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Model Forest and Land Fires in Kahayan Central Forest Management Unit

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ABSTRACT
In 2015 and 2019, the Central Kahayan Forest Management Unit (FMU) experienced forest fires on peatlands that had significant impacts on ecological, economic, and social aspects. Consequently, it is imperative to devise a comprehensive strategy aimed at the enhancement of a susceptibility map for forest and land fires. This research endeavor seeks to construct a detailed framework that assesses the susceptibility of forested areas and land to fire incidents inside of the Kahayan Central Forest Management Unit (FMU). The frameworking procedure will employ an integrated approach that synergizes the Analytical Hierarchy procedure (AHP) by Geographic Information System (GIS) technologies to achieve a more robust analysis of fire susceptibility. The outcomes showed that there are three classes of forest and land fire susceptibility, namely the unsusceptible class covering 152,760 hectares (41%), the moderately susceptible class covering 150,171 hectares (40%), and the very susceptible class covering 72,585 hectares (19%). The outcomes of this research are anticipated to provide a foundational framework for the effective management and mitigation of forest and land fires inside of the Central Kahayan Forest Management Unit (FMU), thereby aiming to alleviate the adverse impacts associated by such incidents.

Keyword: AHP, Central Kahayan Forest Management Unit, Forest and Land Fire Susceptibility, GIS, Peatland

1. Introduction

Central Kalimantan stands out as one of the provinces particularly vulnerable to the occurrence of forest and land fires, especially during the dry season, that tends to manifest at intervals of approximately three to four years. The ramifications of these fires extend beyond mere environmental degradation, leading to significant ecological, economic, and social losses. Notably, the most severe instances of forest and land fires were recorded in the years 2006, 2010, 2015, and 2019, highlighting a troubling pattern of recurring devastation [1]. Forest and land fires contribute significantly to the release of carbon dioxide emissions of about 15% and economic losses [2]. Pollution by forest and peatland fires causes high rates of respiratory diseases, asthma cases, and mortality [3]. The year 2015 marked the largest peatland fire in recent years, outcomeing in significant economic losses [4].

The Central Kahayan Forest Management Unit, or Kesatuan Pengelolaan Hutan (KPH), is a peatland area. It has initially peat forest cover that contributes to carbon sequestration and biodiversity. Nevertheless, according to the monitoring data provided by the Fire Information for Resource Management System, a total of 975 hotspots were identified in the year 2015, indicating a significant prevalence of fire-related incidents during that period [5] and 859 hotspots in 2019, making it one of the FMUs in Kalimantan Central Province by the most hotspots [6]. A factor driving the forest and land fires is the degraded characteristics of peat, that create a high fire potential [2,7]. Degraded peatlands are characterized by a decrease in peat soil quality, disruption of the hydrological cycle, changes in water table capacity, and loss of underground vegetation structure [8]. In addition, forest and land fires are usually caused by human activities such as near settlements or accessibility, expansion of plantations or agriculture by burning land, and climatic factors [5]. Therefore, it is essential to implement comprehensive preventive strategies aimed at mitigating the adverse effects associated by the loss of peat layers and the decline in biodiversity inside of the Kahayan Central Forest Management Unit (FMU) as a means of addressing the challenges posed by forest and land fires.

An increasingly favored and precise methodology for analyzing susceptibility to forest and land fires involves the utilization of an integrated approach that combines the Analytical Hierarchy procedure (AHP) by Geographic Information System (GIS) technologies, thereby enhancing the overall effectiveness and reliability of the analysis [2]. Prior research endeavors have effectively enhanceed frameworks for assessing susceptibility to forest and land fires through the strategic integration of the Analytical Hierarchy procedure (AHP) and Geographic Information System (GIS) methodologies, demonstrating a significant advancement in the field of fire risk assessment [7,9,10]. The initially advantage of this multifaceted approach lies in its ability to deliver a comprehensive analysis of the relative significance of various criteria and indicators that contribute to the drivers of forest and land fires, while simultaneously facilitating seamless integration by Geographic Information Systems (GIS) for the effective visualization of susceptibility maps. Furthermore, the frameworking of forest and land fire susceptibility yields essential information that is invaluable to decision-makers in forest management as well as to firefighters engaged in combating these incidents [11]. Moreover, this frameworking technique represents one of the most efficacious strategies employed in the realm of forest and land fire management, as it facilitates a more nuanced and detailed analysis of regions that are particularly susceptible to fire incidents. The initially objective of this research is to enhance a comprehensive framework that assesses the susceptibility of forest and land fires specifically inside of the Kahayan Central Forest Management Unit (FMU) located in the Central Kalimantan Province.

