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Potential Land Reserves for Agriculture in Indonesia: Suitability and Legal Aspect Supporting Food Sufficiency

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Abstract: Information on land reserves is crucial and required to support agricultural development in relation to increased population pressure, food demand, and food security. This research aims to identify and evaluate idle abandoned land based on biophysical suitability, status of land concessions, and forest areas to determine potential land reserves for agricultural development to support food security in Indonesia. The results show that, at the national level, the area of suitable abandoned lands for agricultural extensification is 27.7 million ha, but most of these lands have concession permits and are located in forest areas, so 12.4 million ha are still available, with the largest area being in dry land. The identification of abandoned land by employing satellite imagery in 54 districts resulted in a smaller acreage compared to abandoned land being mapped formally at 1:250,000. After considering land ownership and forest status, both sources resulted in similar areas at a scale of 1:50,000 and 1:250,000, i.e., 6.1 million ha and 6.0 million ha, respectively. It seems that land ownership and forest status adjusted the total acreage of identified land reserves at different map scales. An area of around 7.4 million ha will be required to meet food demand in 2045 by assuming constant consumption per capita. We found about 1.7 million ha as potential land reserves, most of which are in conversion or production forests areas. Converting forests or utilizing drylands could be potential alternatives to deal with the lack of land for food production. Moreover, due to limited wetlands, the use of reserve land in that agroecological zone should be in accordance with its designation, comply with the priority principles, and be supported by government regulations and policies, so that food security can be maintained until 2045.

Keywords: abandoned land; spatial analysis; development area; land evaluation; prediction of land needs

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Citation: Mulyani, A.; Mulyanto, B.; Barus, B.; Panuju, D.R.; Husnain. Potential Land Reserves for Agriculture in Indonesia: Suitability and Legal Aspect Supporting Food Sufficiency. *Land* **2023**, *12*, 970. https://doi.org/10.3390/land12050970

Academic Editors: Weijie Lan, Leiqing Pan, Shuyang Qu and Shaozong Wu

Received: 21 March 2023
Revised: 16 April 2023
Accepted: 24 April 2023
Published: 26 April 2023

1. Introduction

The world's population has grown substantially within the last few decades, raising competition among land utilizations [1,2]. Indonesia is the fourth most populous country after China, India, and America [3] and is inhabited by 272.7 million people with a growth rate of 1.22% per year [4]. In 2045, Indonesia's population will reach 320 million [3] or 318.9 million [5]. This increase in population of around 3.4 million people per year in Indonesia, or similar in the world, requires land to meet food and infrastructure needs.

It is common that land for housing and infrastructure development is obtained from converted paddy fields [6–10], for instance, the establishment of international airports [11–13] or the development of toll roads [14,15]. Meanwhile, the growth of cities and peri-urban areas raise land-related issues, such as availability and suitability of land for development, either in Indonesia [16,17] or in other countries such as China [18–21] and the United States of America [22]. Rice field conversion in the nearby cities is relatively common. The preference for converting productive paddy fields for development is usually due to their flatness and accessibility, including strategic positioning near city centers and transportation routes [23]. An increase in land conversion has been observed on the outskirts of major cities in Indonesia since the 1990s, especially for settlements and industries [24]. The conversion significantly decreases the existing productive agricultural land for producing staple foods [25], which in turn disrupts food security. Similar phenomena have been observed in some countries, such as Japan, Britain, and the Netherlands as reported by Mori [26] and in Vietnam [27].

On the other hand, land degradation occurs in some agricultural lands due to natural or management-related aspects [28] indicated by a decline in productivity [29]. For instance, dry land in wet climates that could be an alternative for land reserves, including Ultisols and Oxisols generally have undergone further weathering and base leaching, making the soil acidic with high aluminum saturation and low natural fertility [30,31]. Moreover, some agricultural areas have been fragmented due to the inheritance system [32,33], which leads to an increase in abandoned land [34].

The protection of suitable yet productive land for designated uses has been an alternative to warrant sustainable food production through regulation in some countries [35,36]. The regulation may protect croplands while allocating reserve land to maintain suitability and availability for sustainable food production. However, the law cannot fully assure that the most productive land such as paddy fields will be unconverted to non-agricultural use, particularly when they are located on the outskirt of cities. On the other hand, land expansion is likely needed to fulfill future food demand due to population growth. However, a few studies have showed that the available land for agricultural expansion is likely to be less suitable for cropland [37].

Increasing population, land conversion, and other agricultural land issues are interrelated, especially for maintaining the food supply [38]. The higher the population, the higher the demand for food and land will be; simultaneously, the productive agricultural land will decrease due to conversion. Future food security should be warranted by increasing productivity, intensifying the management of uses, and/or expanding the production areas [39,40]. Therefore, a land reserve designated for agricultural production or other uses is needed to support both agricultural and non-agricultural sectors.

The identification of land reserves to meet food and housing needs has been reported on in some countries, such as China [10], Canada [41], and Ghana [42]. In Indonesia, reserved areas are needed for expanding agricultural land to meet long-term food needs. Naturally, the identification of reserved areas would optimize the allocation of uses considering the suitability and resource-carrying capacities to mitigate land degradation and support environmental services [43]. Nonetheless, the selection procedure should be clearly defined. A few studies have documented methods to identify abandoned land as a reserve for expanding food production areas, such as Lambin [43] for global scope and Mulyani, Mulyanto, Barus, Panuju, and Husnain [44] for the case of Indonesia.

Geospatial analysis is the mainstay for delineating and analyzing land reserves particularly for a vast coverage [4]. Satellite imagery has been utilized to support analyses in various countries such as Albania and Romania [45], Carpathian Police—Poland [46], and Romania [47]. Nonetheless, the identification of land for designated reserves should consider not only physical properties that can be observed remotely but also the legal status of the identified land to minimize conflicts of management. In Indonesia, a combination of geospatial analysis of thematic maps at the national level and identification of the reserves by employing high-resolution imagery at the regional level has been implemented since 2016–2021 in 54 districts [48–50]. Nonetheless, the previous identification did not consider legal aspects and ownership status. This study aims to identify potential land reserves and their suitability from abandoned land by integrating legal aspects and ownership status and to predict the sufficiency of land to meet future food demand.

2. Materials and Methods

2.1. The Scope and Operational Definition of Land Reserves

We limited the scope of this research by considering the definition of land reserves as regulated by state or government policies of Indonesia to allow implementation. In this sense, land reserves are viewed as a form of policy that relates to setting priorities of land uses to be regulated by the government. Reserved land was defined specifically in Indonesia through Law No. 41, Year 2009, of The Republic of Indonesia as potential land with designated utilization to maintain its suitability and availability for sustainable food agriculture. The criteria are outlined by government regulation (Peraturan Pemerintah) No. 1, Year 2011, including (a) being inside and/or outside the prime agricultural area; (b) located in the expanse of land supporting productivity and production efficiency; (c) considered either as highly suitable, moderately suitable, or marginally suitable for food crop agriculture; (d) supported by basic infrastructure. They may be from abandoned land meeting the suitability for expanding food production, be part of agricultural areas or conversion production forest and production forests [51], or may be unused or uninhabited land [52]. In this research, we define land reserves as abandoned land that is biophysically suitable for expanding agricultural land, excluding land with cultivation rights (HGU), covering other use areas (OUAs) or agricultural cultivation areas, conversion production areas (CFAs), and production forest areas (PFAs). This consideration is in line with government regulation No. 23, Year 21, article 58 and the regulation of the Minister of Environment and Forestry No. 7, Year 2021, article 273 that allow forest release for several purposes, including national strategic projects, national economic recovery, and land allocation for food and energy security.

