

RESEARCH ARTICLE



Food Self-Sufficiency Based on Local Rice in Flood-Prone Areas of Katingan Regency, Central Kalimantan

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ABSTRACT

Land resources are the essential foundation for providing indispensable food sources. The increasing demand for food necessitates the expansion of land dedicated to food production. Katingan Regency has sufficient land resource potential for local food development but faces natural challenges such as flooding and declining food production. Land suitability evaluation is crucial for planning land use to achieve a sustainable food system. This study aims to identify, analyze, and evaluate the suitability and availability of land for local rice areas in Katingan Regency. The approach used is land suitability evaluation, which integrates multicriteria decision-making (MCDM) and geographical information systems (GIS). The criteria weights were calculated using the analytic network process (ANP), producing flood risk maps and land suitability classes for local food. Spatial planning considerations were employed to obtain land availability according to its designation. The study results show that approximately 76% of Katingan Regency area is suitable for local rice farming. Land classified as highly suitable (S1) for local rice accounts for 7% or 136,130 hectares, with shallow flood-prone level areas reaching 3,890 hectares. According to food balance projections, Katingan Regency is expected to face a rice deficit by 2033. This research is expected to help formulate appropriate land use regulations to increase local food production while preserving biodiversity. Additionally, it provides a foundation for strategic measures that can be taken to ensure long-term resilience, environmental conservation, and ecological sustainability in Katingan Regency.

Introduction

Food security has become an urgent global issue and a major challenge with the increasing demand for food due to the growing population [1,2]. Agricultural land that provides food supply and ensures several ecosystem services, and supports food security and the achievement of the SDGs is becoming increasingly limited [3–5]. Increased production to support Zero Hunger (Goal 2) has negative implications for achieving other goals such as Climate Action (Goal 13) and Life on Land (Goal 15) [6]. The current agri-food systems, coupled with land use changes, are exacerbating soil degradation, loss of biodiversity, and greenhouse gas emissions [7–9]. Therefore, land use management has become an urgent issue that needs to be addressed.

Land-use planning plays a pivotal role in integrating climate adaptation into development strategies, fostering resilient and sustainable landscapes that shield communities from climate-induced challenges [10,11]. Effective land management requires careful land-use planning to ensure that land use aligns with its capabilities and suitability. Inappropriate land use can lead to land degradation, increased poverty, social issues, and the destruction of existing cultures [12]. This process entails assessing current land conditions, anticipating future land demands, and formulating strategies to manage and allocate land resources efficiently [13]. Agricultural land suitability assessment is crucial to ensure food security, maintain ecological balance, and promote sustainable agricultural development [5].

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Additionally, land suitability assessment plays an essential role in optimizing land use allocation and achieving sustainable land resource utilization [14]. Identifying the most productive agricultural areas and those with harmful ecological impacts using modern technologies like remote sensing can significantly improve land management [10,15,16]. In several study of land suitability evaluation for rice cultivation has been widely studied using diverse methods, including the land unit approach [17–19], GIS-based FAO (Food and Agriculture Organization) limitation methods, and multi-criteria decision making (MCDM) combined with geospatial techniques [5,20–24]. Extensive research has been conducted both nationally and internationally on land suitability assessment, focusing on the application of geographic information systems (GIS) and MCDM [16,20,22,25–27]. MCDM provides a structured approach for evaluating options, analyzing problems, and setting priorities [22,28]. The results of land evaluations can serve as a basis for land-use planning [12,20–22,29].

Central Kalimantan, including Katingan, has been prioritized by the government under the food estate program aimed at expanding agricultural land outside Java. According to *Kajian Lingkungan Hidup Strategis* (KLHS) of the Katingan Regency and Rencana Pembangunan Jangka Menengah Daerah (RPJMD) for 2019–2023, the allocation for agricultural land is 237,666.55 hectares [30]. Based on the existing land use area in Katingan Regency, around 18.9 thousand hectares of rice fields have been utilized but not yet optimized [31]. Katingan Regency has significant local resource potential, including local rice varieties. The local community has traditionally planted local rice as an effort to preserve agricultural land [26]. There are 43 types of local rice in Central Kalimantan suitable for swamp and dry lands. The seven main rice varieties commonly cultivated by local farmers include *Sirandah*, *Babilem Haik*, *Babilem Kurik*, *Jargan Mayang*, *Jargan Baputik*, *Budak*, and *Hiup*. Local rice has several advantages, including resistance to floods, drought, acidic soil, iron toxicity, and various pests [32,33]. Local rice plays a crucial role in preserving native germplasm, genetic diversity, and local wisdom.

Optimizing rice production in Katingan Regency requires integrated land management, encompassing both utilized and potential lands, as well as the development and application of local rice varieties suitable for environmental conditions. Efforts to maximize the potential of agricultural land in Katingan face serious challenges related to flood disasters, which can threaten rice productivity [34], especially during the rainy season. Katingan is prone to flooding, causing many villages and sub-districts to be submerged, impacting the lives of local communities [35]. The increasing frequency of extreme floods threatens food production and local livelihoods. Mapping flood-prone areas is crucial to reducing flood risks and minimizing the impact of agricultural land degradation [36]. The characteristics of flood-resistant local rice varieties become a potential adaptive solution, ensuring optimal and sustainable land.

Agricultural land development has long been a central theme in previous studies, particularly in enhancing high-yield rice production [20,22,37,38]. The integration of sustainable agricultural land is a crucial step toward strengthening food security [10], including the optimization of local rice utilization to support a balanced agrarian ecosystem. This research presents a novel and impactful approach by incorporating flood-prone areas into the planning framework, enabling a more detailed and context-sensitive management of agricultural landscapes to reinforce national food security. In particular, this research lies in the development of a more comprehensive and adaptive framework that aligns agricultural practices with both environmental and economic sustainability within a risk-based land use planning context.

This study integrates GIS and MCDM in land evaluation [39,40], creating instruments that can be used for sustainable land planning and management [16,41,42]. Land utilization needs to be well-planned, considering the proper implementation of existing spatial plans and more efficient land use for future agriculture [20,43]. The research combines GIS analysis methodology and ANP (Analytic Network Process) to identify available and suitable land based on flood risk levels in the study area. The study aims to assess flood-prone areas and land suitability for local rice cultivation, taking into account the regional spatial planning of Katingan Regency. This assessment will identify available and suitable land for local rice cultivation and analyze land carrying capacity based on production balance to ensure future food needs are met. The results of this assessment are expected to assist in formulating land-use regulations for food zones in flood-prone areas that are efficient in the long term, thereby encouraging increased food production while preserving local biodiversity and protecting the environment for future generations.