2. Research Method

2.1. Location of Research

The Kahayan Central Forest Management Unit (KPH) encompasses the administrative areas of Palangka Raya City, Pulang Pisau Regency, and Gunung Mas Regency in Central Kalimantan Province. This area has a total size of 376,010 hectares and is divided into three units: unit III, XIII, and XVII (Figure 1). Astronomically, the Kahayan Central FMU is located at South Latitude 2°30'0” to 1°30'0” and East Longitude 113°30'0” to 114°30'0”. The Kahayan Central FMU has diverse geographical conditions by various land cover, including initially and secondary forests, agricultural land, and non-forest. The topography ranges by lowland peatlands to hills, providing a variety of ecosystems and habitats. The data underwent procedureing at the Physical Laboratory of Geographic Information Systems and Remote Sensing, that is situated inside of the Faculty of Agriculture and Forestry at Universitas Muhammadiyah Palangkaraya, thereby ensuring a rigorous analytical framework for the research conducted.

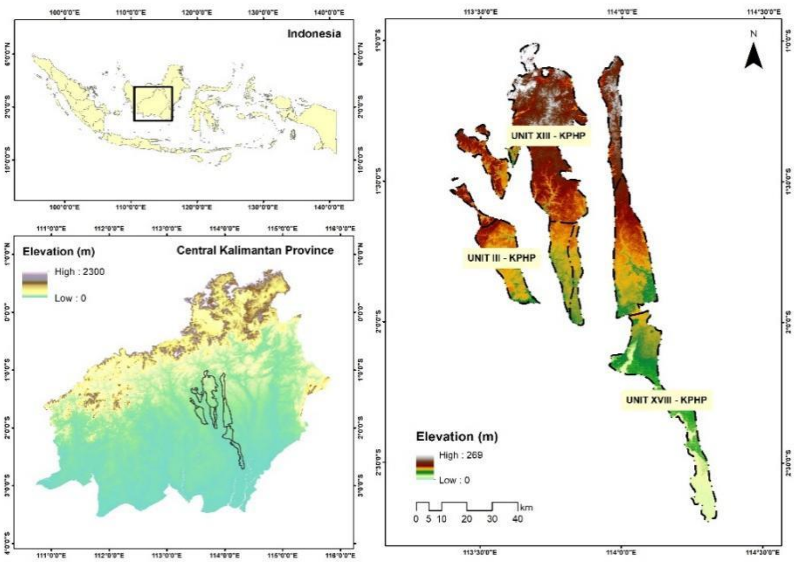

Figure 1. Location of Research

2.2. Material and Software

Materials used in the research (Table 1) and software used to perform data procedureing ArcGIS 10.8 and Expert Choice 11.

Table 1. Research materials

No.	Material	Source
1	Kahayan Central FMU boundary	Ministry of Environment and Forestry (MoEF)
2	Land cover	
3	Slope	https://www.usgs.gov
4	Slope direction	
5	River	https://tanahair.indonesia.go.id/portal-web
6	Road	
7	Settlements	
8	Hotspots	https://firms.modaps.eosdis.nasa.gov

The advancement of forest and land fire susceptibility frameworking is achieved through the strategic integration of the Analytical Hierarchy procedure (AHP) alongside Geographic Information System (GIS) methodologies. The software applications employed in this research included Expert Choice and ArcGIS, that facilitated the analytical procedurees. A concise summary of the research procedure is presented below (refer to Figure 2):