2.2. Data and Location

We employed several thematic maps for sorting land reserves both at the national and regional levels, including the designated paddy field areas at a scale of 1:25,000 produced by the National Land Agency; oil palm plantations at 1:50,000 from the Coordinating Ministry of Economics in 2019; cacao plantations at 1:50,000 [53,54]; land suitability and land management recommendations at a scale of 1:50,000 [48–50]; peatland at 1:50,000 [55]; swamp land at 1:50,000 [56]; forest status map of the Ministry of Environment and Forestry in 2021; land use and tenure status from the National Land Agency in 2012; and administration boundary produced by the National Statistics Agency in 2020. In addition, to support visual image interpretation, Google Earth Pro was employed. The coverage of the spatial analysis of land reserves at the national and regional levels is presented in Figure 1.

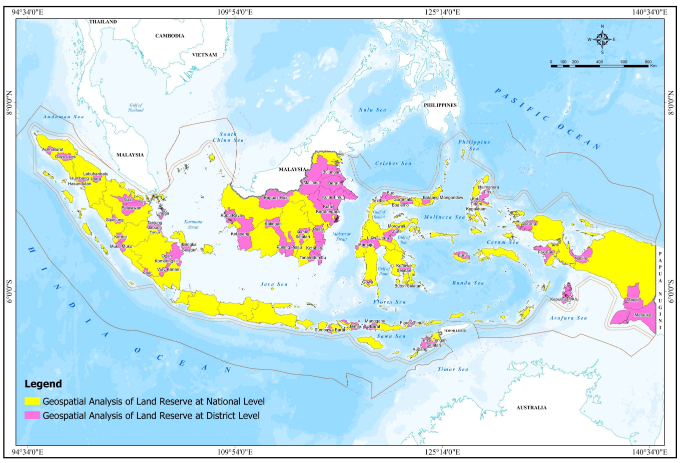


Figure 1. Coverage of analysis for determining land reserves at the national level (yellow color) and regional level (pink color).

2.3. Methods

Several methods were used to address the research aims. The following subsections explain the methods involved.

2.3.1. Spatial Analysis of Land Reserves at the National Level

Geospatial analysis of land reserves at the national level involved several stages, i.e., (a) determining abandoned land by selecting land cover to be included, i.e., secondary forest, shrubs, grass, and open land, which was taken from the legacy data [57] of land cover databases produced by the Ministry of Forestry and Environment of Indonesia scaling at 1:250,000, followed by removing developed areas such as paddy field, oil palm plantations, and cacao and coconut plantation; (b) evaluating the suitability of the abandoned land by using an application called SPKL version 1.0 (Land Suitability Assessing System in Indonesia, BBSDLP, Bogor) [58]; (c) superimposing suitable abandoned land with land concessions and permits status; (d) superimposing point c and the forest status map. The employment of available legacy data has been chosen to fill the data gap by several researchers [57,59]. The procedure resulted the distribution of suitable abandoned land for agricultural development. The criteria to determine land for agricultural development are presented in Table 1, while the flow chart for delineating land reserves is presented in Figure 2.

Table 1. Criteria to determine land reserves for the development of food crops, annual crops, plantations, or horticultures.

Abandoned Land						
Land Suitability	**Concession Status**	**Forest Status**	**Land Types**	**Slopes (%)**	**Land Reserves**	
					Recommendations	Types
Not suitable					No recommendation	-
Suitable	Other concessions	Other uses area	Swamps	-	Recommendation	Food crop
		Conversion forest	Swamps	-	Recommendation	Food crop
		Production forest	Swamps	-	Recommendation	Food crop
		Other forest status	Swamps		No recommendation	-
		Other use area	Dryland	<15	Recommendation	Food crop
				15–40	Recommendation	Perennial crop
		Conversion forest	Dryland	<15	Recommendation	Food crop
			Dryland	15–40	Recommendation	Perennial crop
		Production forest	Dryland	<15	Recommendation	Food crop
			Dryland	15–40	Recommendation	Perennial crop
		Other forest status	Dryland	>40	No recommendation	-
	Concessions/Licenses: Cultivation rights Building rights Management rights Forestry permits Plantation permits Mining permits	Other use area, conversion forest, production forest, other forest status	Dryland/swamps	-	No recommendation	-

2.3.2. Determining Land Reserves at the Regional Level

The procedure to determine land reserves at the regional level resembles that at the national level. The difference lies in the source of abandoned land, which at this level was from the visual interpretation of SPOT 6/7 imageries, while the national one was from legacy data. Initial filtering was performed to remove land being intensively utilized, including paddy fields, plantations, settlements, and other areas. On-screen interpretation was achieved using ArcGIS 10.8, which was optimally adjusted at a scale of 1:5000. Visual interpretation of the land cover was achieved by examining interpretation keys such as color, shape, size and height, shading, pattern, texture, and context [60] in 54 districts, representing selected provinces for 2016 to 2021 (Figure 1). Of the 54 representative districts, around 28 districts were ground checked to collect samples for ground truthing and measuring the accuracy. The result is a distribution of abandoned land at a scale of 1:50,000. The next step was land suitability assessment by weighing up biophysical properties, but social, economic, or other aspects were not considered. The last stage was filtering the result by land ownership and forest status. All the criteria used to determine land reserves are displayed in Table 1, while the flowchart for determining land reserves is presented in Figure 3.

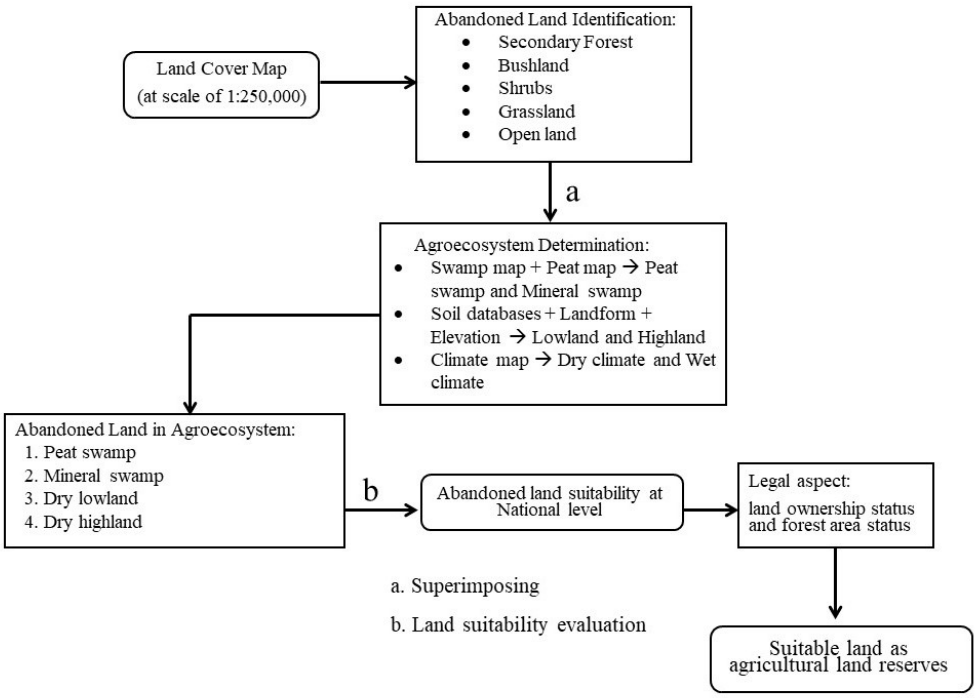


Figure 2. Flowchart for determining land reserves by utilizing abandoned land.