Materials and Methods

Study Area

This research was conducted in Katingan Regency, one of the regencies in Central Kalimantan, stretching from south latitude $50^{\circ}20'$ to $53^{\circ}38'$ and east longitude $112^{\circ}00'$ to $113^{\circ}45'$. This regency borders Malawi Regency and West Kalimantan Province to the north; Gunung Mas Regency, Palangkaraya City, and Pulang Pisau Regency to the east; the Java Sea to the south; and East Kotawaringin Regency and Seruyan Regency to the west. The regency comprises 13 sub-districts: Katingan Kuala, Mendawai, Kamipang, Tasik Payawan, Katingan Hilir, Tewang Sangalang Garing, Pulau Malan, Katingan Tengah, Sanaman Mantikei, Petak Malai, Marakit, Katingan Hulu, and Bukit Raya [44]. Katingan is traversed by the Katingan River, which is approximately 650 km long [45]. In 2023, the population of Katingan Regency reached 169,355 people [45]. Katingan Regency has the potential to become an alternative food granary as one of the high rice-producing regions in Central Kalimantan, reaching 36,180 tons, with a harvested area of 12,042 hectares in 2023 [45]. A Map of the research location is presented in Figure 1.

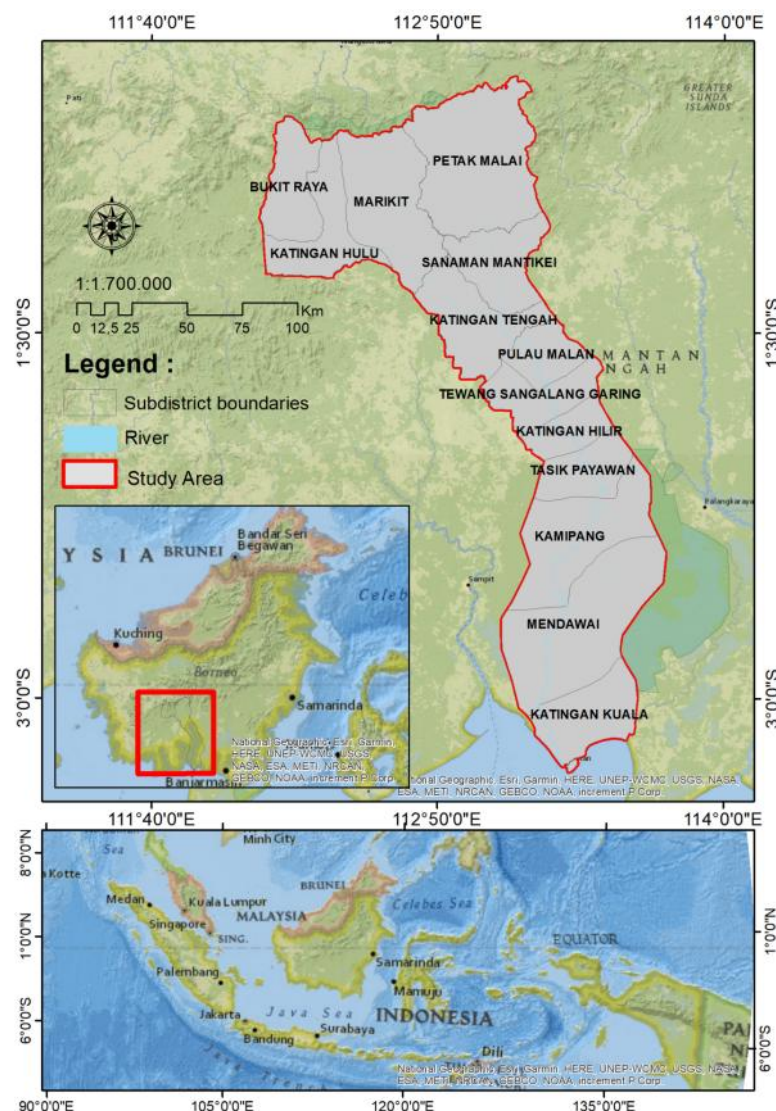


Figure 1. Map of the research location in Katingan Regency.

Data Collection and Sources

The spatial data used in this research includes the 1:50,000 scale soil map unit from *Balai Besar Pengujian Standar Instrumen Sumberdaya Lahan Pertanian* (BSIP SDLP), the 2019–2039 Spatial Plan Map of Katingan Regency from the Regional Development Planning Agency of Katingan Regency, the Forest Area Map from the Ministry of Environment and Forestry, the Geology Map from the Ministry of Energy and Mineral

Resources, Digital Elevation Model (DEM) data from the U.S. Geological Survey (USGS) science for a changing world, map of land use in 2023 from the regional development planning agency of Katingan Regency, rainfall data in 2023 from the meteorology, climatology, and geophysics agency of Central Kalimantan, the Topographical Map of Indonesia of Katingan Regency at a 1:50,000 scale, and population, rice production, and per capita consumption data from Statistics. These data sets will be used to create maps that combine flood risk classifications with assessments of land suitability for local rice cultivation. Other data used include respondent data obtained from experts related to the research topic. ANP was used to weight each criterion used to determine flood-prone areas and land suitability for local rice. Each criterion consists of sub-criteria presented in Figure 2. The tools used in this study include computers with QGIS 3.40 for spatial data processing, Super Decisions 2.10 for ANP analysis, questionnaire forms, stationery, and Microsoft Office.