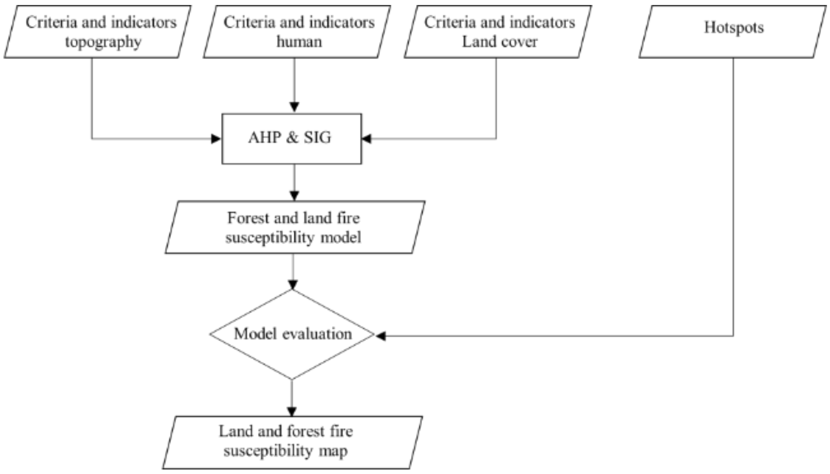

Figure 2. Research flow chart

2.3. Data procedureing

The procedureing of indicator data was conducted utilizing ArcGIS software, that involved the application of various tools to derive critical geographical features; specifically, the aspect tool was employed to determine slope direction, while the slope tool was utilized to calculate the gradient of the terrain. Additionally, distances by key environmental features such as rivers, roads, settlements, and forests were assessed using the multiring buffer tool. Furthermore, land cover data was obtained through meticulous image interpretation conducted by the Ministry of Environment and Forestry (MoEF). Each indicator is associated by a specific unit of measurement and is defined by class criteria, as detailed in Table 2. This research endeavor has enhanceed a comprehensive framework for assessing forest and land fire susceptibility, drawing upon the foundational work of references [12,13], that identified the critical variables influencing the forest and land fire framework. These variables include slope, slope direction, distance by rivers, distance by roads, distance by settlements, land cover, and distance by forests, all of that have a pivotal role in deciding fire susceptibility.

Table 2. Criteria and Indicators

Criteria	Indicators	Unit	Class criteria				
Topography	Slope direction	º	North	South	East	West	
	Slope	%	< 8	9-15	16-25	26-45	>45
Human	Distance by river	Km	< 5	6-8	9-12	13-15	>16
	Distance by the road	Km	< 5	5-8	9-12	13-15	>16
	Distance by settlements	Km	< 7	8-13	14-18	19-24	> 25
Land cover	Distance by forest	Km	< 22	23-43	44-63	64-84	>85
	Land cover	-	Forest	Agriculture	Shrubs	Water body	Settlements

