WILDFIRE RISKS IN THE SOUTHWEST OF KY SON DISTRICT, NGHE AN PROVINCE – A MULTI-CRITICAL MODEL

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Abstract

Wildfires are considered one of the most common hazards in mountainous areas, posing a serious threat to flora, fauna, and humans. This article focuses on building a forest fire risk map based on GIS techniques in the southwest area of Ky Son district, Nghe An province. The selected factors to create the forest fire risk map include 9 indices: NDDI drought index, surface temperature, slope, elevation, distance to roads, distance to rivers and streams, distance to upland fields, distance to residential areas, and aspect. The results of determining the weights of these factors using the AHP hierarchical analysis technique show that drought and surface temperature are the two factors that have the greatest influence on the forest fire risk index. The limit values that lead to forest fire risks for the drought criterion are 0.2 - 0.4 mm and for the surface temperature criterion are 25 - 30°C. The area with high fire risk accounts for the largest proportion, 38%, covering an area of 24,519.78 ha, followed by the average fire risk with 21,012.48 ha, accounting for 33% of the entire study area. The area with extremely high fire risk occupies the smallest area, 1,283.76 ha (2%). While controlling wildfires is challenging, forest fire risk maps can detect areas with higher risk and mitigate them. Therefore, creating forest fire risk maps for the identified areas is necessary.

Keywords: *Wildfires; AHP; drought; temperature.*

1. Introduction

Around the world, climate change and changes in land use have made forest fires increasingly complicated, for example the Amazon rainforest - the green lung of the earth is suffering heavy destruction by a series of fires in 2019; In late 2019 and early 2020, forest fires destroyed hundreds of thousands of square kilometers of forests and vegetation in Australia; the fire in California, the western United States became the largest forest fire in this country as of 2022 when the fire had swept over an area; In addition, there are many large fires across all continents from Europe, America to Asia. According to a report by the United Nations Environment Program UNEP and the non-profit environmental media center GRID-Arendal, GRID-Arendal predicts that severe forest fires globally will increase by 14% by 2030 and 30% by 2050, and the risk may even increase to 50% by the end of the 21st century [1]. Not outside the general trend of

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the world, forest fires in Vietnam occur in many places with different scales. Especially in recent years, when climate change is happening at a rapid pace, unusually prolonged heat waves and droughts make forest fires always present. According to data from the General Statistics Office, in the period from 2009 to 2018, there were 4571 forest fires across the country, with a loss of up to 22,000 ha of forest area, peaking in 2010 when forest fires burned about 6,723 ha of forest. Forest fires often occur in the provinces of Nghe An, Ha Tinh, Ha Giang, Son La, Yen Bai where there are many natural forests and forests planted with combustible trees such as eucalyptus forest, bamboo forest, pine forest, casuarina forest [2]. The multi-criteria approach MCA (Multi-Criteria Analysis) and hierarchical analysis technique AHP (Analytical Hierarchy Process) applied in forest fire research are interested in by many scientists in the world and in the country. Erten et al. [3] used variables to build a formula for calculating forest fire risk, including vegetation, slope direction, slope, distance to roads, and distance to residential areas. Forest fire risk regions are generated by superimposing risk variables with spatial analysis tools in ArcGIS. Ajin's study [4] uses surveillance classification methods to detect land use type and land use cover in combination with factors such as distance to residential area, distance to roads, slope, and elevation. Factors related to climate (average temperature, maximum temperature, precipitation, solar radiation, and wind speed) and terrain (elevation, slope, aspect, topographic wetness index, and distance to roads) were integrated into GIS along with satellite images for forest fire risk analysis in Tam Dao National Park [5]. Bui Manh Hung and Nguyen Thanh Thuy Van used QGIS and AHP to classify forest fire risk in Muong Cha district, Dien Bien province [6]. In addition, there are a number of studies on the application of GIS, AHP, and advanced machine learning algorithms in the evaluation of the forest fire risk index [7-9]. The objective of this article is to apply GIS and MCA multi-criteria analysis methods to evaluate forest fire risk index in Nghe An province. The result of the study is the forest fire risk map, and this document is intended to provide reference information for managers as well as people to have solutions to limit the risk of forest fires.

