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Spatial Analysis of Forest Fire Potential in Pangi Binangga Nature Reserve, Parigi Moutong District, Central Sulawesi

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ABSTRACT

This study aims to analyze the potential for forest fires in Pangi Binangga Nature Reserve, Parigi Moutong District, Central Sulawesi, by utilizing geographic information system data and mapping areas based on fire potential. The research method involved field surveys and the analysis of primary and secondary data. Forest fire hazards maps were obtained from the analysis of Landsat satellite images that were classified to provide information on land cover, slope, distance from roads, and categorized based on predetermined weighting categories. The overlay process was conducted using Geographic Information System software. The main findings indicate that the area has diverse land cover, with reed grassland savanna having the highest fire hazards covering an area of 1203.78 ha. Very steep slopes cover 339.94 ha, and the distance from roads and settlements to the highest hazards point is 140 meters. These variables also influence the level of hazards. Implications of this study include the placement of forest fire prevention patrols, the use of weather modification technology, and post-fire support to restore ecosystems.

Keywords: Fire Hazards, Forest Fires, Geographic Information System (GIS), Pangi Binangga Nature Reserve

INTRODUCTION

Indonesia's tropical forest cover is the third largest in the world following Brazil and Congo. One of the regions in Indonesia with tropical forest cover is Sulawesi Island, making it crucial for maintaining biodiversity. Sulawesi Island's importance is further emphasized by its location within the *Wallace Bio-Region*, which serves as habitat for endemic species of flora and fauna. These endemic species play various roles such as key species, *umbrella species*, or *flagship species*. Sulawesi Island is home to 316 species of mammals, with 113 of them being endemic, including the *Tarsius spectrum* (Mustari, 2021).

Pangi Binangga Nature Reserve is one of the tropical forests on Sulawesi Island, precisely in Central Sulawesi Province. it is located in Parigi Moutong Regency and has been designated as a nature reserve based on the Decree of the Minister of Forestry and Plantation No.399/Kpts-II/1998, dated April 21, 1998, with an initial area of 6000 Ha. The area of Pangi Binangga Nature Reserve increased to 6,158.75 Hastarting in 2014 based on the Minister of Forestry Decree No. 3895/Menhut-VII/KUH/2014 dated May 13, 2014 (Pitopang *et al*., 2021). Pangi Binangga Nature Reserve is dominated by the Euphorbiaceae, Moraceae, Asteraceae, Araceae, and Urticaceae tribes and is an endemic habitat for plants of pinang merah (*A. vestiaria), (A. balgooyi),* eboni (*D. celebica), I. mamasensis,* and *P. celebica* (Saleh & Hartana, 2017). The Pangi Binangga Nature Reserve area has climate type A (tropical rainforest) based on the Schmidt and Ferguson climate classification. The characteristics of an

area with this climate type include an average rainfall of 2,355 mm/year, an average air temperature between 19.8 - 26.2 °C with an average humidity of 80% (Alam, 2015). However, tropical rainforests are also at risk of forest and land fires during the dry season (Suyatno, 2015), which can be influenced by climate change (Halofsky *et al*., 2020).

One of the biggest threats to tropical forests in particular is forest fires, which can have both economic and ecological impacts. The impact of forest fires includes a decrease in forest area and land degradation, eading to a loss of in biodiversity (Yusuf *et al*., 2019). These ecological effects will create uncertainty in the recovery of conditions, making it very dangerous if fires occur in Pangi Binangga CA, given the role of forests in Sulawesi as guardians of biodiversity in the *Wallace Bio-Region*. According the Disaster Risk Index issued by the National Disaster Management Agency, the Parigi Moutong Regency area has a high fire risk index with a score of 18.52, categorizing it as high risk (Adi *et al*., 2022).

Prevention of forest and land fires, is crucial, and one way to address this is by analyzing the potential for fires in forest areas. Previous studies have examined fire potential in various regions, such as Kubu Raua Regency (Jawad *et al*., 2015), Jambi Province (Widodo, 2014), Riau Province (Ramadhani *et al*., 2023; Yusuf *et al*., 2019), and Buru Island (Muin & Rakuasa, 2023). However, there is a gap in research regarding the fire potential of the Pangi Binangga Nature Reserve. Therefore, a study is needed to analyze the potential for forest fires in North Parigi District, Parigi Moutong Regency, Central Sulawesi, using geographic information system data to map the Pangi Binagga Nature Reserve area and asses fire potential. This research can help identify areas for fire prevention patrols, determe locations for weather modification technology, and support post-fire activities to restore ecosystem conditions.

MATERIAL AND METHOD

Location and Time of Research

The research was conducted over a four-month period from September to December 2023 in the Pangi Binangga Nature Reserve area, located in the Parigi Moutong Regency of Central Sulawesi. The reserve is geographically situated at 0°45'03 "S 120°02'38 "E and covers an area of approximately 6158 hectares.

