WILDFIRE RISK ZONE MAPPING FROM GEOGRAPHIC INFORMATION SYSTEM IN TAM DAO NATIONAL PARK OF VIETNAM

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SUMMARY

Tam Dao National Park is located in the north of Vietnam where many wildfires happened during the period from 2013 to 2017. This study applied GIS in forest fire risk mapping in Tam Dao National Park that supports forest fire early detection and prevention. The environmental variables were used in this research including five climatic variables (maximum temperature, average temperature, precipitation, solar radiation, and wind speed) and six topographic variables (vegetation types, elevation, slope, aspect, topographic wetness index, and distances from road). These variables were represented as raster layers, stratified into ranked classes before being weighted overlaid to calculate the total points. Forest fire risks were classified into five levels from very low to very high based on the calculation results. The final result showed that 16% area in the very high-risk zone, 24% area in the high-risk region, 49% area in the medium and low-risk zone, and 11% area appeared with the lowest fire risk. Very high-risk areas are distributed at low elevations along the southwest boundary of the natural park**.** The forest fire risk map in Tam Dao National Park will be a useful reference source for forest management and protection in the fire season.

Keywords: Climatic variables, forest fire, forest fire risk, FFRZ, topographic variables.

1. INTRODUCTION

In recent years, from 2013 to 2017 Tam Dao National Park suffered more than 66 large and small-scale wildfires cases, an average of 124 forest hectares loss (Nguyen Minh Tuan, 2017). According to the results of surveys and statistics of Forest Protection Stations in Tam Dao National Park in September 2017, the total area of forests that are able to catch fire easily in study site is 5,173.5 hectares. Forest fire occurrences depend on many influential variables which contribute to ignition and fire spread. Some groups of variables have a higher influence on wildfire than others, therefore the parameters used in estimating the chance of forest fire occurrence are not equal (Ajin et al., 2016). For example, the leaf litter layer under the Tam Dao forest canopy accumulated over the years will become the most dangerous fuel source for burning in the dry season. Therefore, the risk of forest fires happening from this factor is extremely high.

The topographic and climatic variables were used to map forest fire risk by using algebra formula, they added weight to each parameter which represents the importance of parameters in fire occurrence, and then calculate all variables with their weights to produce wildfire maps (Dong et al., 2005; Ajin et al., 2016; Torres et al., 2016). Nguyen et al., conducted and compared the three advanced machine learning algorithms to analyze the wildlife spatial pattern for the tropical forest of Thuan Chau. The authors collected forest fire locations for the GIS database in 2016 and ten influencing variables used for training and confirming the forest fire susceptibility prediction model (Nguyen et al., 2018). Quy used P_{nes} formula of Nesterov to determine forest fire risk levels, the variables that contribute to this formula including with N is the number of the day without raining or the precipitation less than 6 mm, T is the temperature of the day at 1 pm, D is the saturation difference in air humidity at 1 pm, K is adjusted coefficient according to rainfall. The day with precipitation is more than 6 mm so K = 0, less than 6 mm so K = 1. It took 6 years from 2010 to 2015 for data collection, only data from the December of the last year to April of the following year. The result only showed the number of days in 5 months had fire risk corresponding to 5 levels (Quy et al., 2017). The research was conducted in Turkey used images of Landsat TM before the fire occurrence and the images after the fire to define and identify the burned area, estimating

the vegetation loss also. The variables were used to form a formula for forest fire risk calculating including vegetation, slope, aspect, distance from roads, and distance from settlements. After calculation, the author classified separately and compared images from 2 different dates of fire with statistical results. This study used 5 variables to make a comparison so it could not more precise because forest fire is influenced by many variables such as temperature, wind speed, and humidity so it was better if they could collect more variables (Erten et al., 2002). Ajin used the supervised classification method to detect land use and land cover raster layer of the study site, combined with four other variables including distance from settlement and road, slope and elevation. Every raster data would be reclassified by using Natural Break (Jenk) method, then given weight and rank according to their sensitivity to fire to apply the formula (Index = Rank x Weight). Forest fire risk zone was created by overlaying the index layer by using ArcGIS spatial analyst tool (Ajin et al., 2014).

In this study, topographic and climatic data were integrated into Geographic Information System for analysis to release a forest fire risk zone map in Tam Dao National Park.