2. Materials and Methodology

2.1. Materials

The study was conducted in the southwestern communes of Ky Son district in Nghe An province (Figure 1), including 7 communes: Na Ngoi, Muong Ai, Muong Tip, Tay Son, Ta Ca, Huu Kiem, and Muong Xen town. Most of the study area has complex mountainous terrain, steep slopes with the North Truong Son mountain range, especially the 2,711 m high Phuxailaileng peak, which is the highest mountain in the province. The climate of the area is located in the tropical monsoon region with two distinct seasons: summer from May to October and winter from November to April of the following

year [10]. In the summer, the area affected by the southwesterly wind effect forms hot and dry weather, so the risk of forest fires is very high. Average annual temperature and rainfall are about 23 - 24°C and 1,200 - 2,000 mm.

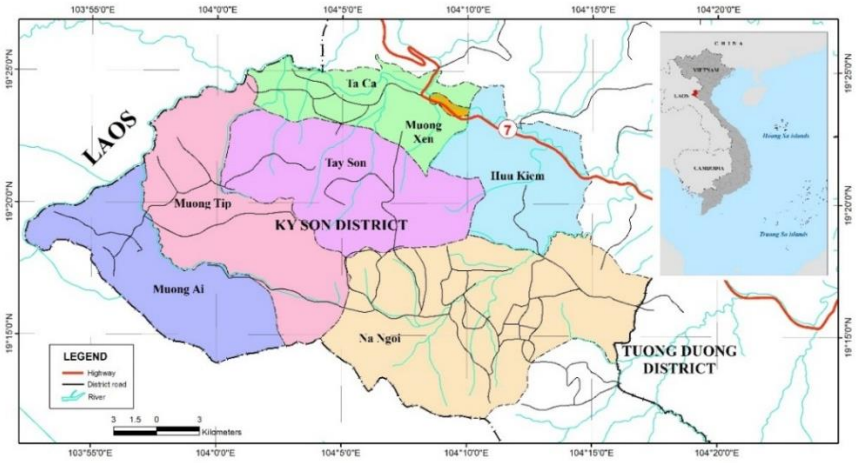

Figure 1. Location of the study area.

There are many causes of forest fires, but common materials can be divided into groups of main causes, which are topographical characteristics, climatic conditions, production activities, human activities, and other objective causes such as war burning materials, burning [6, 11]. Based on the above reasons, the study decided to choose factors affecting the forest, including 9 indicators: drought index NDDI, land surface temperature LST, distance to roads, distance to rivers trench, distance to the fields, distance to the residential area, aspect, slope, and elevation. The level of forest fire risk classification in each factor is divided into five levels from 1 to 5, corresponding to low level, medium level, high level, critical level, and extremely dangerous level [12]. The land use status quo map and the administrative map of Nghe An province at the scale of 1:100000 are the basis for building a map of the distance to roads, distance to fields, distance to residential areas; distance to rivers; the factors related to the terrain are built from the digital model of the height DEM Nghe An 25 m; Landsat 8 satellite image used to calculate NDDI drought index and land surface temperature (LST). All data to build the map of component factors affecting forest fires are transferred to the coordinate system WGS 1984 - Zone 48.

2.2. Methodology

2.2.1. Analytical Hierarchy (AHP) and GIS to build forest fire risk maps

AHP Hierarchy Analysis is a decision support method to select a solution from alternatives based on several evaluation criteria developed by Yoram Wind and Thomas L. Saaty [13].

AHP uses a scale of 1 - 9 to express the importance of expert opinion according to Saaty (Table 1).

Table 1. Scale for comparing the importance of criteria

Intensity of importance	**Definition**
1	Equally preferred more important or preferred
3	Weak importance, moderately important or preferred
5	Strong importance or strongly preferred
7	Very strongly important or preferred
9	Absolute importance
2, 4, 6, 8	Intermediate values between adjacent judgments of the two

On the basis of a scale comparing the importance of the factors, a pairwise comparison matrix is established between pairs of factors to determine their relative importance based on the experience of experts and logic. The relationship between the factors is quantified by the matrix table comparing pairs of n rows and n columns (n is the number of factors) (Table 2).