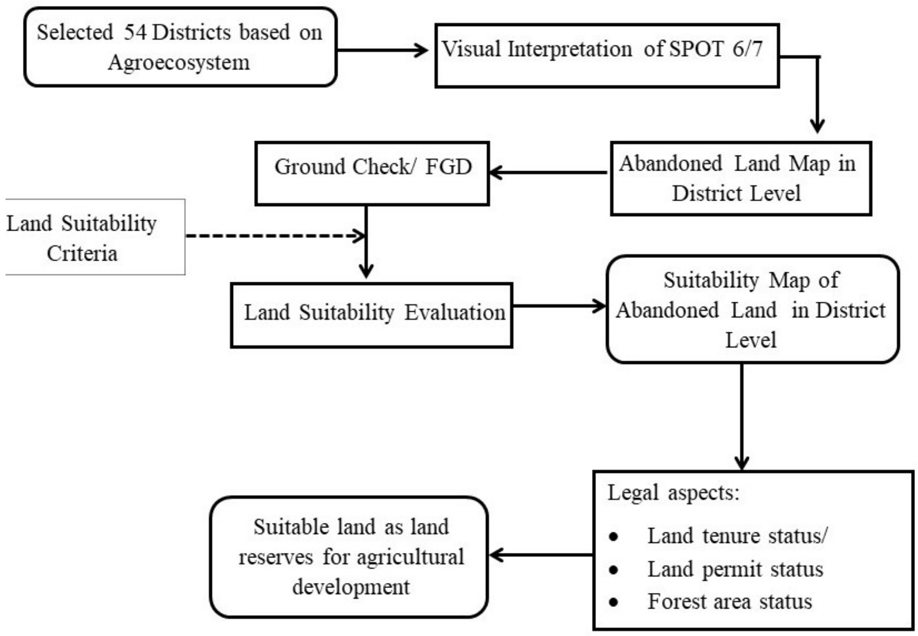


Figure 3. Identification of land reserves at district level.

A complete identification of land reserves of Indonesia ideally should involve 511 districts. However, due to constraints of time, funding, and manpower, recently 54 districts or about 10% of the state were identified by Indonesian government. Meanwhile, previous analysis showed that discrepancies in acreage may be observed when different spatial resolutions of data sources were evaluated [44]. Thus, it is possible to have different estimated acreages from national and district approaches. The area of abandoned land is likely smaller when identified by using a district approach with a finer scale than that using the national one with a coarser spatial resolution. Considering the scale, a detailed approach was then used to predict land reserves at the national level.

2.3.3. Prediction of Land Needs by 2045

Land needs to meet the national food demand by 2045 were estimated by firstly estimating production capacity and food demand. The production capacity of paddy fields was estimated by considering the designated areas for paddy fields, the cropping intensity of the 4 ecosystems, and the average yield per ha. The equation is as follows:

$$PC = \sum(A_{i,t,p,l} \times I_{i,t,p,l} \times Y_{i,t,p,l}) \quad (1)$$

where

PC = Production capacity (tons dried milled grain);

$A_{i,t,p,l}$ = Designated area for paddy field (i: irrigated, t: rainfed, p: tidal swamp, l: freshwater swamp) (ha);

$I_{i,t,p,l}$ = Cropping intensity per year (harvested area divided by standard area) in paddy field (i: irrigated, t: rainfed, p: tidal swamp, l: freshwater swamp);

$Y_{i,t,p,l}$ = Yield (ton/ha) (i: irrigated, t: rainfed, p: tidal swamp, l: freshwater swamp).

Total food demand was estimated by considering food needs, stock, and export as presented in the following expression:

$$FDT = \text{Food needs} + (\text{stock} + \text{export}) = (P \times C) + 0.15\,(P \times C) \quad (2)$$

where

FDT = Food demand total (tons of rice);

P = Projected population equal to 325 million in 2045;

C = Consumption per capita equal to 110 kg/year or 95 kg/year.

Finally, land need was approximated by considering the production capacity, food demand, and estimated productivity of the planned production areas as follows:

$$LN = (FNT - PC)/(1/0.58 \times 2P) \quad (3)$$

where

LN = Land needs (ha);

FNT = Food needs (tons rice):

PC = Production capacity (tons rice);

P = Productivity of new paddy fields (around 3 tons/ha/season or 6 tons/ha/year).

The production capacity was calculated employing the spatial and statistical data of paddy fields classified by type, viz., irrigated, rainfed, tidal swamp, and freshwater swamp fields (locally called lebak) [61]. Meanwhile, cropping intensity was calculated as the ratio between the harvested area and the paddy fields of a district. Each district has been labeled based on the dominant field type; therefore, single cropping intensity and productivity were used for each district. Food needs were calculated based on the projected population between 2020 and 2045 by assuming that stock and export were at 15% of total rice consumption for food [62].

Table 2 shows the list of data sources used to determine potential land reserves both at the national and regional level, as well as to predict production capacity, food demand, and land needs by 2045.

Table 2. List of the data sources for land reserves analyses and prediction of land needs.

Description of Data	Sources of Data		
	Procedure of IARRD (2008)	Procedure of Ritung et al., 2015 [51]	Procedure of this project (2016–2021)
A. Determining land reserves at the national level			
Abandoned land	Land use map 1999 at a scale of 1:1,000,000 [63]	Land use map 2012 at a scale of 1: 250,000 [64]	Land cover map 2019 at a scale of 1:250,000 [65]
Soil database, land suitability, land management recommendation	Soil map 2001 at a scale of 1:1,000,000 [66]	Soil map 2014 at a scale of 1:250,000 [67]	Soil map 2016–2018 at a scale of 1:50,000 [48–50]
Forest status	Forest status 1999 at a scale of 1:1,000,000	Forest status 2013 at a scale of 1:250,000	Forest status 2019 at a scale of 1:250,000 [68]
Land tenure/land permit status			Land use map at a scale of 1:50,000 [64]
Other supporting maps: Paddy field Estate Peat Swamp			 Paddy field of 2019 [69] Oil palm plantations 2019 [70] Peatlands map at a scale of 1:50,000 [55] Swamp areas at a scale of 1:50,000 [56]
B. Identification of land reserves at district level			
District selection for sample collection			Selection of six agroecosystems from 54 districts
Abandoned land identified by visual interpretation			SPOT 6/7 mosaic imageries LAPAN (2015–2019)
Soil database, land suitability, land management recommendation			Soil map 2016–2018 at a scale of 1:50,000 [48–50]
Forest status			Forest status 2019 at a scale of 1:250,000 [68]
Land tenure/land permit status			Land use map 2012 at a scale of 1:50,000 [64]
C. Prediction of land needs by 2045 (tabular data)			
Paddy field area (irrigated, rainfed, tidal, and freshwater swamp lands) Cropping intensity Rice yield Projected population (2020–2045) Consumption per capita			Mulyani et al. [61] Statistik Indonesia 2020 [62] Statistik Indonesia 2020 [62] Statistik Indonesia 2021 Study of Indonesian Staple Foods [71]