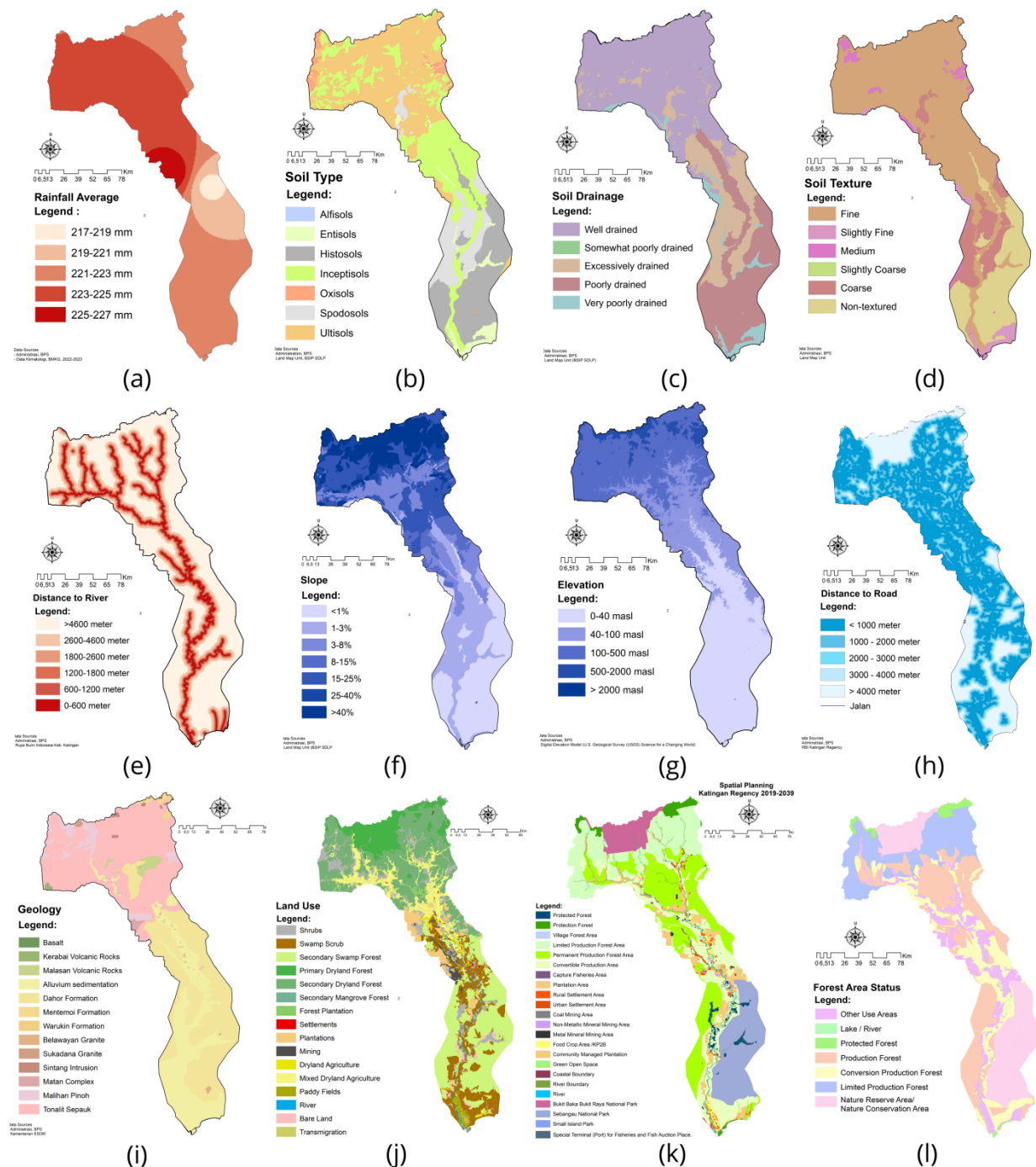


Figure 2. Spatial distribution of: a) Rainfall, b) Soil type, c) Soil drainage, d) Soil texture, e) Distance to river, f) Slope, g) Elevation, h) Distance to road, i) Geology, j) Land use, k) Spatial planning, and l) Forest area status.

Data Analysis

Flood-Prone Area

The initial stage of the research began with analyzing flood-prone areas. This analysis used spatial ANP, which combined spatial analysis and the ANP [46]. ANP is a technique used to obtain relative importance or priority based on multiple criteria assessed by individuals or based on the normalization of measurement results [47]. It allows all elements at all levels to be connected within a network. ANP analysis was used to obtain the weights of each flood-prone area criterion. Identifying criteria for flood-prone areas was conducted by studying various references and discussions. The selected criteria were soil type, slope gradient, elevation, distance to the river, average monthly rainfall, land use, and landforms. Criteria weights were obtained from four experts in this assessment, including those from academia, the Meteorology, Climatology, and Geophysics Agency, and the regional disaster management agency. Experts rate the criteria on a scale of 1 to 9 using a pairwise comparison on questionnaire form 1. The scale of comparative assessment of criteria in ANP is presented in Table 1. The opinions of different experts were then combined using the geometric mean [48].

Table 1. Rating for pairwise comparison.

1/9	1/7	1/5	1/3	1	3	5	7	9
Extreme Less important	Very strong	Strong	Moderate	Equal	Moderate More important	Strong	Very strong	Extreme

Sources: [44].

The process began with creating a pairwise comparison matrix to evaluate criteria and sub-criteria, allowing consistency ratios and decision sustainability assessment to be calculated. Next, the relative weights of decision-making elements were determined using the Eigenvector Method, which provides a systematic approach to measuring preferences. This analysis created an unweighted supermatrix that incorporated the weights obtained from the Eigenvector method, which were then placed into the pairwise comparison matrix. Considering these results, a weighted supermatrix was formulated, integrating the priorities established in the previous steps. Finally, a limited supermatrix was built, allowing for the prioritization of alternatives, thus facilitating a structured and rational decision-making framework. This comprehensive approach ensured that all essential factors were considered, resulting in more informed and sustainable decisions in network management [47,49]. The consistency ratio value is expected to be below 10% [50]. The final weight of the land suitability analysis was the sum of the weighted criteria results from the ANP, multiplied by the score of each sub-criteria [37]. The weighted linear combination (WLC) results will be classified into four categories of flood vulnerability levels, namely safe, low, medium, high.

Land Suitability and Land Availability for Local Paddy

The methods used are land suitability and land availability evaluation. The land suitability evaluation was conducted using the MCDM procedure [16,20,26,37,38]. Land suitability analysis refers to the systematic evaluation of land characteristics to determine its appropriateness for a specific use, such as agricultural development, typically conducted at regional or landscape scales [51,52]. The seven criteria used consist of several sub-criteria. Land suitability criteria for local rice include soil type, soil texture, soil drainage, slope, distance to roads, and rainfall. Then, the criteria assessment process uses the ANP methodology. Criteria weights were obtained from four experts in this assessment, who came from academia, the Central Kalimantan Agricultural Instrument Standardisation Centre, the Katingan District Agriculture and Food Security Office, and agricultural extension workers. The final weight of the land suitability analysis was the sum of the weighted criteria results from the ANP, multiplied by the score of each sub-criteria [37]. Furthermore, overlays were conducted for all criteria and then scored to obtain a land suitability class for local rice. The results of the land suitability evaluation are classified into land suitability classes consisting of S1 (highly suitable), S2 (moderately suitable), S3 (marginally suitable), and N (not suitable) [12].