Table 2. Pairwise Comparison Matrix

C	A_1	A_2	...	A_n
A_1	1	a_{12}	...	a_{1n}
A_2	a_{21}	1	...	a_{2n}
...	...	...	...	...
A_n	a_{n1}	a_{n2}	...	1

2.2.2. Remote sensing techniques

NDDI index: Research using remote sensing technique to calculate NDDI drought index and surface temperature by Google Earth Engine technology with Landsat 8 satellite image data. Multi-temporal information of Landsat 8 image is used to calculate the vegetation index NDVI and water index NDWI [16], thereby determining the normalized difference index of drought NDDI according to formula (1):

$$\mathrm{NDDI} = \frac{\mathrm{NDVI} - \mathrm{NDWI}}{\mathrm{NDVI} + \mathrm{NDWI}} \quad (1)$$

LST index: This study used multi-year data from Landsat 8 images to calculate the LST value of the surface temperature of the study area for the period 2014 - 2021. The

results showed that the temperature value ranged from 16.2 - 38.2°C, in which the temperature value ranges from 20 - 30°C mainly concentrated in the center and occupied the majority of the area, the area with high LST > 35°C distributed mainly in the north. When the surface temperature of the study area reaches the threshold of 25 - 30°C, it is the limiting value for the risk of forest fires.

The process diagram for creating and forest fire risk index map is summarized in Figure 2, with 9 data layers analyzed and interpolated from 6 original data layers.

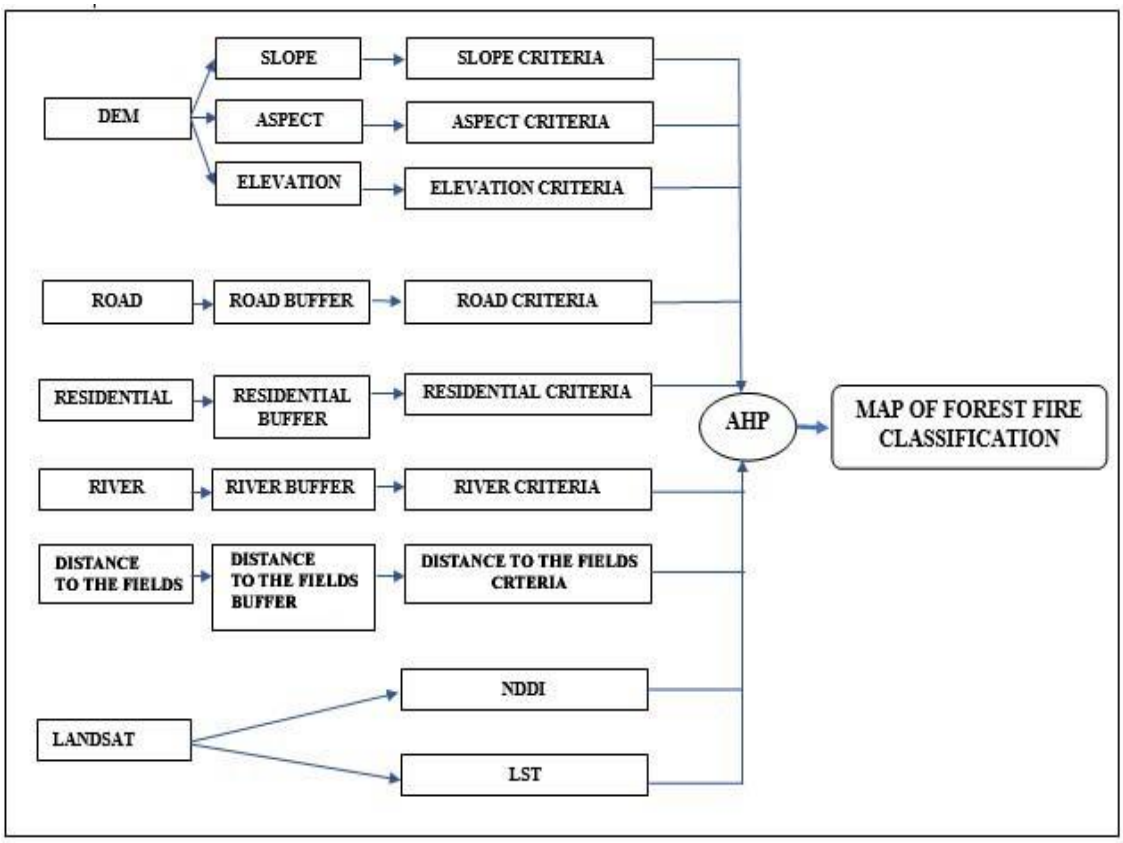

Figure 2. Forest fire risk mapping process.