3. Results and Discussion

3.1. The Suitability of Abandoned Land at the National Level

The initial study identified abandoned areas at 42.60 million ha, with the largest category in dry lowland, i.e., 32.84 million ha, and 6.96 million ha in dry highland [72]. The distribution of abandoned land in swamps covered 2.81 million ha, consisting of 0.46 million ha of peat swamps and 2.35 million ha of mineral swamps (Figure 4).

The results show that 27.72 million ha of 42.60 million ha abandoned lands is suitable for agricultural commodities (Table 3). The largest area is in dry land with slopes less than 15%, covering 14.02 million ha, and on slopes between 15% and 40%, covering 11.20 million ha. About 2.4 million ha of suitable abandoned land was in swamps consisting of 0.30 million ha in peat swamps and 2.18 million ha in mineral swamps. Unsuitable land was around 14.88 million ha, mostly in dry land with limiting factors of a slope of more than 40%, very shallow and rocky soil, and quartz sandy soil, and the largest area was on the island of Kalimantan. Whereas for peat swamps, the unsuitability was due to a peat thickness of more than 3 m or the decomposition degree of fibric peat, while in mineral swamps, it was due to the depth of the pyrite or sulfidic layer [73].

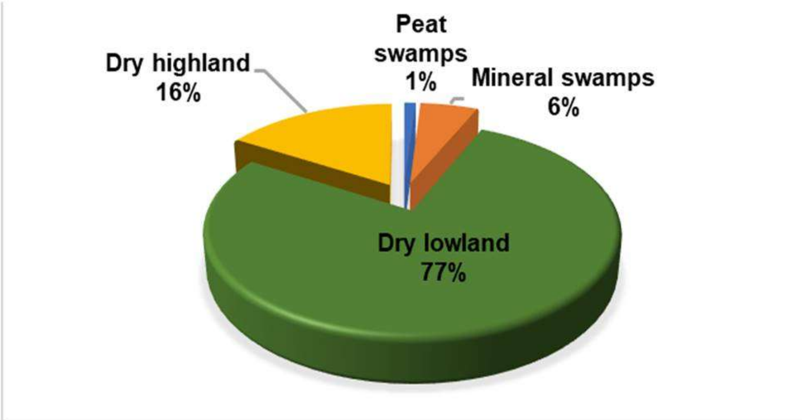


Figure 4. Distribution of abandoned land in dry and swamp land in Indonesia.

Table 3. Land suitability of abandoned land for agricultural development in Indonesia.

Island	Suitability of Abandoned Land				Not Suitable Land	Total Area
	Swamp Land		Dry Land			
	Peat	Mineral	Slope < 15%	Slope 15–40%		
	- ha -					
Sumatera	40,621	343,240	2,286,296	1,684,586	2,132,166	6,486,908
Jawa	-	7658	140,216	195,301	244,641	587,816
Bali + Nusa Tenggara	-	4185	597,786	1,821,295	1,014,177	3,437,442
Kalimantan	95,842	483,810	4,654,714	3,361,823	6,352,622	14,948,811
Sulawesi	871	31,422	1,145,021	1,293,022	2,780,010	5,250,346
Papua + Maluku	175,370	1,314,370	5,199,926	2,843,672	2,358,478	11,891,815
Total area	312,704	2,184,684	14,023,959	11,199,698	14,882,094	42,603,139

3.2. Land Suitability Based on the Legal Aspect at the National Level

The suitability of abandoned land for agricultural development was biophysically analyzed, resulting in an area of 27.72 million ha. Combining biophysical evaluation and land concession reduced the suitable area for agricultural development due to permits and cultivation rights for various businesses such as plantations, mining, and forestry. Of the 27.72 million ha of land suitable for agriculture (Table 3), approximately 12.45 million ha (44.9%) had permits and cultivation rights; thus, the remaining area was about 15.3 million ha (Table 4).

Most of the suitable land was in dry lowland (82.76%), distributed in the Papua, West Papua, Central Kalimantan, and East Kalimantan provinces. Moreover, the largest areas of suitable swamp land, both in mineral swamps and peat swamps, were distributed in the Papua and Central Kalimantan provinces. It seems that, at the national level, the prospective locations for future agricultural development were predominantly in dry land. Although mineral swamp has potential for the development of paddy fields, no more than 10% of suitable land was available for agricultural development, while in peat swamps it was about 1.08%. Table 5 and Figure 5 present suitable abandoned land for agricultural development considering land concession, tenure maps, and forest status maps. It shows that around 12.45 million ha of suitable abandoned land met the legal aspects, consisting of 10.72 million ha in dry lands and 1.72 in wetlands (swamps). The largest distribution was in dry land and in OUAs, of which, 4.80 million ha was in agricultural cultivation areas, 4.16 million ha was in production forest areas covering, and 1.76 million ha was in conversion production forest areas. Whereas in wetlands, a balanced coverage among OUAs, CFAs, and PFAs was observed. There were around 0.57 million ha in OUAs of prospective land reserves for the development of food agricultural land, especially paddy rice. The rest were in the conversion production forest area (0.53 million ha) and 0.62 in the production forest area. Figure 5 shows that the land reserves for agricultural development in the Kutai Timur District, East Kalimantan Province, were about 481,751 ha, mostly in dry land (99.1%) and in production forest areas.

Table 4. Distribution of suitable abandoned land for agricultural development considering permits and cultivation rights.