Tools and Materials

The tools used in this research include hardware in such as laptop, software like ArcGIS 10.4 and *Microsoft Office*, GPS, and a digital camera. The materials used in this research consist of satellite imagery, administrative maps of Parigi Moutong Regency (Specially the Pangi Binangga Nature Reserve area) at a scale of 1; 50,000, land cover maps, road network maps river network maps, population data, digital elevation model (DEM) data, and rainfall data.

Research Procedure

This research approach involved conducting a survey to collect primary and secondary data. The forest fire hazards map was obtained by analyzing data from Landsat satellite imagery, which was then adjusted to the geographical location of the Pangi Binangga Nature Reserve area in North Parigi District, Parigi Regency through a geometric process to ensure accuracy. The image map was classified to identify land cover, and other variables such as slope, distance from roads, and settlements were obtained through a buffering process based on predetermined criteria. These variables were then combined using the overlay technique in

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Geographic Information System (GIS) software, assigning scores based on predetermined criteria to create a map of forest fire hazard levels. (Viviyanti *et al.*, 2019).

Land Cover Class Analysis

In the next stage, land cover data was obtained from the interpretation of satellite imagery (Landsat). This information on land cover reflects the variation in vegetation types present. These vegetation types are key indicators in determining the amount of fuel available for forest fires (Putra *et al*., 2019). The weighting process is based on the sensitivity of each vegetation type to fire risk, as classified by Pratondo *et al*. (2006) and Salsabilah et al. (2021) which was then adjusted to the conditions in Pangi Binangga Nature Reserve.

The weighted parameters were then used to generate fire susceptibility maps, which were crucial for identifying high-risk areas and developing effective fire management strategies. (A. Putra *et al*., 2018). The land cover data follows the classification regulated by the Directorate General of Forestry Planology Regulation No. P.1/VII-IPSDH/2015 with modifications according to conditions in Pangi Binangga Nature Reserve. This classification distinguishes various types of land cover such as primary dryland forest, secondary dryland forest (logged), plantation forest, shrubs, savanna, dryland agriculture, plantations, and settlements (Directorate General of Forestry Planning, 2015). The results of weighting by land cover type are presented in Table 1.

Table 1. Land Cover Weighting

Land Cover Class Forest Area	Score	Level of Hazards
Primary dryland forest, Plantation, Swamp	5	Very low
Plantation Forest, Secondary Dryland Forest	4	Low
Scrub	3	Medium
Dryland Agriculture,	2	High
Savanna/ Reedbed	1	Very high

Source: Pratondo *et al.* (2006) and Salsabilah *et al*. (2021)

Slope Class Analysis

The slope of an area is closely related to the availability of water sources. This is because the more sloping an area is, the less rainwater can infiltrate into the ground (Husen *et al.*, 2020). The weighting of the land slope, settlement distance class, and road distance is presented in Table 2, Table 3, and Table 4 below.

Table 2. The Weighting of Slope Class

Slope Class	Score	Slope Category
>40%	5	Very steep
25 to <40%	4	Steep
15 to <25%	3	Somewhat Steep
8% to <15%	2	Ramps
0 to <8%	1	Flat

Source: (Erten *et al.*, 2004)

Analysis of Distance from Roads and Settlements

The use of the distance from roads variable is important because roads serve as land transportation infrastructure. the closer an area is to a road, the more vulnerable it is to fire. Additionally, distance from settlements is also a significant factor in increasing the risk of forest and land fires (Eko, 2013). Distance measurements are taken from the center point of a settlement or the outermost boundary of a settlement, especially if the settlement boundary has a polygon shape.

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Table 3. Road Distance Weighting

Road Distance Class (m)	Score
<1000 m	5
1000 – 2000	4
2000 – 3000	3
3000 – 4000	2
>4000	1

Source: (Salsabilah *et al.*, 2021)

In a technical context, the creation of the distance from settlements map involved a neighborhood analysis approach, where one of the techniques used was a *buffering* process. These classes of distance from settlements were then grouped into five categories, which can be seen in the scoring table below.

Table 4. Weighting of Settlement Distance Classes

Settlement Distance Class	Score
0 to <2 Km	5
2 to <4 Km	4
4 to <6 Km	3
6 to <8 Km	2
>8 Km	1

Source: (Bana *et al*., 2022)

Rainfall Analysis

Rainfall is classified based on the analysis of rainfall data in North Parigi Sub-district, Parigi Moutong District. Areas with the lowest rainfall are assigned a value of one, indicating higher sensitivity to fire, while areas with the highest rainfall are assigned a value of five, indicating higher resistance to fire. Rainfall is a significant factor influencing forest fires, with areas of low rainfall posing a higher risk. This study focuses on this parameter, where lower rainfall corresponds to greater weight and higher risk of forest and land fires. The data on rainfall presented in Table 5 is as follows:

Table 5. Rainfall Weighting

Rainfall (mm)	Score	Hazards Class
>4000	5	Very Not Vulnerable
3000 – 4000	4	Not Vulnerable
2000 – 3000	3	Moderate
1000 – 2000	2	Vulnerable
<1000	1	Very Vulnerable

Sumber: (A. Putra *et al.*, 2018)

Analysis of Forest Fire Hazards Level

After scoring all variables, the total score for each variable was calculated using a multiple-variable linear combination equation. The total score for each typology is the sum of the product of the score and the weight of each variable. The Sturges formula was used to determine the class interval for the hazards class (Sari et al., 2020)**.**

$$C = \frac{Xn - Xi}{k}$$

Description:

C = estimated class size
k = number of classes
Xn = highest observed value
Xi = lowest observed value

The hazards analysis of the weighting is presented in Table 6 below.

Table 6. Analysis of Hazards from Weighting

No	Prone Class	Score Range	Description
1	Very Low	0	The chance of forest and land fire occurrence is very low, almost none, and the chance of occurrence is less than 20%.
2	Low	1-<2	The chance of forest and land fire occurrence is between 20-40% with relatively very low fire intensity.

No	Prone Class	Score Range	Description
3	Medium	2-<3	Chance of forest and land fire occurrence between 40-60% with relatively low fire intensity
4	High	3-<4	The chance of forest and land fire occurrence ranges from 60-80% with moderate fire intensity.
5	Very High	4-<5	The chance of fire occurrence is more than 80% with fire intensity generally very high.

Source: (Directorate General of Climate Change Control, 2021)

RESULT AND DISCUSSION

The analysis of forest fire hazards in Pangi Binangga Nature Reserve aims to produce information on the level of forest fire hazards based on factors such as land cover class, slope, distance from roads, distance from settlements, and rainfall.

Land Cover Classes

Based on the classification results of Landsat satellite images shown in Figure 1, five land cover classes were identified: primary dryland forest, secondary dryland forest, shrubs, dryland agriculture, and savanna or reed grassland. More detailed information on the land cover classes can be found in Table 7.

Table 7. Land Cover of Pangi Binangga Nature Reserve

Land Cover Class Forest Area	Score	Level of Hazards	Area (Ha)
Primary dryland forest, Plantation, Swamp	5	Very low	3395,16
Plantation Forest, Secondary Dryland Forest	4	Low	335,55
Scrub	3	Medium	1091,93
Dryland Agriculture	2	High	131,56
Savanna/ Reedbed	1	Very high	1203,78
Total			6158

Source: Primary Data is Processed (2023)

The Pangi Binangga Nature Reserve area consists of primary dryland forest covering 3395.16 Hawith a very low level of hazards, secondary dryland forest covering 335.55 Hawith a low category, shrubs covering 1091.93 Hawith a medium category, dryland agriculture covering 131.56 Hawith a high category, and savanna grassland covering 1203.78 Hawith a very high fire hazards category. The results of the land cover mapping are shown in Figure 1 below.

Based on spatial analysis, dryland mixed shrub, savanna, and reed grassland cover are most susceptible to fire hazards compared to other land cover types. These cover types contain the highest amount of light fuels that are relatively dry and supported by low humidity conditions (Pualilin et al., 2019). The availability of these fuels triggers fires in tropical forests. The fuel in question is the abundant and sustained presence of dry fuels in forest expanses, allowing fires to quickly develop and spread (Fitria et al., 2021). Overall, the land cover in Pangi Binangga Nature Reserve, North Parigi District, is dominated by primary dryland forest.