3. Result and discussion

3.1. Remote sensing techniques

The analysis results show that the NDDI drought index is divided into 5 levels, level 1 with NDDI value < 0 is no drought, level 2 NDDI 0 - 0.2 is mild drought, 0.2 - 0.4 is moderate drought, 0.4 - 0.6 is severe drought, and > 0.6 is very severe drought (Table 3). This index has also been used to assess drought in agricultural crops [17].

Table 3. Classification of drought conditions based on NDDI index [14, 15]

NDDI value	Classify
< 0	No drought
0 - 0.2	Mild drought
0.2 - 0.4	Average drought
0.4 - 0.6	Severe drought
> 0.6	Very severe drought

Therefore, when the drought index reaches the threshold of 0.2 - 0.4 mm, there is a risk of forest fires. In other words, the threshold value leads to the forest fire risk of the drought criterion being 0.2 - 0.4 mm.

3.2. Hierarchical results of map layers from AHP technique

From the factors that have been identified: drought index (X_1); surface temperature (X_2); distance to the fields (X_3); aspect (X_4); distance to rivers (X_5); distance to roads (X_6); distance to residential area (X_7); slope (X_8); and elevation (X_9). Research has been conducted to establish component maps (Figure 3), then build forest fire risk maps. The hierarchical criteria for the component map layers are shown in Table 4 [3, 5-7].

Table 4. Hierarchical criteria for mapping forest fire risk components

Map layer	Classify				
	I	II	II	IV	V
(X_1) Drought index	< 0	0 - 0.2	0.2 - 0.4	0.4 - 0.6	> 0.6
(X_2) Surface temperature (^{o})	0 - 20	20 - 25	25 - 30	30 - 35	> 35
(X_3) Distance to the fields (m)	> 400	350 - 400	300 - 350	200 - 300	< 200
(X_4) Aspect	North, East, South	East - North	East - South	West - South, West - North	West
(X_5) Distance to rivers (m)	< 200	200 - 400	400 - 600	600 - 800	> 800
(X_6) Distance to roads (m)	< 500	500 - 1000	1000 - 1500	1500 - 2000	> 2000
(X_7) Distance to residential area (m)	0 - 1500	1500 - 2000	2000 - 2500	2500 - 3000	> 3000
(X_8) Slope (^{o})	< 8	8 - 15	15 - 25	25 - 45	> 45
(X_9) Elevation (m)	< 500	500 - 1000	1000 - 1300	1300 - 1600	> 1600