2. RESEARCH METHODOLOGY

2.1. STUDY AREA

The present study area, Tam Dao National Park is located within 21° 21' N - 21° 42' N and 105° 23' E - 105° 44' E. With a total area of 34,995 hectares, this national park is shared by Thai Nguyen, Vinh Phuc, and Tuyen Quang provinces. There are 20 high mountains over 1000 m, the highest peak is Tam Dao Nord with a height of 1592 meters (Cuong et al., 2013)

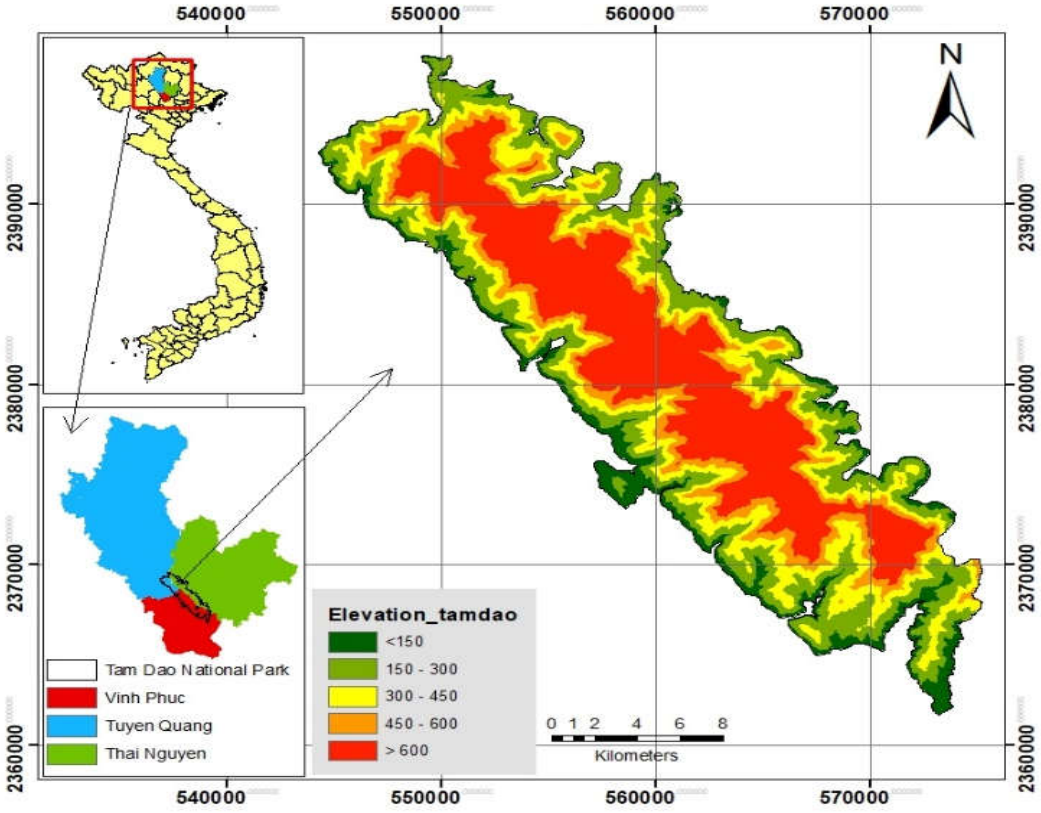

Figure 1. Location and elevation of Tam Dao National Park

The rainy season starts from April to October, the average rainfall annually in the westside is from 1.603 mm to 2.630 mm, approximately 700 mm on the east side. The dry season starts from November to March of the following year with the characteristics are very cold and dense fog. The average temperature of a year is 18 degrees of Celsius over 700 meters

and 23 degrees of Celsius in the foothills of the mountain. The average humidity annually is from 80% to 87% and there are 1400 sunny hours per year (Nguyen Minh Tuan, 2017).

2.2. MATERIAL AND METHOD

This study used 11 variables corresponding to 11 rasters, 5 rasters of climatic variables were downloaded from WorldClim climate data version 2.0, with the smallest spatial resolution is approximately 1 km^2. The chosen data for analyzing were from January to May and November to December (7 months totally), because these months were known as a dry and forest fire season in Tam Dao National Park. Each climatic variable raster contained 7 layers corresponding for 7 months. Six topographic variables were made by using Landsat 8 Satellite Imagery Aster Global Digital Elevation Model (NASA) while vegetation types layer and the boundary of the study site were provided by National Park.