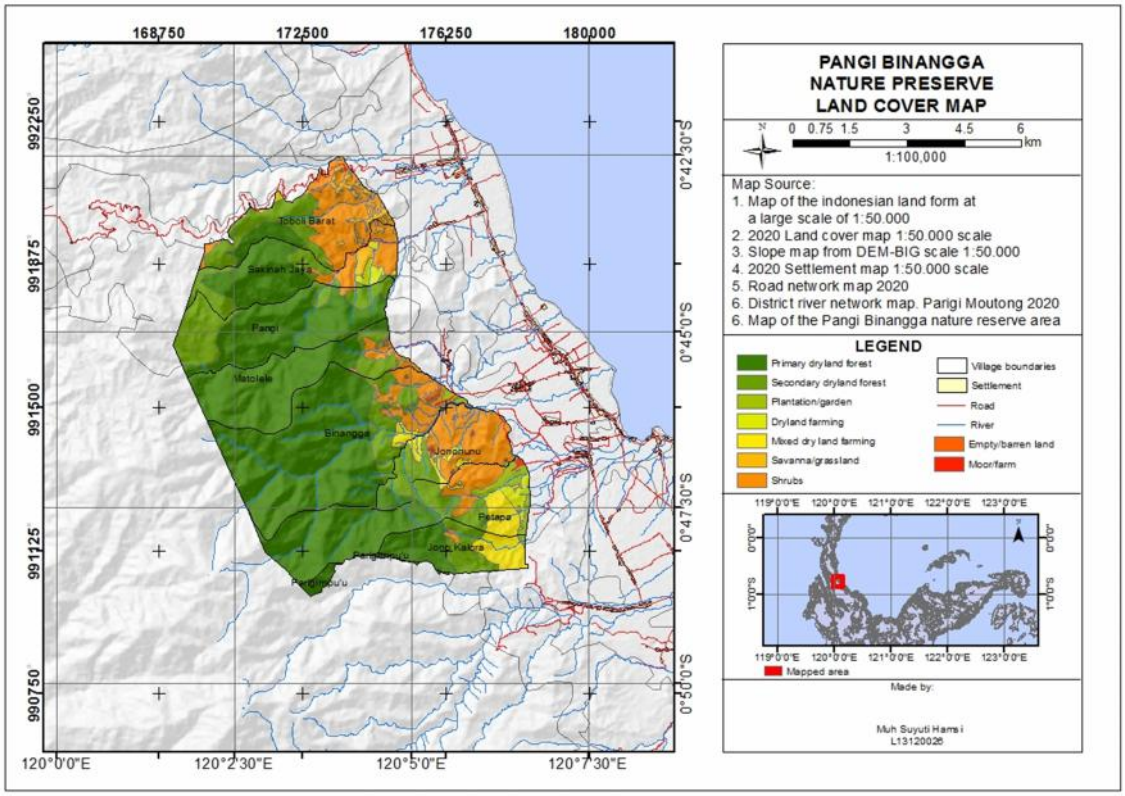

Figure 1. Land Cover Map of Pangi Binangga Nature Reserve

Slope Class

This analysis was conducted to determine the slope level, which is necessary its relationship with waterways during fire incidents. The results of the spatial analysis of the slope in Pangi Binangga Nature Reserve are presented in Table 8. The area that with a flat slope category of 0-<8% is 490.42 Ha, the largest slope area falls in 25-<40% with a steep category of 2993.16 Ha, and the the smalles are of 339.94 Ha is categorized a very steep. These results are also shown in Figure 2.

Table 8. Slope of Pangi Binangga Nature Reserve

Slope Class	Score	Slope Category	Area (Ha)
>40%	5	Very steep	339,94
25 to <40%	4	Steep	2993,16
15 to <25%	3	Somewhat Steep	1082,95
8% to <15%	2	Ramps	1193,53
0 to <8%	1	Flat	490,42

Source: Primary Data Processed (2023)

The slope of the area is closely related to the availability of water sources. These topographic conditions are closely related to the drainage system, rainwater catchment areas, and hydrological conditions (Husen *et al.*, 2020).

The analysis results indicating the presence of land slopes greater than 40% will further elevate the risk of fires in the Pangi Binangga Nature Reserve. This is due to the reduced likelihood of water seepage into the soil in areas with steeper slopes. Similar findings were reported by Choiruddin et al. (2018), indicating that land fires have occurred in areas with slopes of up to 30%.