Provinces	Swamp Land		Dry Land		Total (ha)
	Peat	Mineral	Lowland	Highland	
Aceh	5	21,727	188,492	62,587	272,812
Sumatera Utara	8676	13,862	310,580	107,136	440,254
Riau	7195	21,265	88,368	-	116,827
Sumatera Barat	138	8465	550,410	21,952	580,966
Jambi	621	30,367	571,754	51,949	654,692
Bengkulu	-	179	37,219	25,723	63,121
Sumatera Selatan	-	3213	52,478	3364	59,055
Bangka Belitung	4963	38,243	303,368	-	346,573
Kep Riau	-	304	97,066	1264	98,634
Lampung	495	19,901	143,029	5754	169,179
Banten	-	124,179	423,287	-	547,466
Jawa Barat	-	2	21,995	7783	29,781
Jawa Tengah	-	904	1611	19	2534
Yogyakarta	-	13	223	525	761
Jawa Timur	-	56	44,809	13,746	58,611
Bali	-	-	24,096	280	24,375
Nusa Tenggara Barat	-	1301	78,783	5726	85,809
Nusa Tenggara Timur	-	2191	704,660	119,908	826,759
Kalimantan Utara	-	29,839	658,355	9122	697,316
Kalimantan Barat	1632	90,006	324,906	-	416,545
Kalimantan Tengah	78,932	228,976	1,377,977	-	1,685,885
Kalimantan Selatan	3	28,155	111,507	378	140,043
Kalimantan Timur	5979	81,823	1,508,741	135,415	1,731,958
Sulawesi Utara	-	135	18,057	2098	20,290
Sulawesi Selatan	-	2493	97,141	18,091	117,725
Sulawesi Tengah	7	3879	670,670	193,340	867,897
Sulawesi Tenggara	-	10,747	499,679	2410	512,836
Sulawesi Barat	204	376	23,542	80,973	105,096
Gorontalo	-	364	76,625	1630	78,619
Maluku	-	8081	824,763	4748	837,592
Maluku Utara	-	884	303,291	7893	312,068
Papua	35,140	712,674	1,512,157	43,216	2,303,188
Papua Barat	21,767	49,139	987,304	5347	1,063,556
Total	165,759	1,533,743	12,636,943	932,377	15,268,822

Land reserves in Indonesia can be grouped into two types: The first is designated land reserved to be protected as agricultural land, which is protected by Law No. 41/2009. This form resembles what was discussed by Nixon and Newman [74] and Androkovic [41] in British Colombia; Guerra et al. [75] in the Amazon forest in Brazil; and Aksu and Iban [76] in Istanbul. The second is agricultural land to fulfill future needs (in 2045) by extending agricultural areas by considering the legal aspects such as tenurial and forest status.

Table 5. The distribution of suitable abandoned land for agricultural development considering permits, cultivation rights, and forest status.

Islands	Swamp Land			Dry Land			Total (ha)
	OUAs	CFAs	PFAs	OUAs	CFAs	PFAs	
Sumatera	95,838	11,605	40,625	1,370,137	91,760	862,429	2,472,393
Jawa	122,251	0	2050	407,993	0	83,978	616,275
Bali + NT	2334	0	3	663,334	13,016	71,590	750,279
Kalimantan	276,479	61,456	140,055	1,062,962	483,586	1,600,103	3,624,642
Sulawesi	14,090	0	1	741,560	84,625	246,816	1,087,095
Papua + Maluku	63,834	457,574	435,747	558,904	1,084,458	1,296,486	3,897,003
Total	574,826	530,635	618,481	4,804,890	1,757,445	4,161,402	12,447,687

Note: OUAs = other use areas, CFAs = conversion forest areas, PFAs = production forest areas.

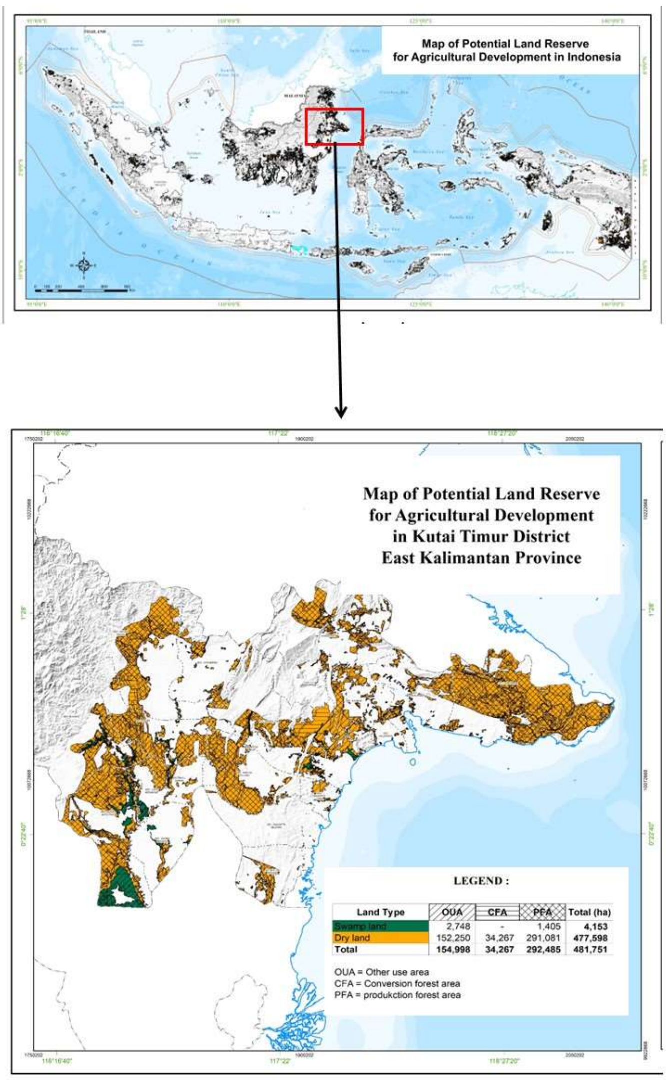


Figure 5. Distribution of potential land reserves at the national level and at the district level (Kutai Timur District, East Kalimantan Province).

3.3. Assessing the Land Suitability and Land Reserves of Abandoned Land at the District Level

Abandoned land at the national level was analyzed for 54 districts/cities to represent provinces. The detailed biophysical characteristics of abandoned lands and their characteristics have been discussed by Mulyani et al. [53].

Table 6 shows biophysically suitable areas for food production filtered by legal aspects, i.e., land tenure, permits, and forest status. The screening was to delineate the most probable locations for expanding agricultural areas, which can then be defined as land reserves. Table 5 shows that, of the 16.89 million ha of abandoned land in 54 districts, around 8.49 million ha or 50.26% is suitable for agricultural land development. Meanwhile, adding the criteria of area selection with land tenure, permits, and forest status resulted in 6.11 million ha or 36.17% of the total abandoned land in the 54 regencies available for land reserves. The result is comparatively equivalent to the outcome of the national approach employing data at the scale of 1:250,000. It seems that land tenure, permits, and forest status dictate the selection of land reserves for agricultural development.

Table 6. Distribution of abandoned land by the visual interpretation of SPOT 6/7 imagery—land suitability and land reserves for agricultural development.

Island	Sum of District	Abandoned Land	Land Suitability	Land Reserve
			ha	
Sumatera	15	1,765,576	663,701	506,491
Kalimantan	14	8,326,549	4,332,034	3,147,575
Sulawesi	9	1,347,432	640,546	356,873
Nusa Tenggara	6	1,147,916	692,112	420,661
Maluku dan Papua	9	4,306,771	2,162,771	1,679,207
Total	54	16,894,244	8,491,164	6,110,808
Land cover (scale 1:250,000)	54	18,137,873	11,198,120	6,010,697

Figure 6 and Table 7 present the abandoned land in Katingan District, Central Kalimantan Province, at a scale of 1:250,000 from the thematic map and 1:50,000 from visual interpretation. Different acreages of each land use were observed when comparing both data sources. For instance, it was found that grasslands covered 6227 ha from satellite interpretation that was unidentified at a scale of 1:250,000. Likewise, open land and shrubs were larger at a scale of 1:250,000, whereas secondary forests were larger at a scale of 1:50,000.

