loss of a large area at the Air Manjuto irrigation facility. In reality, the production capacity has severely dropped due to natural resource competition for land and water and low land productivity (Wibawa et al., 2009). Rice output has decreased in the previous 10 years, but the demand has increased to meet rapid population growth, implying that the future staple food supply may be unclear.

4. Conclusion

Rice production sustainability in Bengkulu Province is faced with uncertain circumstances because of land use change from rice fields to oil palm plantations. These plantations are expanded on the arable dry lands, which are unproductive use closed to rice fields. However, in the last decade, no more arable dry land was available, and the expansion of oil palm plantations invaded the marginal rice fields. Furthermore, the rice fields in the Air Manjuto irrigation area were an extraordinary loss of 6,819 ha or about 74% in the last decade, from 9,187 ha in 2008 to 2,308 ha in 2019. The land use changes threaten food supply and security in Bengkulu. Therefore, to restore the rice fields' function from oil palm plantation and avoid land use change, the Bengkulu provincial government should support infrastructure facilities and financial incentives for rice farmers such as agrochemical subsidies and insurance.

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