Availability analysis was conducted to identify areas with potential for local rice expansion. Land availability is analyzed using spatial overlays of three parameters: forest area status, land allocation in the spatial pattern of spatial planning, and land use/land cover maps [20]. The available land is chosen from areas designated for other land use in the forest area status. Then, the available land is also chosen from agricultural areas based on spatial planning. The current existing conditions for agricultural land were also considered. The land suitability and availability evaluation results were analyzed to identify suitable and accessible land for agricultural activities, such as land for local rice cultivation.

Rice Balance Calculation until 2050

Before establishing the rice balance, rice needs for Katingan Regency until 2033 were estimated based on population projections. Population data, consumption amounts, rice production, and harvested area from 2018–2023 were used to analyze food needs and were assumed to remain constant in the following years. The per capita rice consumption was 93.79 kg/capita/year [53] and the rice productivity was 2.87 tons/ha [45]. Population projections were made to depict population development over a specified period, as shown in the following equation [54]:

$$P_n = P_0 (1 + r)^n \quad (1)$$

Where, P_n = Projected population (people); P_0 = Base year population (people); and r = Population growth rate (%). The annual rice consumption needs of the population can be calculated using the following equation:

$$K_{pb} = K_b / (P_n * x) \quad (2)$$

Where, K_{pb} = Rice demand in GKG (tons); K_b = Per capita rice consumption; P_n = Population in year t (people); and x = Conversion from GKG to rice at 62.74%. The next step was to calculate the rice balance until 2050 using the following equation:

$$S/D = SP_t - K_{pb} \quad (3)$$

Where, S/D represents surplus/deficit; SP_t represents sugar production at time t (tons) projected until 2050; and SC_t represents rice consumption needs at time t (tons). The following is the overall research workflow showing the relationship of the methodology in determining flood-prone areas, local rice, and projected future food needs presented in Figure 3.

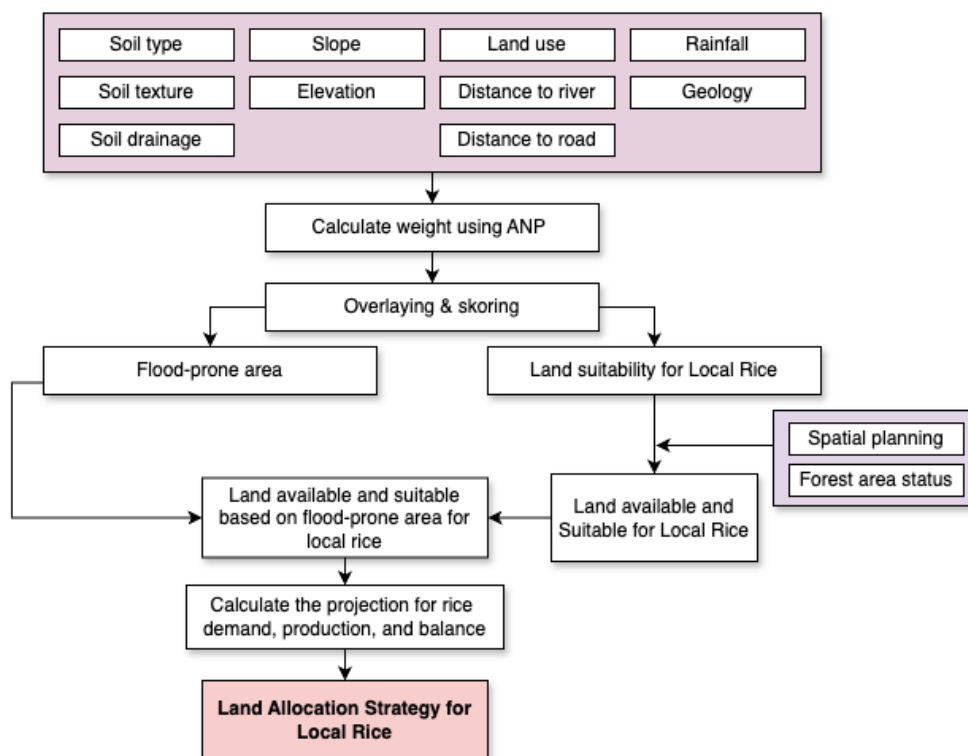


Figure 3. Research workflow.

Results

Criteria Weights and Sub-criteria Scores

Table 2 and Table 3 present the weights of the pairwise comparison matrix and the rankings of each criterion based on all expert opinions analyzed using the ANP method. The consistency ratios from the ANP analysis for flood-prone areas and land suitability for local rice are 0.021 and 0.059, respectively, making the criterion weighting results acceptable as they are below the 10% inconsistency threshold. These values indicate that the decisions were not made randomly [47].

Table 2. Pairwise comparison matrix results based on all expert opinions for the flood-prone area.

	ST	SLO	EL	LS	DTR	RF	GEO	Weight
ST	1.00	0.76	1.85	0.38	0.59	0.28	2.89	0.084
SLO	1.32	1.00	4.49	0.68	0.73	0.38	4.53	0.152
EL	0.54	0.22	1.00	0.35	0.25	0.17	1.57	0.048
LS	2.66	1.48	2.82	1.00	1.28	0.64	2.94	0.189
DRT	1.70	1.38	3.98	0.78	1.00	1.18	4.90	0.201
RF	3.60	2.63	5.73	1.57	0.85	1.00	5.90	0.277
GEO	0.91	0.22	0.64	0.34	0.20	0.38	1.00	0.047

Information: ST: Soil type; SLO: Slope; EL: Elevation; LS: Land use; DTR: Distance to river; RF: Rainfall; GEO: Geology.

Table 3. Pairwise comparison matrix results based on all expert opinions for land suitable for local paddy.

	ST	SLO	ST	SD	DR	LU	RF	Weight
ST	1.00	2.59	0.61	2.34	5.79	1.50	1.73	0.236
SLO	0.39	1.00	0.53	0.85	2.06	0.83	0.77	0.082
ST	1.63	1.89	1.00	1.16	3.87	3.87	1.73	0.225
SD	0.43	1.17	0.86	1.00	3.64	0.77	2.57	0.103
DR	0.17	0.49	0.26	0.27	1.00	0.32	1.00	0.090
LU	0.67	1.21	0.58	1.30	2.94	1.00	1.73	0.162
RF	0.58	1.29	0.58	0.87	1.00	0.58	1.00	0.099

Information: ST: Soil type; SLO: Slope; ST: Soil texture; SD: Soil drainage; DR: Distance to road; LU: Land use; RF: Rainfall.