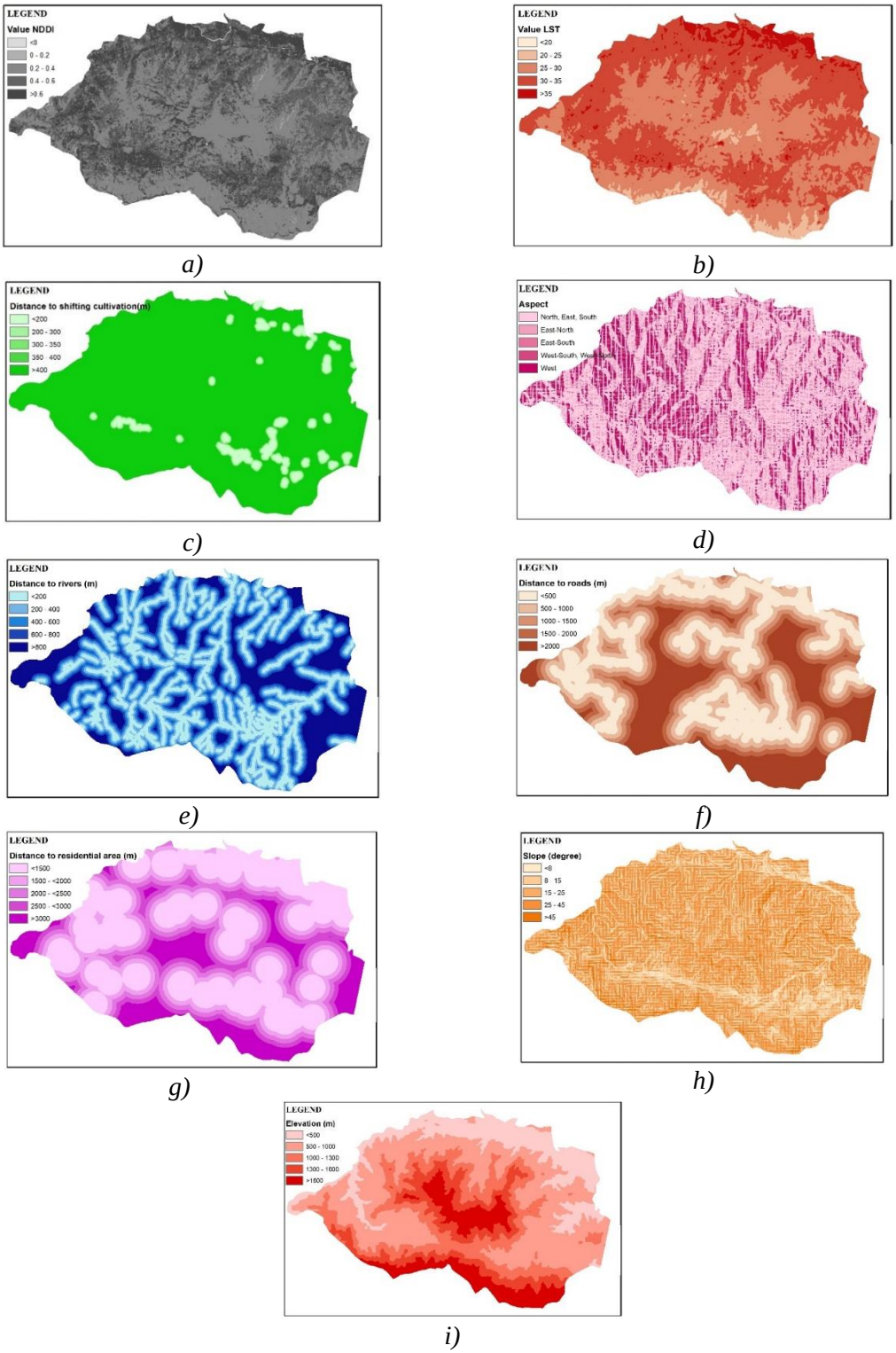

Figure 3. The current status map of information layers in forest fire risk assessment (a - Drought; b - Surface temperature; c - Distance to the fields; d - Aspect; e - Distance to rivers; f - Distance to roads; g - Distance to residential area; h - Slope; i - Elevation).

3.2. The results of weight analysis by the AHP method

Based on the opinions of experts, forest rangers and people are quantified according to Saaty, then put into a pairwise comparison matrix, calculate the sum of the priority of each factor and check the consistency according to the AHP method (Table 5).

Table 5. Pairwise comparison matrix table and factor weights

Criteria	**(X_1)**	**(X_2)**	**(X_3)**	**(X_4)**	**(X_5)**	**(X_6)**	**(X_7)**	**(X_8)**	**(X_9)**	**Weight**
(X_1) Drought index	1.00	2	3	3	3	4	4	5	6	0.30
(X_2) Surface temperature	0.50	1.00	1.5	1.5	1.5	2	2	2.5	3	0.15
(X_3) Distance to the fields (m)	0.33	0.67	1.00	1	1	1.5	1.5	2	2	0.10
(X_4) Aspect	0.33	0.67	1.00	1.00	1	1.5	1.5	2	2	0.10
(X_5) Distance to rivers (m)	0.33	0.67	1.00	1.00	1.00	1.5	1.5	2	2	0.10
(X_6) Distance to roads (m)	0.25	0.50	0.67	0.67	0.67	1.00	1	1	1.5	0.07
(X_7) Distance to residential area (m)	0.25	0.50	0.67	0.67	0.67	1.00	1.00	1	1	0.07
(X_8) Slope (^{o})	0.20	0.40	0.50	0.50	0.50	1.00	1.00	1.00	1	0.06
(X_9) Elevation (m)	0.17	0.33	0.50	0.50	0.50	0.67	1.00	1.00	1.00	0.05
With CI = 0.003; λ = 9.026; RI = 1.45; CR = 0.002 < 0.1 $\rightarrow$ Satisfy										

The results of the AHP analysis show that the three most important factors affecting forest fires are drought, followed by surface temperature. The distance to the fields, the distance to the river, and aspect have the same effect on forest fires. Consistency index CR = 0.001 is smaller than the consistency threshold of 0.1, so the judgment of experts, forest rangers, and people ensures consistency.