Table 7. Distribution of abandoned land at a scale of 1:250,000 and the results of the visual interpretation of SPOT 6/7 imagery.

Land Cover	Abandoned Land (ha)	
	Land Cover Map (1:250,000)	Visual Interpretation of SPOT Images
Secondary forest	824,069	888,375
Shrubs	349,615	275,632
Grassland	-	6277
Open land	29,636	2828
Total	1,203,321	1,173,112

Figure 7 illustrates the process of selecting an area for land reserves considering permit and forest status. It is shown that considering legal permits to land and forest status significantly reduced the acreage of potential area for land reserves. Table 8 describes an example of the distribution of abandoned land suitable for the development of food, annual, or perennial crops in Katingan District, Central Kalimantan Province, after eliminating land that already has permits or cultivation rights. The widest distribution is in dry land covering an area of 547,260 ha (86.38%), while in mineral swamps it is 86,295 ha and is recommended only for food crops.

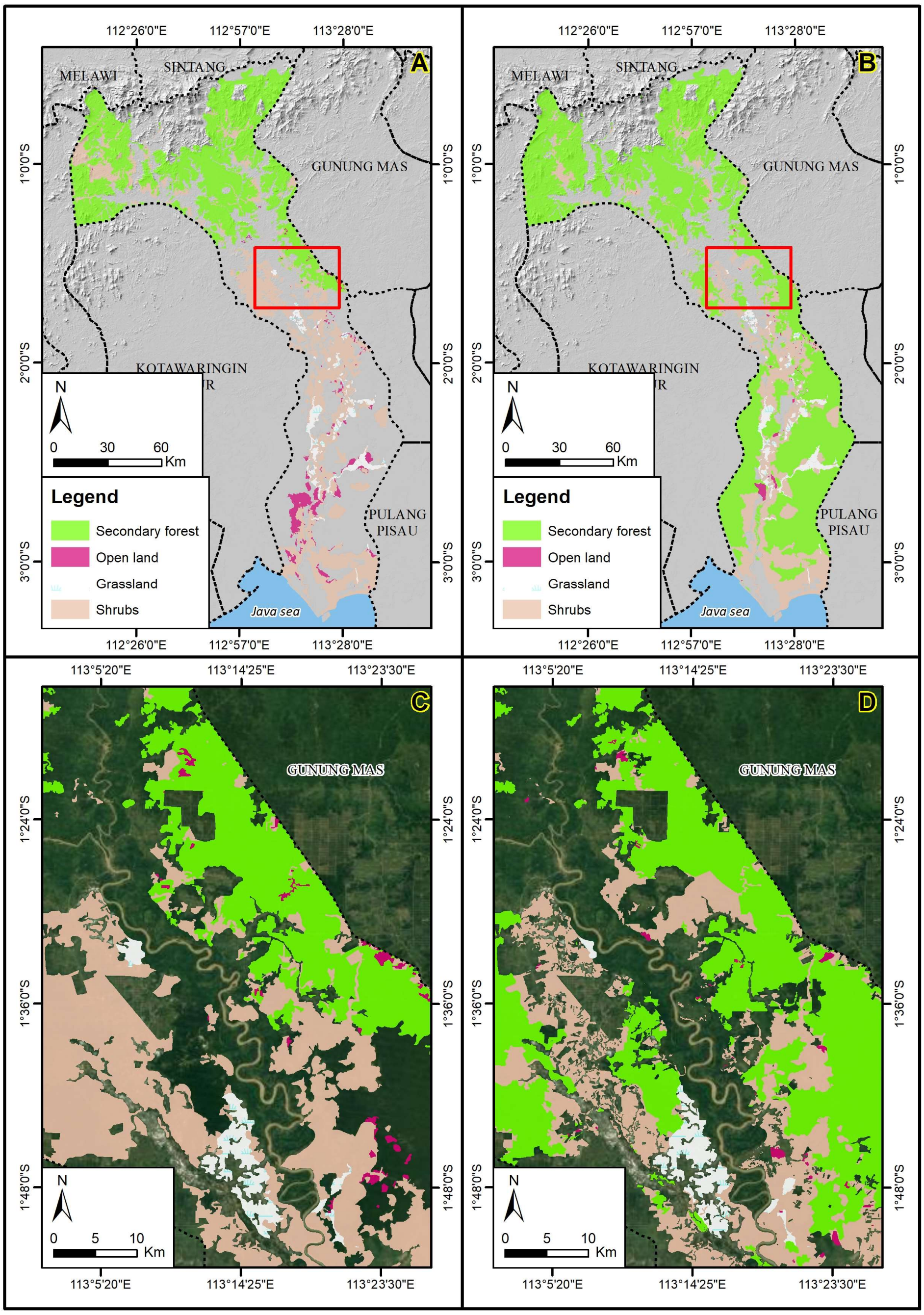


Figure 6. Distribution of abandoned land at a scale of 1:250,000 (KLHK 2019) (**A**) and distribution of abandoned land resulted from the interpretation of SPOT6/7 imagery (**B**) in Katingan District, Central Kalimantan Province. Differences in the appearance of the distribution of abandoned land at a scale of 1:250,000 (**C**) and satellite interpretation of the Malan Island District, Katingan Regency, Central Kalimantan Province (**D**).

Table 8. The suitability of abandoned land for annual and perennial crops, considering land tenure in Katingan District, Central Kalimantan Province.

Land Typology	Annual Crop	Perennial Crop	Total (ha)
Mineral swamp	86,295	-	86,295
Upland	258,797	288,463	547,260
Total	345,092	288,463	633,555