The results of the criterion weighting (Table 2) for flood-prone areas indicate that rainfall is the most significant criterion in determining the level of flood vulnerability [55–59] in Katingan Regency, with a final weight of 0.227. When it rains, the amount of water in the soil increases, and depending on the intensity and duration of the rain, water can accumulate and cause flooding [56]. Slope gradient, land use, and distance to the river [57] were also essential criteria in modelling flood vulnerability in the study area, with final weights of 0.152, 0.189, and 0.201, respectively. The analysis results also indicate that the role of soil type, elevation, and geology is smaller for flood-prone areas [56].

The results of the criterion weighting (Table 3) indicate that soil type is the most significant criterion [20–22] in determining land suitability for local rice in Katingan, with a final weight of 0.236. Soil texture [60,61], drainage [29], and land use are also crucial in determining land suitability for local rice in the study area, with final weights of 0.225, 0.103, and 0.162, respectively. Meanwhile, slope gradient, distance to roads [62], and rainfall were less critical in determining land suitability for local rice. Several studies [29,61,62] identified rainfall and slope as key factors in land suitability. However, in Katingan, where farmers cultivate local rice varieties on steep slopes [33], these criteria are considered less critical. Similarly, since local rice is resilient to extreme weather [33], rainfall is not deemed a major determinant.

Each criterion used in the land suitability analysis consisted of several sub-criteria set with thresholds and intervals based on literature reviews, field investigations, and other recommendations [42]. Sub-criteria were scored from 1 to 5. The higher the score on the sub-criteria, the more accessible the land is from flooding and the more suitable it is for local rice cultivation. The scores of each sub-criterion for flood-prone areas and land suitability for local rice in Katingan are presented in Table 4.

Table 4. Criteria weight and subcriteria score.

Criteria	Subcriteria	Area		Flood-Prone		Local paddy	
		Hectares (ha)	%	Weight	Score	Weight	Score
Soil type	Alfisols	340	0.02	0.084	3	0.236	3
	Entisols	76,270	3		1		4
	Histosols	428,140	20		5		0
	Inceptisols	615,580	28		2		5
	Oxisols	44,880	2		3		1
	Spodosols	242,960	11		4		0
	Ultisols	779,340	36		3		2
Soil texture	Fine	1,354,720	62	0.225		0.225	5
	Slightly fine	88,610	4				4

Criteria	Subcriteria	Area		Flood-Prone		Local paddy	
		Hectares (ha)	%	Weight	Score	Weight	Score
Soil drainage	Medium	55,890	3				3
	Slightly coarse	60	0				2
	Coarse	240,580	11				1
	Not textured	433,300	20				0
	Well drained	1,038,840	48				5
	Excessively drained	447,210	21				3
	Somewhat poorly drained	220	0			0.103	2
	Poorly drained	572,390	26				1
Slope	Very poorly drained	111,250	5				0
	> 1 %	513,310	24		1		5
	1–3%	372,000	17		1		5
	3–8 %	337,750	15		2		4
	8–15%	125,650	6	0.152	3	0.082	3
	15–25%	422,510	19		4		2
	25–40%	80,930	4		5		1
	> 40 %	327,630	15		5		1
Elevation	0–40 mdpl	818,800	41		1		
	40–100 mdpl	446,300	22		2		
	100–500 mdpl	661,920	33	0.048	3		
	500–2,000 mdpl	93,860	5		4		
	> 2,000 mdpl	170	0		5		
Landuse	Primary forest	179,440	9		5		1
	Secondary forest	1,019,450	50		5		1
	Plantations	79,040	4		3		3
	Dryaland agriculture	214,960	11		2		4
	Bare land	28,070	1	0.189	2	0.162	4
	Paddy field	18,900	1		1		5
	Shrubs	439,870	22		1		3
	Mining	24,220	1		2		0
	Settlement	4,290	0.21		3		0
	Water body	11,570	1		4		0
Average Monthly Rainfall	217–219 mm	41,920	2		5		2
	219–221 mm	189,750	9		4		3
	221–223 mm	818,410	40	0.227	3	0.099	3
	223–225 mm	900,540	45		2		5
	225–227 mm	70,420	3		1		5
Distance to Road	< 1,000 m	1,034,170	51				5
	1,000–2,000 m	364,670	18				4
	2,000–3,000 m	171,200	8			0.090	3
	3,000–4,000 m	97,390	5				2
	> 4,000 m	353,650	17				1
Distance to River	0–600 m	184,670	9		1		
	600–1,200 m	140,280	7		2		
	1,200–1,800 m	128,500	6	0.201	3		
	1,800–2,600 m	160,900	8		4		
	2,600–4,600 m	365,610	18		5		
	> 4,600 m	1041,090	52		5		
Geology	Basalt	170	0.01		3		
	Volcano rocks	32,700	2		3		
	Alluvial deposits	489,610	23		1		
	Dahor formation	648,850	30		2		
	Mentemoi formation	16,750	1		2		
	Warukin formation	150	0.01	0.047	1		
	Granite	5,680	0.27		4		
	Sintang intrusion	7,420	0.35		5		
	Matan complex	8,510	0.40		5		
	Malihan pinoh	93,380	4		2		
	Sepauk tonalite	838,690	39		4		

Sources: Adapted from [8,59] for flood; [20,30,63] for paddy.

Heavy rainfall between 217–219 mm is given a score of 5; lighter rainfall of 225–227 mm is given a score of 1 because the intensity affects surface runoff [59]. Additionally, water storage capacity, infiltration rate, and drainage systems depend on soil type [64]. Entisols and inceptisols (score 1 to 2) are the most vulnerable, while Spodosols (score 4) and Histosols (score 5) exhibit greater resistance. Sandy soil has high transmission and permeability due to its large particle size, while clay soil, with its small particles, shows the opposite [65]. Steep slopes (25 to 40%) are assigned a score of 5 due to rapid water flow, which helps reduce flood risk [66], whereas lowland areas with slopes less than 3% are given a score of 1. Water flows from high to low areas, making lowlands more susceptible to flash floods [67]. An altitude of over 2,000 m above sea level (score 5) is safer than below 40 m above sea level (score 1), which is the most vulnerable.