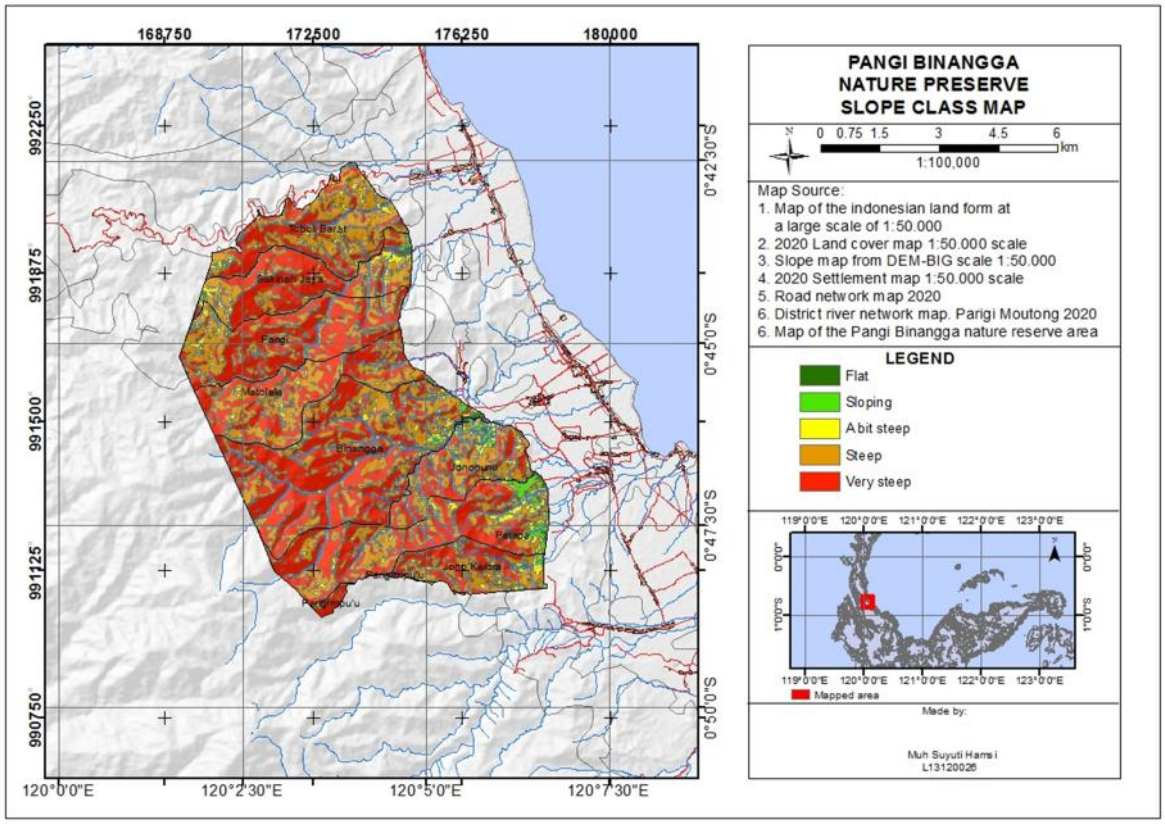

Figure 2. Slope Map of Pangi Binangga Nature Reserve

Distance from Settlement

The results of observations and spatial analysis of settlement distances around the Pangi Binangga Nature Reserve area revealed that areas within a distance of 0-<2 km cover 1241.23 Ha and fall under the very high hazards category. Areas within a distance of 2-<4 km cover 2977.17 Ha and are classified as high hazards. Points within a distance of 6-<8 km cover 1688.15 Ha and are categorized as medium hazards, while areas beyond 8 km cover 252.19 Ha and are considered low hazards. The spatial analysis results are depicted in Figure 3. When considering the type of land cover with the highest fire hazards, such as savanna and reed grassland, the closest distance to residential areas covers an area of 1241.23 Ha, indicating a very high level of hazards.

The presence of settlements that are very close to forest areas will further increase the risk of fire, as this is closely related to human activity. Most forest fires occur due to intentional or unintentional human activity. Putra *et al.* (2018) stated that proximity to the forest will increase economic activities such as processing and land clearing. These activities may be accidental or unintentional, which can lead to fires.