3.3. Forest fire risk classification results

A forest fire risk prediction map (FFRPM) is conducted by aggregating and superimposing component maps base on integrating weights of factors according to multivariable linear equations in GIS.

$$FFRPM = 0.30*(X_1) + 0.15*(X_2) + 0.10*(X_3) + 0.10*(X_4) + 0.10*(X_5) + 0.07*(X_6) + 0.07*(X_7) + 0.06*(X_8) + 0.05*(X_9) \quad (2)$$

The map of the forest fire risk hierarchy and the statistical results of the forest fire area according to the classification of the southwestern communes of Nam Ky district are shown in Figures 2 and 3.

Table 6. Summary of forest fire hazard classification in the study area

Forest fire risk classification	Area (ha)	Percentage (%)
Low risk	6645.78	10
Moderate risk	21012.48	33
High risk	24519.78	38
Severe risk	10232.01	16
Extremely risk	1283.76	2

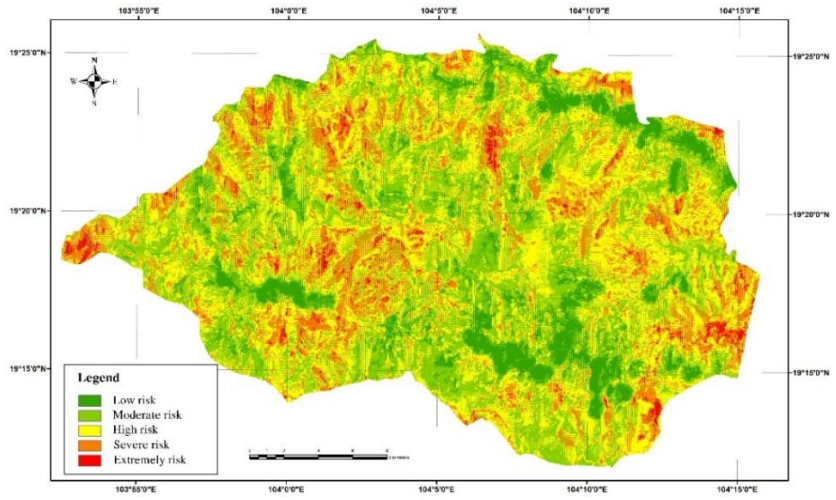

Figure 4. Map of forest fire classification results in the western area of Ky Son district, Nghe An province.

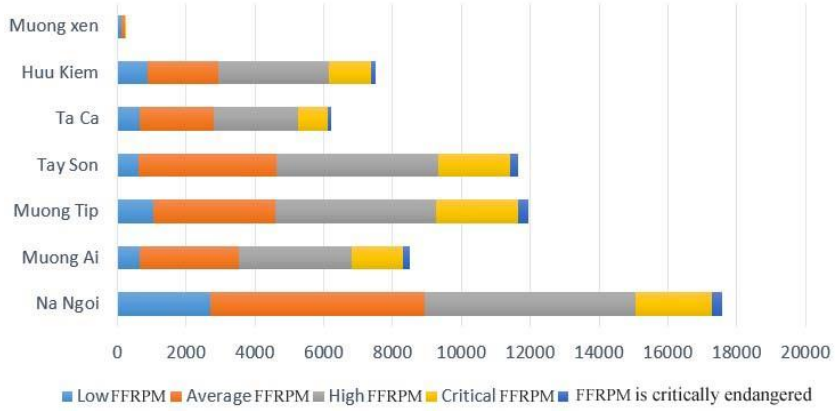

Figure 5. Forest fire risk area hierarchical by commune (ha).

From the results of the establishment of the zoning map and the statistical table of the area with forest fire risk of the study area, it is shown that the highest fire area in the southwest of Ky Son district is Muong Tip commune, with an area of extreme fire risk. The critical period is 309.96 ha (accounting for 0.49% of the entire area), the risk of fire danger is 2377.71 ha (accounting for 3.74%); next is Na Ngoi commune with an area of extremely dangerous fire risk of 297.09 ha (accounting for 0.47%), the risk of dangerous fire is 2222.91 ha (accounting for 3.49%); The area of Muong Xen town of Ky Son district is the place with the least fire risk. This reflects the reality in the study area [18].