Land use affects hydrological response, where areas with more vegetation have less runoff than those without vegetation [68]. Land use type: Forests (score 5) are the most effective in mitigating surface runoff, whereas agriculture and shrubs are assigned a score of 1. A distance of more than 2,600 m from the river is scored 5, whereas a distance of less than 600 m is scored 1, as the closer it is, the greater the risk [69]. The geology of an area, particularly the permeability of geological formations, plays a role in infiltration and surface runoff processes, which can exacerbate flood events [37,55].

Furthermore, in the criteria of land suitability for local rice, soil type plays an important role, with preference order: inceptisols (high fertility), entisols (high fertility but less mature), alfisols (high pH, good nutrient availability), and ultisols (acidity constraints and high Al^{3+}) [26]. The most suitable soil types are Inceptisols (score 5), followed by entisols (4), alfisols (3), ultisols (2), oxisols (1), and histosols and spodosols (0). Fine-textured soils are rated 5 for their high water and nutrient retention, while coarse or structureless soils receive scores of 1–0 due to their lower retention capacity [54]. Suitable to moderate drainage is required for optimal root zone aeration, preventing surface runoff, and maintaining soil moisture [38]. Well drainage is assigned a score of 5, whereas severely obstructed drainage receives a score of 0. Localized rice requires good or moderate drainage. Furthermore, flat or gently sloping land is ideal for rice cultivation [22], and slope of less than 3% is ideal for rice (score 5), while over 40% is given a score of 1. Road networks play an essential role in connecting crop products to markets [70]. Therefore, access to the market within < 1,000 m is given a score of 5, and > 4,000 m is given a score of 1. Rainfall is closely related to the availability of planting water [12]. The optimal rainfall of 223–227 mm is scored 5, while 217–219 mm is scored 2.

Flood-Prone Areas in Katingan Regency

Figure 4 shows the distribution of flood vulnerability levels in Katingan Regency. The map illustrates that the central to downstream areas of the regency are flood-prone. This distribution follows the flow pattern of the Katingan River. The flood threat is most evident in the closest proximity to the river and vice versa at the furthest distance [56]. Most of Katingan's population lives along the river [63], posing a significant threat to infrastructure damage and land degradation, especially agricultural land [71].

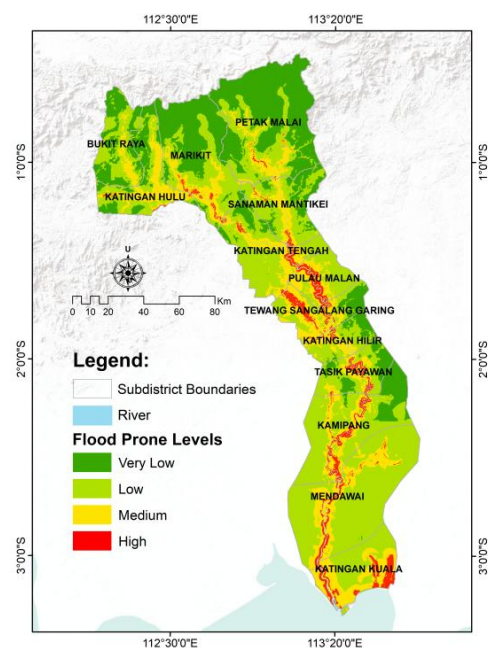


Figure 4. Flood-Prone Map of Katingan Regency.

The largest flood-prone area in Katingan Regency was at the lowest level, with a percentage of 48% or 973,790 hectares of the total area of Katingan. At the very low and medium flood-prone levels, the respective area percentages are 27% or 541,650 hectares and 21% or 425,620 hectares of the total area of Katingan. Meanwhile, the high vulnerability level only accounted for 4% or 89,280 hectares of the total area of Katingan. The table of flood-prone areas in Katingan Regency is presented in Table 5.

Level	Area flood-prone	
	Hectares (ha)	Percentages (%)
Very low	541,650	27
Low	973,790	48
Medium	425,660	21
High	89,280	4
Total	2,030,390	100

Figure 5 and Table 6 show the land suitability classes for local rice in Katingan Regency. Most of the area in Katingan Regency is suitable for local rice farming. The suitable land for local rice in this area covers 1,587,780 hectares or 76% of the study area. Land suitability for local rice falls into the highly suitable (S1) class with an area of 489,290 hectares or 24% and the moderately suitable (S2) class with an area of 877,370 hectares or 43% of the total study area. Most of the highly suitable (S1) areas are located in the central part of the study area (Katingan Tengah, Pulau Malan, Tewang Sagalanggaring, and Sanaman Mantikei) and along the Katingan River. This condition is mainly due to the Inceptisol soil type, which is suitable for local rice cultivation. Meanwhile, in the northern and southern parts of the study area (Katingan Kuala), the land suitability levels are also highly suitable (S1) and moderately suitable (S2). This region is a rice production centre, making Katingan a major rice-producing regency in Central Kalimantan [21].

Figure 5. The land suitability for local rice in Katingan Regency.

Suitability level	Total area classified by the suitability analysis	
	Hectares (ha)	Percentages (%)
Highly suitable (S1)	489,290	24
Moderate suitable (S2)	877,370	43
Marginal suitable (S3)	163,260	8
Not suitable (N)	500,470	25
Total area	2 030 390	100

Figure 6(a) shows the distribution of available land for local rice in Katingan Regency. The total potential available land is 257,950 hectares or 12.59% of the total study area. Most of the available land is located in the central and southern regions of Katingan Regency. The distribution of available land follows the river flow pattern. While, figure 6(b) shows the available land based on suitability classes for local rice and flood-prone levels. This analysis shows that the available land with the S1 suitability class represents the most significant area, with a total area of 136,130 hectares or 7% of the total study area. Based on flood-prone levels, the largest area of S1 land is at the medium level, with 71,390 hectares, while the flood-safe area is only 3,890 hectares. At the high flood-prone level, the S1 land area is large, at 18,000 hectares. Highly suitable land for local rice cultivation due to its optimal conditions and minimal constraints. When located in areas with very low or low flood risk, it offers both high productivity and safety. However, since this category is limited in area, its use should be optimized.