Criteria	Indicators	Unit	Class criteria			
			bare land	Plantation	Swamp	Mining

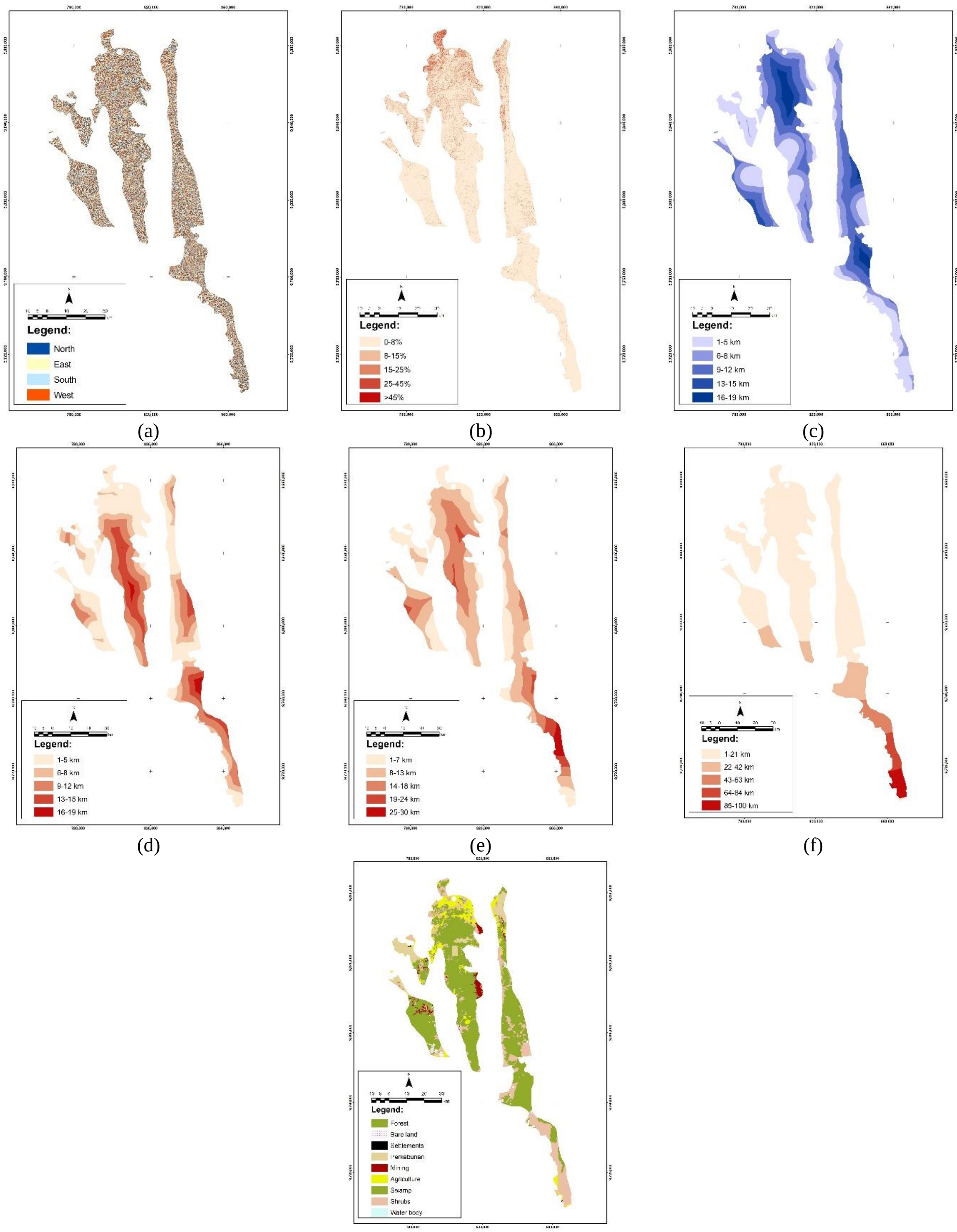

Figure 3. The factors influencing the framework encompass the following variables: (a) the orientation of the slope, (b) the gradient of the slope, (c) the proximity to rivers, (d) the distance by roadways, (e) the spatial relationship to settlements, (f) the distance by forested areas, and (g) the classification of land cover.

2.4. Analytical Hierarchy procedure (AHP)

AHP is one of the most widely implemented Multi-Criteria Decision Analysis (MCDA) techniques for vulnerability analysis [14,15]. This research uses AHP for thematic layers representing criteria integrated by GIS to produce forest and land fire vulnerability maps. The integration of AHP and GIS for forest and land fire susceptibility mapping has been widely implemented [7,16,17]. As AHP can consider many variables affecting land and forest fires, while GIS enhances descriptions of the phenomenon in the form of susceptibility maps, the integration of AHP and GIS will outcome in a better understanding of the land and forest fire phenomenon.

The AHP technique produces criteria and indicator weights based on the relative importance assessment of experts (Table 3). The weighting of the various criteria and indicators is subsequently assessed through the application of the Consistency Index (CI) and the Consistency Ratio (CR). These metrics, that serve to evaluate the reliability of the weighting procedure, can be computed utilizing the formulas delineated as Formulas 1 and 2. [18]:

$$IK = \frac{\lambda_{max} - n}{n-1} \quad (1)$$

$$RK = \frac{CI}{RI} \quad (2)$$

Where λ_{max} is the sum of the weights and *n* weights of criteria or indicators, *RI* is a random number and *RK* ≤ 10% or 0.10 is considered acceptable.

Table 3. Importance scale/value

Importance scale/value	Description
1	Equally important
3	Rather more important
5	More important
7	Very important
9	Extremely important
2, 4, 6, 8	Intermediate

In the next stage, the weighting of the class criteria variables was conducted out by experts. The experts involved in this research totaled six people. The objective of weighting the class criteria is to standardize the units for all variables used. Each variable is given the lowest weight of one to three [19]. In this context, a value of one signifies a variable that does not act as a driver of forest and land fires, whereas a value of three indicates a variable that is indeed a significant driver of such fires; conversely, a value of two represents an intermediate position between these two extremes, reflecting a variable that exerts a moderate influence on fire dynamics.