Through actual investigation, the area of Muong Tip commune has mainly mountainous terrain, with many dangerous high mountain ranges, steep slopes, population density reaching 22 people/km^2; shifting cultivation is quite common, drought is concentrated in the Northwest, the average surface temperature ranges from 30°C to 35°C. The factors reflect the severity of the forest fire research, making this area highly susceptible to forest fires. Muong Xen is the town of Ky Son district, Nghe An. This is also the last town on National Highway 7A as well as on the banks of the Ca River. The terrain is mainly forest and mountains, descending from the Northwest to the Southeast, the area of the small town is separated from Ta Ca commune, with a gentle slope, many river systems pass through, traffic and population are concentrated; drought and surface temperatures are both moderate. This also shows that this area has very little fire risk, consistent with the research results.

Similar to this study, the role of drought (index X_1) and surface temperature (index X_2) are considered as determining factors to forest fire risk. Numerous studies have shown that surface temperatures are affected by atmospheric temperature, driving trends in the occurrence of wildfires globally, the frequency and activity of fires have increased, and this increase is likely to associate with warming in spring and summer [19]. Therefore, ecosystem management and social and technological solutions are needed to deal with fire risks effectively and in the long term.

4. Conclusion

Forest fire depends on many factors, so the application of the AHP technique, and MCA multi-criteria analysis method combined with GIS and remote sensing images to build a forest fire risk forecast map is suitable to solve the problem. The study used 9 factors to evaluate the forest fire risk index in the southwest region of Ky Son district in Nghe An province, including drought, surface temperature, distance to the fields, aspect, distance to hydrology, distance to traffic, distance to population, slope, and elevation.

The results show that drought and surface temperature are two factors that have a great impact on the forest fire risk index. In particular, the highest forest fire risk in the whole region is concentrated in Muong Tip - a commune near the border with more than 309 ha of extremely endangered; this is also an area with a variety of landscapes from natural forests to shifting cultivation. Although the research method is not new, the research results can be directly applied to local management units to provide solutions to prevent forest fire risks and at the same time, be useful documents for researchers with comparative and contrasting material for future research.

References

[1] "Spreading like Wildfire: The Rising Threat of Extraordinary Landscape Fires," a report by UNEP and GRID-Arendal, UN Environment Programme.

[2] Lê Thị Hồng, "Vấn nạn cháy rừng ở Việt Nam," *Tạp chí Con số & Sự kiện*, Tổng cục Thống kê, Bộ Kế hoạch và Đầu tư, ISSN 2734-9144, 2020.

[3] Erten, E., Kurgun, V., Musaoglu, N., *Forest fire risk zone mapping from satellite imagery and GIS - A case study*, 2002.

[4] Ajin, R. S., Mathew, K. J., A. R. R. Menon., Vinod, P. G., "Forest fire risk analysis using geoinformation technology: A study of Peppara Wildlife Sanctuary Thiruvananthapuram, Kerala, India," *Disaster Risk and Vulnerable Conference*, 2014.

[5] Pham Duc Dat, Le Thai Son. "Wildfire risk zone mapping from geographic information system in Tam Dao National park of Vietnam," *Journal of Forestry Science and Technology*, No. 13, 2022, DOI: 10.55250/jo.vnuf.2022.13.045-055.

[6] Bùi Mạnh Hưng, Nguyễn Thanh Thủy Vân, "Sử dụng Qgis và phân tích thứ bậc (AHP) để phân cấp nguy cơ cháy rừng tại huyện Mường Chà, tỉnh Điện Biên," *Tạp chí Khoa học và Công nghệ Lâm nghiệp*, số 2-2019, ISSN 1859-3828, tr. 38-47, 2019.

[7] Nguyen, N. T., Dang, B. T. N., Pham, X. C., Nguyen, H. T., Bui, H. T., Hoang, N. D., Bui, D. T., *Spatial pattern assessment of tropical forest fire danger at Thuan Chau area (Vietnam) using GIS-based advanced machine learning algorithms: A comparative study*, Elsevier, 2018, pp. 74-85.

[8] Xu, D., Dai. L. M., Shao, G. F., Tang, L., Wang, H. "Forest fire risk zone mapping from satellite images and GIS for Baihe Forestry Bureau, Jilin, China," *Journal of Forestry Research*, pp. 169-174, 2005.

[9] Ajin, R. S., Loghin, A. M., Vinod, P. G., Jacob, M. K., "Forest Fire Risk Zone Mapping Using RS and GIS Techniques: A Study in Achankovil Forest Division, Kerala, India," *J. Earth Environ Health Sci.*, pp. 109-115, 2016.