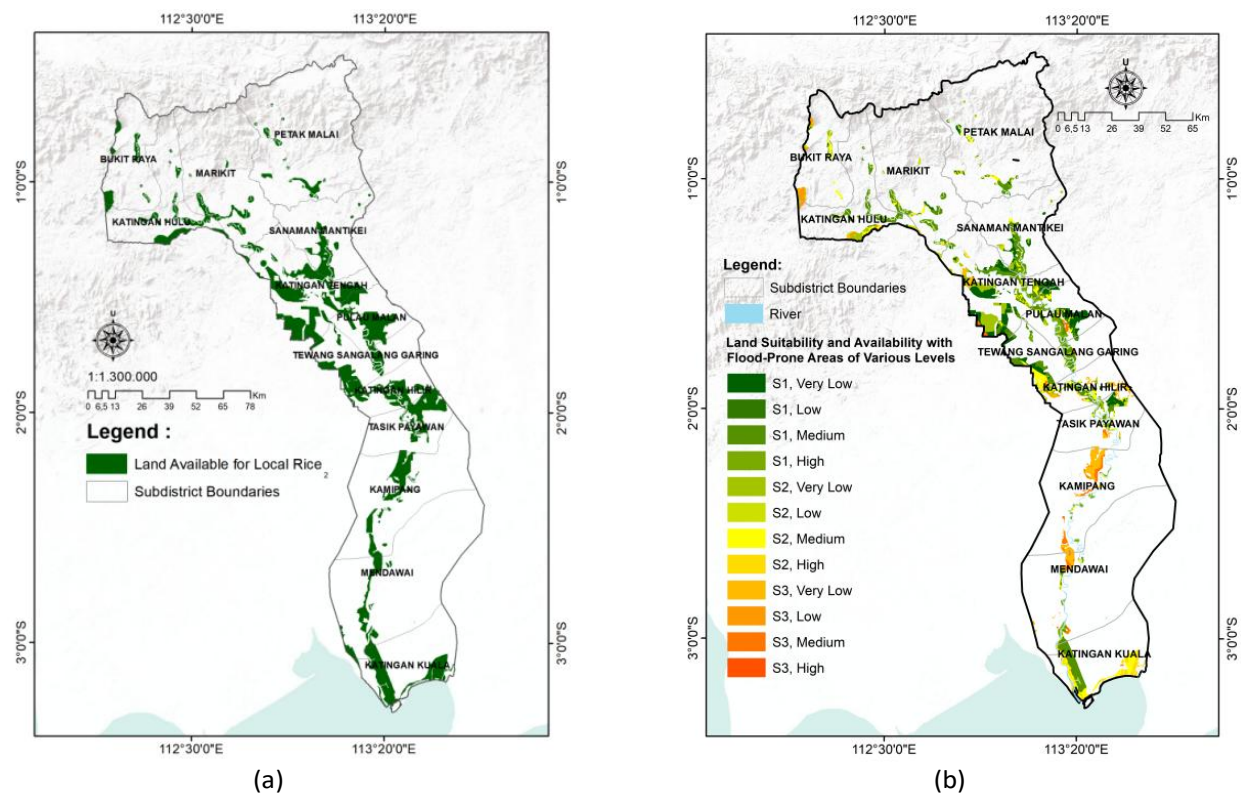


Figure 6. (a) The land availability for local rice; (b) The land available and suitable for local rice based on flood-prone area in Katingan Regency.

The most significant available and suitable land is at the low to medium levels, with 94,630 hectares and 11,4880 hectares, respectively. In the very low flood-prone area, the available and suitable land that can be utilized is only 19,020 hectares, while at the high flood-prone level, it is 28,200 hectares. Land in this class requires additional effort to boost productivity, even when situated in flood-safe zones. However, as flood risk increases with elevation in flood-prone areas, cultivation costs also rise, necessitating more intensive management. The area of available land based on availability classes and flood-prone levels is presented in Table 7.

Table 7. Distribution area of Land available and suitable based on flood-prone area levels in Katingan Regency.

Land available and suitable	Flood-prone areas of various levels (ha)				Total area (ha)	Percentage (%)
	Very low	Low	Medium	High		
Highly suitable (S1)	3,890	42,840	71,390	18,000	136,130	7
Moderate suitable (S2)	10,240	29,850	32,700	9,950	82,750	4
Marginal suitable (S3)	4,880	21,930	10790	240	37,840	2
Not available					1,773,670	87
Total	19.020	94,630	114,880	19,020	2,030,390	100

Rice Balance in Katingan Regency until 2033 in Katingan Regency

Based on population projections, Katingan Regency is expected to experience an increase in population, reaching 195.191 people by 2033. This implies an increase in rice consumption is projected to increase to 15.792 tons. The rice balance analysis shows that Katingan Regency will remain in a rice surplus until 2033, thus maintaining rice self-sufficiency until that year. However, after 2033, Katingan Regency is projected to start experiencing a rice deficit due to increasing food demand in line with population growth. To mitigate food deficits and enhance agricultural production, a strategic approach centered on the development of locally-based food production zones is imperative. This strategy must prioritize the utilization of land resources that are both available and suitable for local rice cultivation in Katingan Regency, thereby supporting long-term agricultural sustainability and food security. The projections of population, rice needs, rice production, and surplus/deficit status until 2033 in Katingan Regency are presented in Figure 7.