2.5. frameworking forest and land fire susceptibility

The spatial frameworking of susceptibility to forest and land fires is meticulously enhanceed through the application of a weighting methodology, that is systematically articulated in the following manner:

$$Y = A(a_1.x_1 + a_2.x_2 + \cdots + a_n.x_n) + B(b_1.y_1 + b_2.y_2 + \ldots + b_n.y_n) + C(c_1.z_1 + c_2.z_2 + \cdots + c_n.z_n) \quad (3)$$

where Y is forest and land fire susceptibility; A, B, and C are criteria weights; a, b, and c are indicator weights; x, y, and z are class criteria weights.

2.6. Evaluation framework

The enhancement of the forest and land fire susceptibility framework was conducted out utilizing fire data obtained by remote sensing satellites, that provided critical insights into fire dynamics. The evaluation of the framework's effectiveness was performed by superimposing the polygons representing the forest and land fire vulnerability framework onto the identified fire hotspots, thereby facilitating a comprehensive assessment of the framework's predictive accuracy. According to [15], framework evaluation uses the overall accuracy and Kappa accuracy approaches, by the mathematical equation 4 and 5.

$$Overall\ Accuracy = \frac{\sum_{i=1}^{r} X_{ii}}{N}\ x\ 100\% \quad (4)$$

$$Kappa\ Accuracy = \frac{N\sum_{i=1}^{r} X_{ii} - \sum_{i=1}^{r} X_{i+}\ X_{+i}}{N^2 - \sum X_{i+}\ X_{+i}}\ x\ 100\% \quad (5)$$

Where X_{ii} is the diagonal value of the i-th row and i-th column; X+i and Xi+ are the total area and N is the total area.

Overall accuracy and kappa accuracy are popular techniques used to measure map accuracy. A contingency matrix is necessary to calculate overall accuracy (OA) and kappa accuracy (KA) [20]. The calculation of OA uses the number of correct pixels/area/counts divided by the total number of pixels/area/counts used in the accuracy test. Furthermore, KA considers all elements in the contingency matrix [21]. It is considered the most relevant measure as it considers all columns and rows in the contingency matrix [21]. According to [22], KA classes are based on accuracy levels (Table 4).

Table 4. Kappa Accuracy class

Kappa Accuracy (%)	Description
75-100	Excellent
40-75	Fair to good
0-40	Poor

2.7. Mapping of forest and land fire susceptibility

The susceptibility maps for land and forest fires were generated through the procedure of overlaying all relevant variables, each assigned specific weights, and subsequently calculated utilizing mathematical equations derived by the framework formulation. The outcomes of this calculation were categorized into three distinct classes of forest and land fire vulnerability, employing the equal interval method, as articulated in the following Equation 6.

$$equal\ interval = \frac{maximal\ value - minimal\ value}{class\ size} \quad (6)$$

3. outcomes and Discussion

3.1 Analytical Hierarchy procedure (AHP) Forest and Land Fires

The outcomes of this research indicated that the criteria pertaining to human factors and land cover factors exhibited substantial weight contributions of 0.646 and 0.294, respectively, as illustrated in Table 5. Notably, the weight contribution attributed to human factors surpasses that of both land cover and topography factors, underscoring the considerable impact of human activities on the incidence of forest and land fires inside of the Kahayan Central Forest Management Unit (FMU). It is evident that the initially drivers of these fires are predominantly linked to human activities, including practices such as land clearing through burning for agricultural purposes, the establishment of plantations, or the enhancement of forest plantations [2,23]. Land cover is also a driving factor, as it provides fuel. Dryland-cover classes have a high potential to burn, while wetland-cover classes have a low potential to burn [24].