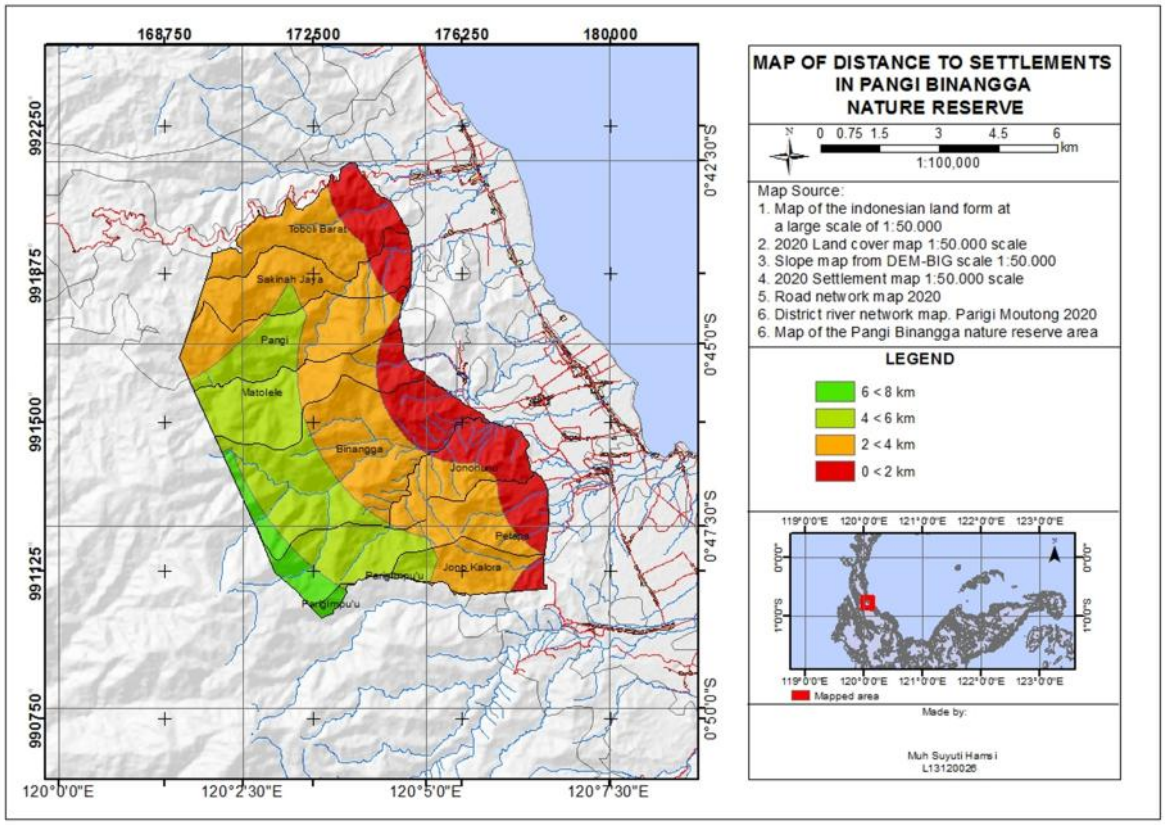

Figure 3. Map of Settlement Distances to Pangi Binangga Nature Reserve

Distance from Road

Road access in this study includes roads outside the area, main roads within the area, as well as patrol routes and other routes that are often used for illegal activities. These road distance classes are detailed in Table 9. From the table, it can be concluded that most of the Pangi Binangga Nature Reserve area in the North Parigi sub-district has accessibility that includes high to very high hazards. The area with very high forest fire hazards is located 140 meters from the road, covering 1750.32 hectares. The high hazard area is situated 1200 meters from the road, spanning 1479.19 hectares. Additionally, the moderate hazard area is found 2050 meters from the road, covering 1106.93 hectares. In the low-level category, the area is approximately 3000 meters from the road, with an area of 962.19 hectares. Lastly, the very low hazard area is located over 4000 meters from the road, covering 869.11 hectares.

Table 9. Distance of Pangi Binangga Nature Reserve from Roads in North Parigi Sub-district

No	Distance from Road (m)	Level of Hazards	Score	Area (Ha)
1	< 1000	Very High	1	1750,32
2	1000 < Distance ≤ 2000	High	2	1470,19
3	2000 < Distance ≤ 3000	Medium	3	1106,93
4	3000 < Distance ≤ 4000	Low	4	962,19
5	> 4000	Very Low	5	869,11
	Total			6158

Source: Primary Data Processed (2023)

The distance between forest areas and roads influences significantly influence on the incidence of forest fires. The closer the forest area is to the road network, the higher the risk of forest fires. Conversely, the farther the forest area is from the road network, the lower the risk of forest fires. Additionally, according to Rianawati *et al.* (2016), one of the factors that determine the level of forest fire hazards is the accessibility of population activities. The closer the accessibility of people's activities to the forest area, the greater the possibility of opening fields or agricultural land using forest burning as a method.

Rainfall

Rainfall has a significant influence on the moisture and water content of fuels. When the moisture content in the fuel is high due to sufficiently high rainfall, it is difficult for fires to occur. However, when rainfall is low, accompanied by high temperatures and a long dry season, the risk of fire becomes higher (Ningsih *et al.*, 2022). Rainfall data in North Parigi Sub-district, Parigi Moutong Regency is considered representative to reflect the rainfall conditions in Pangi Binangga Nature Reserve. This is becauseof the proximity or location of the Pangi Nature Reserve,