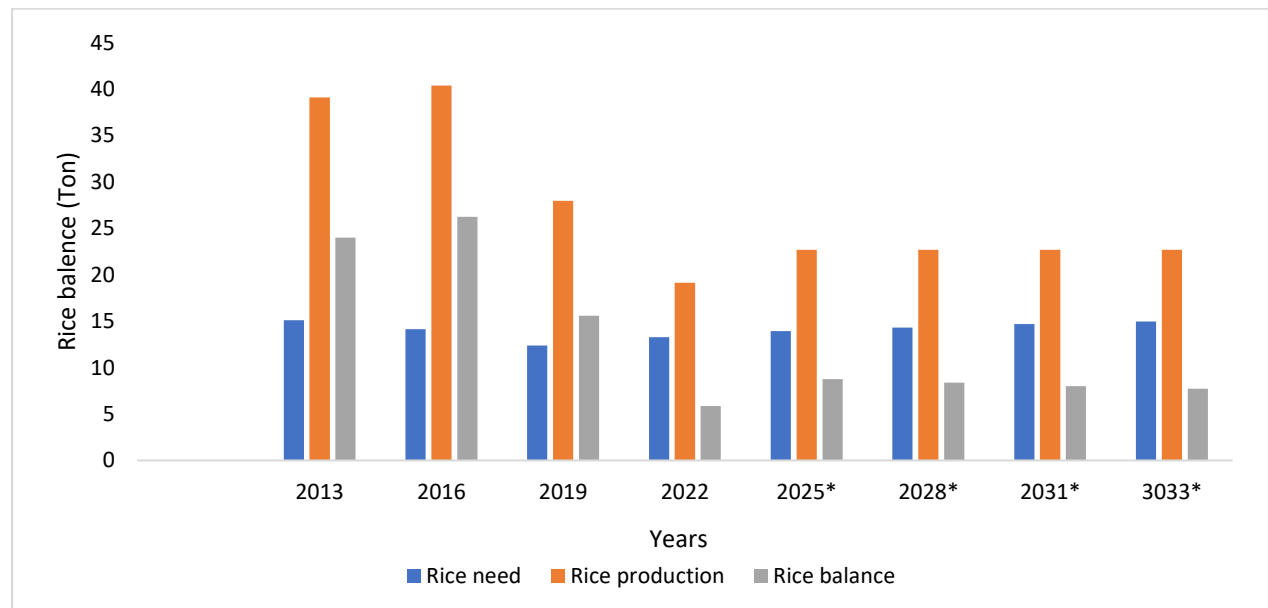


Figure 7. Rice balance in Katingan Regency until 2033. Notes: (*) = Projections.

Discussion

The flood-prone level is related to the intensity of agricultural land management required. Special handling might not be very significant in areas with very low vulnerability. Conversely, areas with high vulnerability require comprehensive flood mitigation strategies. In high-vulnerability locations, developing and using local rice varieties with adaptive and flood-tolerant characteristics are potential approaches to optimizing agricultural productivity. Improving food security in Katingan Regency requires an integrated strategy that expands local rice farming areas on flood-free land [72]. Although the productivity of local rice is relatively low (5 to 6 months growing period), optimizing the available and suitable land, combined with the development of flood control infrastructure (irrigation, drainage, levees), will increase productivity and stability of food supply. The food balance analysis will be an adequate planning basis for achieving food security goals. Additionally, sustainable agriculture development in flood-prone areas requires flood-tolerant rice varieties. Adaptation strategies include adjusting planting times, selecting short-duration or flood-tolerant varieties, and employing post-flood recession farming techniques. This study highlights the importance of breeding and using rice varieties resistant to various environmental stresses, including floods, as proven effective in Southeast Asia [73,74].

We recommend that policymakers consider expanding potential agricultural land for local rice in flood-prone areas of Katingan Regency on unused land. Furthermore, the cultivation of local rice should be prioritized in areas with the highest land suitability and optimal productivity potential. The sub-districts of Katingan Kuala, Pulau Malan, Kamipang, and Katingan Hilir present strong potential to become key centers for local rice production in Katingan Regency. In addition, flood-tolerant local rice varieties offer a promising opportunity for cultivation in flood-prone areas, particularly in zones located near riverbanks. Implementation of the allocation of flood-free S1 class land has the potential to increase national food production. The allocation of

38,900 hectares for local rice cultivation, assuming a 2 tonnes/hectare productivity, is estimated to produce 77,800 tonnes of grain (equivalent to 48,200 tonnes of rice). This production has the potential to fulfil the needs of Katingan Regency and contribute to Central Kalimantan's rice production, increasing regional economic value, especially given the higher price of local rice compared to superior varieties. Spatial planning policies not only ensure sustainable food security through high agricultural productivity but also contribute to the preservation of the genetic diversity of local rice and support sustainable farming practices that have been passed down through generations by indigenous communities. These efforts play a vital role in strengthening food sovereignty in Katingan Regency.. Policies based on scientific research and local knowledge enable the adaptation of best practices suited to local conditions. Furthermore, promoting and enhancing the implementation of agricultural practices has a positive impact on the environment [75].

Land of local rice cultivation should be integrated into the Sustainable Food Agricultural Area (*Kawasan Pertanian Pangan Berkelanjutan/KP2B*) within the Spatial Plan of Katingan Regency to ensure the preservation and protection of productive agricultural land. Information about flood-prone areas is crucial in conservation policies to minimize negative impacts on agricultural land in highly flood-prone areas. In regions frequently affected by floods, preserving agricultural land can help reduce flood risks and protect biodiversity [76]. Additionally, prioritizing the conservation of agricultural land around river confluences is an effective strategy in land use policy [76]. Lastly, policies to promote diverse and sustainable local food can reduce reliance on commercial food, increase biodiversity, and minimize the impact of climate change. Thus, such policies will have implications for ecological sustainability and food security in Katingan Regency.

While this study offers valuable insights into food availability in Katingan Regency, it is important to acknowledge certain limitations. First, the impact of extreme climate events and disasters on agricultural production was not considered. Second, specific differences in local rice varieties were not accounted for in this research. Third, socio-economic factors were not included in the assessment of sustainable agricultural land. Therefore, additional research is essential to explore these aspects comprehensively. In addition, projections of food availability do not fully account for highly dynamic and interactive factors such as ongoing land use change and the widespread impacts of climate change. Future research efforts should therefore prioritise the development and application of dynamic modelling approaches. Such models will provide more comprehensive and robust projections of food availability by integrating complex spatial and temporal dynamics, thus enabling evaluation of various future scenarios and assessment of policy interventions under evolving environmental and socio-economic conditions.

Conclusion

Achieving food self-sufficiency in Katingan Regency requires an integrated approach that takes into account the region's geographical characteristics and its varying levels of flood vulnerability. This approach underscores the importance of integrating spatial planning, agricultural innovation, and disaster risk mitigation in the pursuit of sustainable regional development. Despite the presence of flood-prone areas, the region holds significant potential for the development of local rice cultivation. Approximately 256,720 hectares have been identified as suitable for local rice cultivation, encompassing a range of flood susceptibility levels. This potential necessitates adaptive land management strategies, including the development of flood-tolerant local rice varieties and the construction of flood control infrastructure to ensure sustainable agricultural production. The strategic allocation and management of flood-prone land not only contribute to increased local rice production but also serve as a critical foundation for ensuring regional food security through 2033. Moreover, safeguarding productive agricultural land is essential for strengthening both ecological resilience and the social well-being of local communities. Therefore, Katingan Regency holds strategic potential to serve as a model for adaptive agricultural development in flood-prone regions across Indonesia.

Author Contributions

WK: Conceptualization, Methodology, Software, Investigation, Writing - Review & Editing; **WDA, DRP:** Writing - Review & Editing, Supervision.

Conflicts of Interest

There are no conflicts to declare.

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