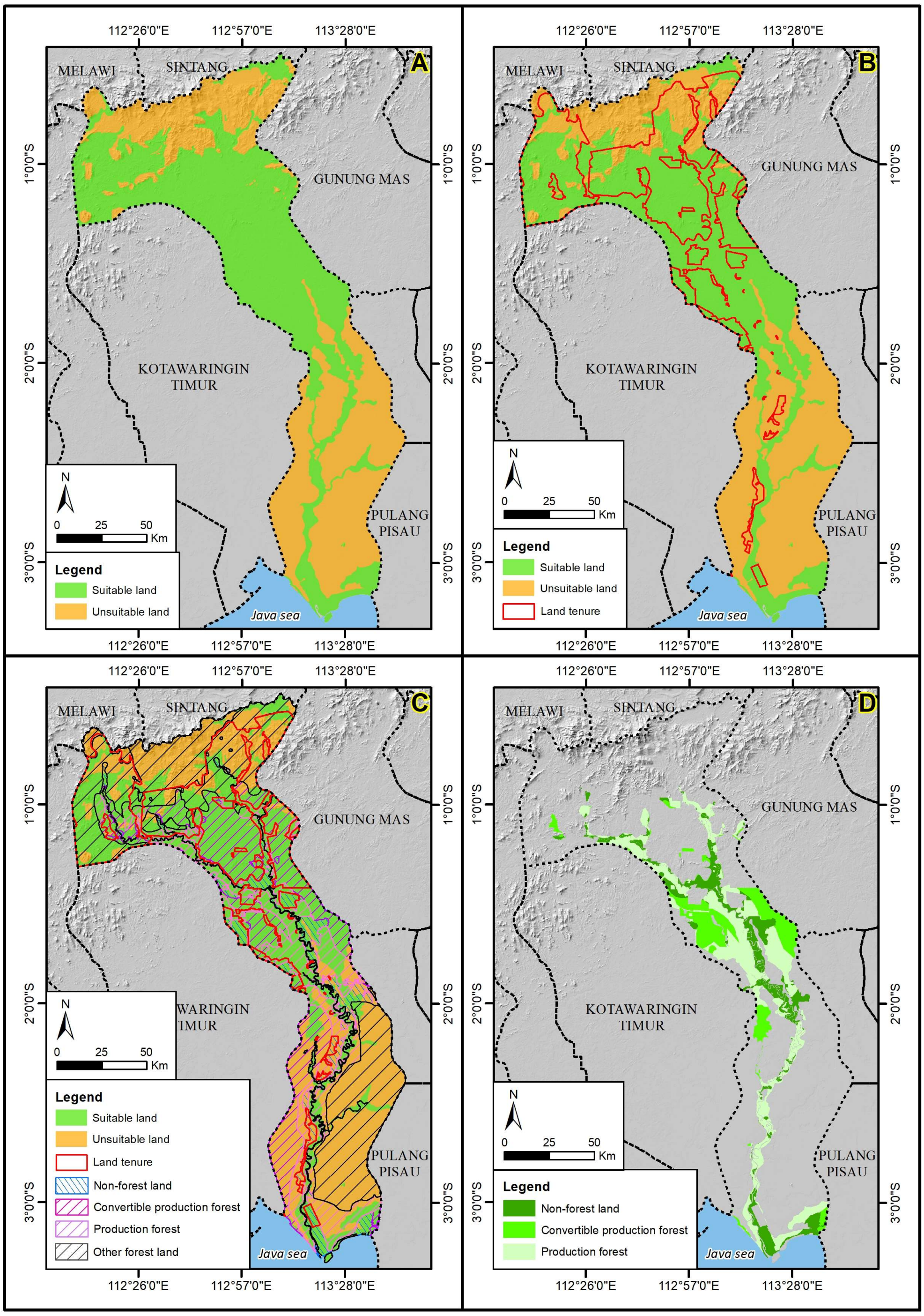


Figure 7. Figures represent the sequential process of determining land reserves, i.e., (**A**) identification of suitable abandoned land, (**B**) screening the area based on permits, (**C**) screening the area based on forest status, and (**D**) land reserves in three forest statuses, viz., OUAs, CFAs and PFAs.

Table 9 and Figure 7D present the distribution of land reserves that meet all criteria of suitability and legal aspects in Katingan District including biophysics, land tenure (permits), and forest status. The results show that only 463,588 ha (73.19%) can be used as land reserves. This means that around 169,867 ha are in other forest areas, such as protected forest areas, conservation forests, or other forests. The land reserves consist of 243,469 ha for food crops and 220,220 ha for annual crops, most of which (65.00%) are in forest areas, both CFAs and PFAs. The largest reserve land is in dry land, especially in CFAs, 186,340 ha for food crops and 199,006 ha in agricultural cultivation areas or outside forest areas recommended for annual crops. Utilizing forest areas for agricultural purposes, including land reserves for food security may be an alternative. Nonetheless, the allocation of land reserves for agricultural development should not compromise natural forest services as highlighted by Lambin et al. [43] and Knoke et al. [77].

Table 9. Land reserves for annual and perennial crop development considering forest status in Katingan District, Central Kalimantan Province.

Land Typology	Land Reserves for Agricultural Development						
	Annual Crop			Perennial Crop			Total
	OUAs	CFAs	PFAs	OUAs	CFAs	PFAs	(ha)
Mineral swamp	23,820	51,885	5258	-	-	-	80,964
Upland	19,425	134,455	8625	119,006	28,168	73,046	382,724
Total	43,245	186,340	13,883	119,006	28,168	73,046	463,688

3.4. The Need and Availability of Land to Meet Food Demand (Rice) by 2045

Land needs are predicted based on the production capacity of paddy fields and food needs, including food stocks (approximated at 15% of food demand). Paddy fields for producing rice could be classified based on their water sources, including irrigated, rainfed, tidal, and lowland swamp. If rice field conversion is at around 96,500 ha/year, the production capacity would decrease annually at 1.0 million tons of milled grain (MG) if the average yield is 5.2 ton/ha and cropping indexes are at 2 [6].

By using Equations (1)–(3), estimated food need, projection of food capacity, and land needs are presented in Table 9. It shows that, if per capita consumption remains at around 110 kg of rice/year, then food needs by 2045 will be around 64.3 million tons of MG with production capacity decreasing from 55.0 million tons in 2020 to 38.4 million tons in 2045 due to land conversion of around 90,000 ha/year, resulting in a food shortage of 25.9 million tons of MG. If per capita consumption can be reduced from 110 kg to 95 kg rice/capita by 2045, then the need for additional production will be 17.7 million tons of MG. Moreover, if land conversion can be reduced to 60,000 ha/year, then rice production will reach 15.0 million tons of MG in 2045. Various conditions of the conversion rate have been considered to estimate the possibility of increasing production by enhancing cropping intensity and its productivity [28]. It showed that rice sufficiency would not likely be reached if conversion is constant at 90,000 ha/year and consumption per capita is 110,000 kg/year.

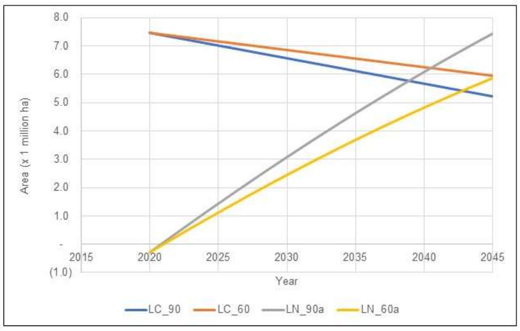
Figure 8 shows that if consumption per capita is 110 kg of rice/year with the productivity of the new area being around 3 ton per ha that was cultivated twice a year, while the acreage of paddy fields is at 7.4 million ha in 2020 with land conversion at about 90,000 ha/year, then, in 2045, there would be 5.2 million ha left, and around 7.4 million ha land will be required to replace it (Table 10). If land conversion can be reduced to 60,000 ha/year in 2045, the land need will be about 5.9 million ha. If decreasing conversion rates are combined with reducing consumption per capita, then the land need will be about 3.5 million ha. The figure shows that, for every converted land unit, twofold the land acreage should replace it as the land is less productive.

Table 10. The projection of food needs (milled grain—MG), production capacity (MG), and land needs (hectares).