[10] https://nghean.gov.vn/

[11] Bế Minh Châu, *Quản lý lửa rừng*, Nxb Nông nghiệp, Hà Nội, 2012.

[12] Nghị định số 156/2018/NĐ-CP ngày 16/11/2018 của Chính phủ.

[13] Yoram Wind, Thomas L. Saaty, "Marketing Applications of the Analytic Hierarchy Process," *Management Science*, 26(7), pp. 641-658, 1980.

[14] Saaty T. L., "Decision making with the analytic hierarchy process," *International Journal of Services Sciences*, 1, pp. 83-98, 2008.

[15] Saaty T. L., *Fundamentals of decision making and priority theory with the analytic hierarchy process*, RWS Publications, Pittsburg, 2000.

[16] Y. Gu, J. F. Brown, J. P. Verdin, and B. Wardlow, "A five-year analysis of MODIS NDVI and NDWI for grassland drought assessment over the central Great Plains of the United States," *Geophys. Res. Lett.*, Vol. 34, No. 6, pp. 1-6, 2007.

[17] Charat, M., Wattanakij, N., Kamcbai, T., Mongkolsawat, K, Chuyakbai, D., "Exploration of Spalio-Tenporal Drought Patterns using Satellite-Derived Indice for Crop Management in Northeastem Thailand," *Asian Association on Remote Sensing*, Beijing, China, 2009.

[18] https://truyenhinhnghean.vn/xa-hoi/201104/sang-tao-trong-cong-tac-tuyen-truyen-mot-kinh-nghiem-pcccr-o-ky-son-634177/

[19] Amiri, M., & Pourghasemi, H. R., "Predicting areas affected by forest fire based on a machine learning algorithm," in *Computers in Earth and Environmental Sciences*, pp. 351-362. Elsevier, 2022. DOI: 10.1016/B978-0-323-89861-4.00004-X

NGUY CƠ CHÁY RỪNG PHÍA TÂY NAM HUYỆN KỲ SƠN, TỈNH NGHỆ AN - MỘT MÔ HÌNH TIẾP CẬN ĐA TIÊU CHÍ

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Tóm tắt: *Cháy rừng được coi là một trong những mối nguy hiểm phổ biến nhất ở các khu vực rừng núi, đe dọa nghiêm trọng đối với hệ động thực vật và con người. Bài báo sử sử dụng kỹ thuật phân tích hệ thống thông tin địa lý GIS ở khu vực phía Tây Nam của huyện Kỳ Sơn thuộc tỉnh Nghệ An, nơi có hàng ngàn hecta rừng tự nhiên phòng hộ đầu nguồn được chọn để tiến hành thực nghiệm. Các nhân tố được lựa chọn để thành lập bản đồ nguy cơ cháy rừng bao gồm 9 chỉ số: chỉ số khô hạn NDDI, nhiệt độ bề mặt, độ dốc, độ cao, khoảng cách đến đường giao thông, khoảng cách đến sông suối, khoảng cách đến nương rẫy, khoảng cách đến khu dân cư và hướng phơi. Kết quả xác định trọng số của các nhân tố theo kỹ thuật phân tích thứ bậc AHP cho thấy hạn hán và nhiệt độ bề mặt là hai nhân tố có ảnh hưởng lớn nhất đến chỉ số cháy rừng. Chỉ số tới hạn dẫn đến nguy cơ cháy rừng của chỉ số khô hạn là 0,2 - 0,4 mm và nhiệt độ bề mặt là 25 - 30°C. Diện tích có nguy cơ cháy cao chiếm tỉ lệ lớn nhất là 38% với diện tích 24519,78 ha, tiếp đến là nguy cơ cháy trung bình với 21012,48 ha chiếm 33% diện tích toàn khu vực nghiên cứu. Nguy cơ cháy cực kỳ cao chiếm diện tích nhỏ nhất với 1283,76 ha (2%). Mặc dù việc kiểm soát các đám cháy là rất khó khăn, song bản đồ nguy cơ cháy rừng có thể phát hiện các khu vực có rủi ro lớn hơn và giảm thiểu chúng. Vì vậy, việc lập bản đồ vùng có nguy cơ cháy rừng là cần thiết như một giải pháp bảo vệ rừng trước nguy cơ cháy rừng.*

Từ khóa: Cháy rừng; AHP; hạn hán; nhiệt độ.

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