Table 5. Weight of criteria and indicators

Criteria	Criteria Weight	Indicator	Indicator Weight
Topography	0.060	Slope direction	0.134
		Slope	0.866
Human	0.646	Distance by river	0.356
		Distance by the road	0.329
		Distance by settlements	0.315
Land cover	0.294	Distance by forest	0.120
		Land cover	0.880

The research yielded a weighted average of the criteria associated by the classification of forest and land fire drivers, that was determined through relative expert judgment, as presented in Table 6. Analyzing the data in Table 5 reveals that the trend of the highest average weights among the three factors includes slope (ranging by 0 to 8%), distance by roads (between 1 and 5 kilometers), distance by settlements (spanning 1 to 7 kilometers), distance by forests (ranging by 84 to 105 kilometers), and the presence of shrubs. It is noteworthy that flatter slopes generally exhibit a greater potential for fire occurrence compared to their steeper counterparts; however, the spread of fire is markedly more pronounced on steeper slopes, indicating a complex interhave between slope gradient and fire dynamics [25]. The distances by roads, settlements, and forests serve as critical indicators of human accessibility, that inherently possess the potential to facilitate activities that may lead to the occurrence of forest and land fires [26]-[28] and shrubs are land covers that have a high potential for fuel ignition and rapid fire spread [27].

An analysis of the significance derived by the pairwise matrix comparing the various criteria revealed that the human factor holds a greater level of importance than the topography factor, by a corresponding value of 7.7, thereby underscoring the predominant influence of human activities in the context of forest and land fire susceptibility, and the land cover factor is more important than the topography factor at 6.7 (Table 6). Thus, human factors are the main drivers of forest and land fires in Kahayan Central FMU. [18,29,30] that stated that the driving factor of forest and land fires is human activity. These human activities include land clearing by burning for plantations or agriculture, unwise use of fire in daily activities, and extreme weather that exacerbates conditions. Based on the research outcomes, the CR value is 0.10, or 10%, that means that the assessment between experts is consistent in assessing the level of importance of forest and land fires (Table 7). According to the CR value threshold ≤ 0.1 or 10% [29,30].

Table 6. Criterion class weights

Criteria	Indicator	Criteria class	Average Weight
Topography	Slope direction (º)	North	1
		South	1
		East	2
		West	1
	Slope (%)	0-8	3
		8-15	2
		15-25	1
		25-45	1
		>45	1
Human	Distance by river (Km)	1-5	2
		5-8	2
		8-12	1
		12-15	1
		15-19	1
	Distance by the road (Km)	1-5	3
		5-8	2
		8-12	1
		12-15	1
		15-19	1
	Distance by forest (Km)	1-7	3
		7-13	2
		13-18	1
		18-24	1
		24-30	1
Land cover	Jarak dari Hutan (Km)	1-22	1
		22-43	1
		43-63	2
		63-84	2
		84-105	3
	Land cover	Forest	1
		Agriculture	2
		Shrubs	3
		Water body	1
		Settlements	2
		Bare land	1

Criteria	Indicator	Criteria class	Average Weight
		Plantation	2
		Swamp	1
		Mining	1

Table 7. Pairwise comparison matrix between criteria

	Topographical	Human	Land cover
Topographical	1	7,7	6,7
Human	0,1	1	3,0
Land cover	0,1	0,3	1
Consistent Ratio (CR)		0,10	

3.2. frameworking forest and land fire susceptibility

The frameworking of forest and land fire susceptibility is based on the weight values of the criteria, indicators, and criteria classes so that it can be formulated by a linear framework as follows: Y = (0.06 x (0.134 x weight of slope direction + 0.866 x weight of slope) + 0.646 x (0.356 x weight of distance by river + 0.328 x weight of distance by road + 0.315 x weight of distance by settlement) + 0.294 x (0.120 x weight of distance by forest + 0.880 x weight of land cover). The outcomes showed that the not susceptible class is 152,760 hectares (41%), while the moderately susceptible class is 150,171 hectares (40%), and very susceptible is 72,585 hectares (19%) (Table 8). Gunung Mas Regency, Pulang Pisau Regency, and Palangka Raya City. To effectively mitigate the occurrence of forest and land fires in this region, it is imperative to engage the local community actively in prevention initiatives, thereby fostering a sense of collective responsibility towards fire management efforts, as highlighted in reference [24]. Furthermore, the establishment of scheduled patrols, in conjunction by the construction of monitoring towers, is recommended in areas identified as highly susceptible or moderately vulnerable to forest and land fires. The vulnerability map illustrating the susceptibility of forest and land to fire incidents is depicted in Figure 4.