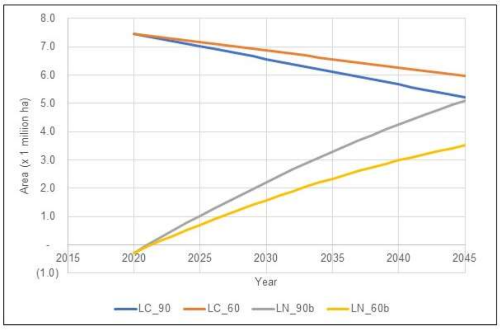
Year	FN_110	FN_95	PC_90	PC_60	LN_90a	LN_60a	LN_90b	LN_60b
	Million Tons MG				Million ha			
2020	54.0	54.0	55.0	55.0	(0.3)	(0.28)	(0.3)	(0.3)
2021	54.6	54.3	54.3	54.3	0.1	0.01	(0.0)	(0.1)
2022	55.1	54.5	53.6	53.7	0.4	0.29	0.3	0.1
2023	55.6	54.8	53.0	53.0	0.8	0.57	0.5	0.3

Table 10. *Cont.*

Year	FN_110	FN_95	PC_90	PC_60	LN_90a	LN_60a	LN_90b	LN_60b
	Million Tons MG				Million ha			
2024	56.2	55.0	52.3	52.4	1.1	0.85	0.8	0.5
2025	56.7	55.2	51.7	51.7	1.4	1.13	1.0	0.7
2026	57.2	55.4	51.0	51.1	1.8	1.40	1.3	0.9
2027	57.7	55.6	50.3	50.5	2.1	1.66	1.5	1.1
2028	58.1	55.8	49.7	49.9	2.4	1.93	1.8	1.3
2029	58.6	55.9	49.0	49.3	2.8	2.19	2.0	1.4
2030	59.1	56.1	48.3	48.7	3.1	2.45	2.2	1.6
2031	59.5	56.2	47.7	48.2	3.4	2.70	2.4	1.7
2032	59.9	56.3	47.0	47.6	3.7	2.95	2.7	1.9
2033	60.4	56.4	46.4	47.0	4.0	3.20	2.9	2.1
2034	60.8	56.4	45.7	46.5	4.3	3.44	3.1	2.2
2035	61.2	56.5	45.0	46.0	4.6	3.68	3.3	2.3
2036	61.5	56.5	44.4	45.4	4.9	3.92	3.5	2.5
2037	61.9	56.6	43.7	44.9	5.2	4.15	3.7	2.6
2038	62.2	56.6	43.0	44.4	5.5	4.38	3.9	2.7
2039	62.6	56.5	42.4	43.9	5.8	4.60	4.1	2.9
2040	62.9	56.5	41.7	43.4	6.1	4.82	4.3	3.0
2041	63.2	56.5	41.1	42.9	6.4	5.04	4.4	3.1
2042	63.5	56.4	40.4	42.4	6.6	5.25	4.6	3.2
2043	63.8	56.3	39.7	42.0	6.9	5.45	4.8	3.3
2044	64.1	56.2	39.1	41.5	7.2	5.66	4.9	3.4
2045	64.3	56.1	38.4	41.1	7.4	5.86	5.1	3.5



(**a**)



(**b**)

Figure 8. The trend of estimated paddy field from 2020 to 2045 by assuming (**a**) a per capita consumption of 110 kg/year and paddy field conversion (LC) at 90,000 ha/year (LC_90), LC around 60,000 ha/year (LC_60), additional land needs (LN) if LC equal to 90,000 ha/year (LN_90a) and LN for LC equal to 60,000 ha/year (LN_60a), (**b**) per capita consumption of 95 kg/year, LC equal to 90,000 ha/year (LC_90) and 60,000 ha/year (LC_60), land needs for conversion at 90,000 ha/year (LN_90b) and at 60,000 ha/year (LN_60b).

3.5. Conclusions and Policy Implications

The increasing population has a major effect not only on raising food demand but also on enlarging the need for land. Settlements, infrastructures, and industrial and services areas are needed to support growing populations either in big cities, peri urbans areas, or newly developed locations. Relatively flat yet accessible areas are generally preferred. These characteristics are typical for paddy fields; thus, paddy fields are highly preferred for developing infrastructure. Consequently, the conversion of agricultural land, particularly paddy fields, to non-agricultural land is unavoidable. The enactment of law and its derivative regulations to protect food-agricultural land and control land conversion in Indonesia seems ineffective in reducing the rate of land conversion for supporting the economic and industrial sectors. Decreasing paddy fields are continuously observed, which directly impacts on decreasing production capacity of food, whereas food demand is increasing due to population growth. Hence, expanding food production areas by utilizing suitable abandoned land as land reserves is a strategic way to meet the demand.

The requirement for establishing new rice fields to expand the food production area appears unproportional to the loss of paddy fields due to conversion since less productive areas would likely be available. The loss of 1 ha of rice fields due to conversion should be replaced by two times the acreage, which may possibly be located in swamp areas. However, insufficient swamp lands are available, so forest areas could be alternatives for agricultural land expansion. Creating new paddy fields on dry land is comparatively more expensive than on swamp land, due to the need to establish irrigation networks. Meanwhile, dry land is commonly used for producing non-rice food commodities, such as corn, soybeans, cassava, sugar cane, or horticulture including onions, chilies, potatoes, carrots, green vegetables, and estate crops, such as oil palm, rubber, cacao, coffee, coconut, and pepper. This creates competition for various land uses, including among agricultural uses and non-agricultural ones, such as mining, industry, urban areas, and others. Moreover, considering not only biophysical properties but also government policy in the form of forest status, permits, and land ownership would avoid management conflicts.

This research noted that the identification of land reserves for food production expansion should consider the use of legacy data to fill data gaps that are likely to be encountered in developing countries. Meanwhile, the limited land reserves being identified necessitate the prioritization of land for various uses. This may apply to many countries including Indonesia. A thorough assessment of cost, benefit, risk, and consequences is needed to prioritize land uses. It is imperative to develop a strategic plan for meeting future food demand. A few strategies such as optimizing the use of agricultural land, mitigating the rate of agricultural land conversion, controlling yet reducing the rate of population growth, diversifying food, utilizing reserve land according to its designation, and regulating policies to support such targets should be undertaken to strengthen the capacity for realizing sustainable food security.

Author Contributions: A.M., B.M., B.B., D.R.P. and H. designed the research. A.M. collected and analyzed the data; the initial draft was written by A.M. and D.R.P.; B.M., B.B. and H. provided critical feedback and gave editorial oversight; then A.M. and D.R.P. finalized the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research was financially supported by the Indonesian Agency for Agricultural Research Development (ICALRRD), Ministry of Agriculture, through the research program "Analysis of land resource management policies to support agriculture in 2016–2020" and "Analysis of the distribution of agricultural land in 2020–2021".

Data Availability Statement: Not applicable.

Acknowledgments: The authors would like to thank the head of ICALRRD for the funding that supports this research's implementation. This endeavor would not have been possible without the assistance of researchers and technicians within the ICALRRD during the data collection and processing.

Conflicts of Interest: The authors declare no conflict of interest.

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