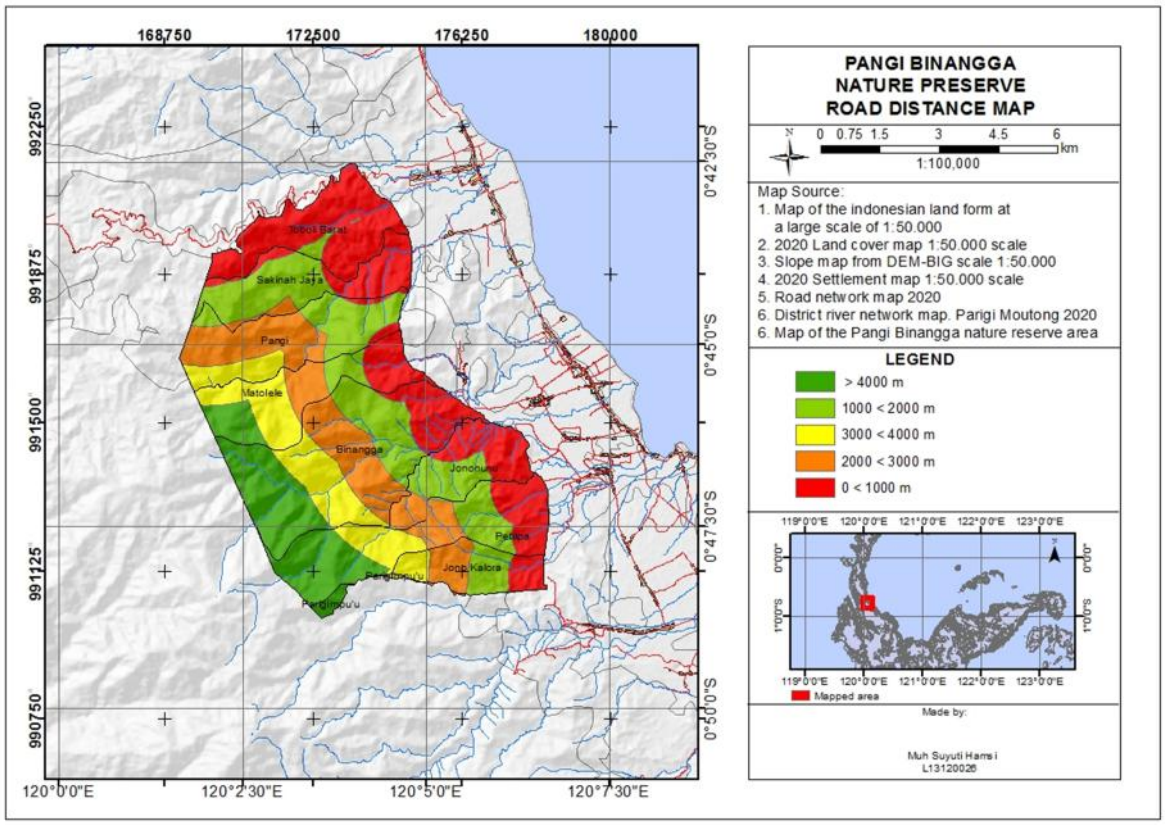

Figure 4. Road Distance Map of Pangi Binangga Nature Reserve

the data collected in the area representative of rainfall conditions in the Pangi Binangga Nature Reserve. The rainfall data from 2012 to 2013 can be found in Table 10 below:

Table 10. Monthly Average Rainfall Data for the Period 2012-2013

Month	Monthly Rainfall (mm)	Maximum Rainfall (mm)	Rainy day	Score	Level of Hazards
January	274,75	32,97	16,5	4	Low
February	226,34	34,2	16,3	3	Medium
March	235,45	40,5	19,6	4	Low
April	232,78	31,4	19,0	4	Low
May	247,63	45,97	18,7	4	Low
June	215,76	34,56	15,4	3	Medium
July	197,31	56,0	14,7	3	Medium
August	124,95	35,78	12,5	2	High
September	94,60	28,51	7,8	1	Very High
October	115,76	25,5	8,5	2	High
November	97,58	36,2	11,5	2	High
December	177,26	34,8	18,0	2	Medium
Average	186,91	36,36	14,87		

Source: Primary Data Processed (2023)

Based on Table 10, the average monthly rainfall in Pangi Binangga Nature Reserve is 186.91 mm. The highest monthly average rainfall occurs in January at 274.75 mm, the lowest monthly average rainfall is in September at 94.62 mm. The highest average maximum rainfall is in May and the lowest is in October. Additionally, the highest monthly average rainy day is in March, while the lowest is in September.

It can be observed that the level of fire hazards is very high in September with monthly rainfall ranging from 0-96 mm, while the level of fire hazards is low in January, March, April, and May with monthly rainfall ranging from 229-294 mm. The highest frequency and area of fires occurred in months with low rainfall. Purnawan *et al.* (2021) stated in their research that low rainfall results in low fuel moisture and low water content, leading to a high potential for fire. These findings align with the opinion of Itsnaini *et al.* (2017), who also emphasized that weather and climate factors influencing forest and land fires are primarily related to air humidity, air temperature, rainfall, and wind.

Forest Fire Hazards Level of Pangi Binangga Nature Reserve

The results of the regional overlay show analysis the level of forest fire hazards in the Pangi Binangga Nature Reserve in North Parigi District classified into four classes, very high, high, medium, low, and very low. The results of overlaying variables in the study of the distribution of forest and land fire hazards in the Pangi Binangga Nature Reserve in the North Parigi sub-district can be presented in Table 7 and visually represented in Figure 5.

Table 11. Distribution of Forest and Land Fire Hazards in Pangi Binangga CA

No	Category	Area (Ha)	Percentage (Ha)
1	Very Low	37.54	1%
2	Low	1360.08	22%
3	Medium	2050.58	33%
4	High	1643.69	27%
5	Very High	1066.86	17%
	Total	6158.75	100%

Source: Primary Data Processing Results (2023)

Based on data analysis and fire hazards mapping in Pangi Binangga Nature Reserve, there are four levels of

fire hazard categories. The level of fire hazard in the very low category is 37.54 hectares or 1%. This location point is an area with land cover in the form of primary and secondary dryland forests and shrubs, while the very high category is 1066.86 Ha or 17%. This location point is an area with land cover in the form of a savanna or consisting of reed grass. According to Andria *et al.* (2010), one of the natural factors that has a significant impact on forest fires is land cover. Vegetation such as savannas and reed grasslands tend to be the most susceptible to fires because they are generally dry. In addition, low rainfall during the four months from August to November can increase the level of fire risk to high or even very high. Suliman *et al.* (2014) also state that low rainfall correlates with drought, which can exacerbates the spread of fire and make it difficult to control.