Table 8. Forest and land fire susceptibility class

Classes	Area (ha)	Percent (%)
Not susceptible	152.760	41
Moderately susceptible	150.171	40
Very susceptible	72.585	19
Total Area (ha)	375.516	100

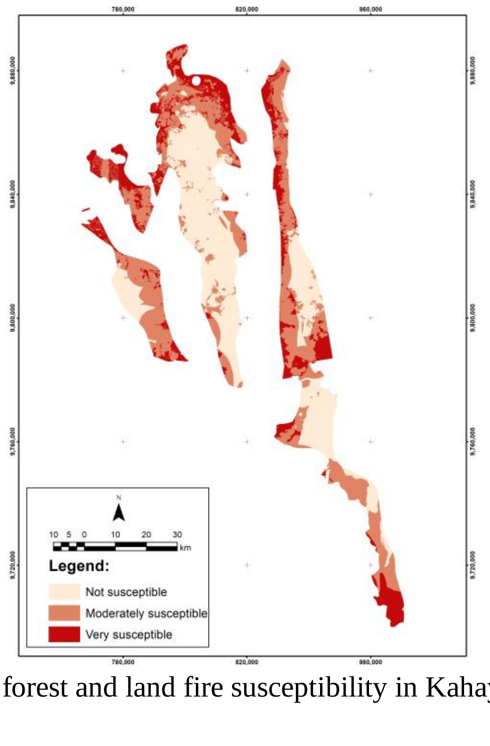

Figure 4. Map of forest and land fire susceptibility in Kahayan Central FMU

3.3. framework evaluation

The evaluation of the framework was conducted out by juxtaposing the outcomes of the forest and land fire susceptibility map against the distribution of identified hotspots, by a confidence level exceeding 80%. This evaluative procedure is designed to assess the accuracy of the susceptibility map generated by the framework. The determination of accuracy was accomplished through the utilization of an error matrix, as detailed in Table 9.

Table 9. Contingency matrix

Reference	framework			Total
	Not susceptible	Moderately susceptible	Very susceptible	
Not susceptible	26	-	-	26
Moderately susceptible	8	112	37	157
Very susceptible	3	3	185	191
Total	37	115	222	374
Overall Accuracy				86 %
Kappa Accuracy				76 %

The conclusion of map accuracy generally uses the kappa accuracy value because it takes into account all values in the contingency matrix (Table 8). The outcomes of this research show a kappa accuracy of 76% and an overall accuracy of 86%. According to [22], the accuracy of this research is in a good category by the perspective of kappa accuracy. Several similar researches on forest and land fire vulnerability mapping showed 75% kappa accuracy [31], and there are also other studies showing 90% kappa accuracy [32]. Thus, the outcomes of this research can be used as data and decision-making information for efforts to control forest and land fires in Kahayan Central FMU.

4. Conclusion

The outcomes of this research conclusively illustrate that the forest and land fire vulnerability framework enhanceed for the Kahayan Central Forest Management Unit (FMU) effectively delivers a precise representation of fire potential, grounded in the comprehensive analysis of the relevant variables. This framework exhibits an overall accuracy rate of 86%, accompanied by a kappa accuracy of 76%, thereby signifying its reliability and robustness in identifying vulnerabilities associated by forest and land fires. The importance of this research is underscored by its potential to enhance the effectiveness of forest fire mitigation strategies inside of the Kahayan Central Forest Management Unit (FMU) region. By providing a more nuanced understanding of the various factors that contribute to fire vulnerability, this research equips forest managers by the necessary insights to implement more targeted and data-driven preventive measures, thereby improving overall fire management practices. The potential for future research is extensive, including integrating additional variables such as climate and soil types to enhance the framework's accuracy. Moreover, the methodology employed in this research possesses the versatility to be adapted for application in other regions exhibiting analogous conditions, thereby creating avenues for extensive implementation in the realm of forest fire risk management across diverse geographical areas. Consequently, this research not only enriches the existing body of scientific knowledge but also carries substantial practical implications for the advancement of sustainable forest management practices.

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