Slopes categorized as steep and slightly steep dominate the area, totaling 4076.11 hectares out of a total area of about 6000 hectares. These slopes play a significant role in fire incidents due to limited access to waterways. The steeper the slope, the more challenging it is for water to reach, leading to prolonged dryness and increasing the risk of forest fires. (Devara *et al.*, 2023).

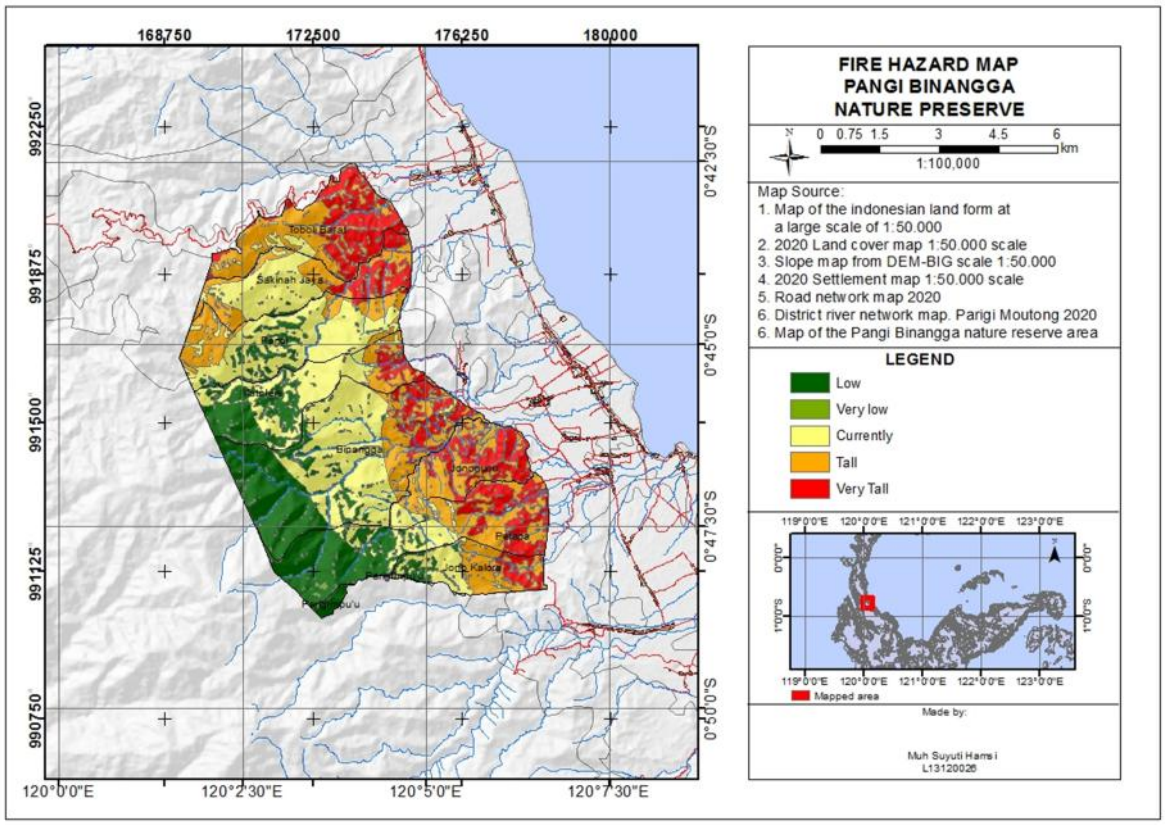

Figure 5. Forest Fire Prone Map of Pangi Binangga Nature Reserve

However, during dry seasons or droughts, the risk of fires increases significantly, especially in areas with savanna and grassland cover. Therefore, it is important to consider the proximity of forests to human settlements and infrastructure when assessing the risk of forest and land fires. Additionally, implementing fire prevention measures and raising awareness about the dangers of forest fires can help reduce the occurrence of fires in these areas. (Putra *et al.*, 2019).

CONCLUSION

There are five levels of fire hazard distribution in the Pangi Binangga Nature Reserve, North Parigi District, Parigi Regency, very high, high, medium, low, and very low categories. The variables that most influence the level of hazards to forest fires in the research location are land cover in the form of savanna or reed grassland, community accessibility distance such as distance from roads, and distance from settlements. Slope and rainfall also play a role as they determine the availability of water in the forest and impact its humidity. However, slope and rainfall do not have a significant effect on forest fire hazards because high rainfall occurs more often than low rainfall.

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