Stage 1 is for building the data set: 11 raster layers were converted to spatial resolution 30 x 30 m and extracted by Tam Dao National Park boundary. The coordinate system in this study was WGS_1984_UTM_Zone_48N. Stage 2 is for analyzing the data: There were 5 ranks indicating forest fire risk zones so five value classes of each variable would be classified by using the manual method based on their sensitivity to fire. Every variable has also marked a weight to show how important when they contribute to forest fire occurrence. Variable (Ve) contained 13 types of vegetation in Tam Dao National Park, they had different risk levels based on their flammability. Table 1 below shows the description of 13 vegetation types.

Table 1. Variable (Ve) description

Types	Description
F1	Rich secondary evergreen broadleaved forest on soil mountain
F2	Medium secondary evergreen broadleaved forest on soil mountain
F3	Poor secondary evergreen broadleaved forest on soil mountain
F4	Regeneration on soil mountain
F5	New plantation on soil mountain
F6	Rehabilitation secondary evergreen broadleaved forest on rocky mountain
F7	Rehabilitation secondary evergreen broadleaved forest on soil mountain
F8	New plantation on soil mountain
F9	Mixed wood-bamboo forest on soil mountain (mainly wood)
F10	Mixed bamboo-wood forest on soil mountain (mainly bamboo)
F11	Neohouzeana bamboo forest on soil mountain
F12	Bamboo plantation on soil mountain
F13	Other bamboo forests on soil mountain

Table 2. Ranking and their weights to determine forest risk zone

Variables	Weights	Classes	Risk levels
Vegetation (Ve)	10	F9, F10, F11, F12, F13	5
		F6 – F7 – F8	4
		F4 – F5	3
		F3	2
		F1 – F2	1
Elevation (El)	7	<150	5
		150 – 300	4
		300 – 450	3
		450 – 600	2
		>600	1

Variables	Weights	Classes	Risk levels
Topographic Wetness index (TWI)	7	<4	5
		200 – 500	4
		500 – 800	3
		800 – 1100	2
		>1100	1
Distances to roads (Road)	7	<200	5
		200 – 400	4
		400 – 600	3
		600 – 800	2
		>800	1
Slope (Sl)	7	$>50^0$	5
		$40^0 – 50^0$	4
		$30^0 – 40^0$	3
		$15^0 – 30^0$	2
		$<15^0$	1
Aspect (As)	7	South ($135^0 – 225^{0)}$	4
		West ($225^0 – 315^0$)	3
		East ($45^0 – 135^0$)	2
		North ($315^0 – 45^0$)	1
Maximum Temperature (Tmax)	5	>23.5	5
		23 – 23.5	4
		22.5 – 23	3
		22 – 22.5	2
		<22	1
Average Temperature (Tavg)	5	>19.5	5
		19 – 19.5	4
		18.5 - 19	3
		18 – 18.5	2
		<18	1
Precipitation (Prec)	5	<56	5
		56 – 57	4
		57 - 58	3
		58 - 60	2
		>60	1
Solar radiation (Srad)	5	>12700	5
		12600 – 12700	4
		12500 – 12600	3
		12420 – 12500	2
		<12420	1
Wind speed (Wind)	5	>1.9	5
		1.8 – 1.9	4
		1.7 – 1.8	3
		1.6 – 1.7	2
		<1.6	1

The final FFRZ map of Tam Dao National Park was made by using the raster calculator, a mathematic equation was formed to calculate the forest fire risk layer.

FFRZ = 5(Tmax + Tavg + Prec + Wind + Srad + Road) + 7(El + Sl +As + TWI) + 10Ve

3. RESULT AND DISCUSSION

This part shows the map layer results of eleven variables that influence forest fire risk zones in Tam Dao National Park. There are three parts: (A) Climatic variables results, (B) topographic variables results, (C) FFRZ map result.

3.1. Climatic variables results

The maximum temperature: It plays an important role in ignition activities with fire materials so the higher temperature, the more dangerous. It showed 35% area has the lowest fire risk while 9% of the area is very close to residential places and low altitude that have the highest fire risk in the fire season.

The average temperature: 28% area in Tam Dao National Park has a temperature lower than 18 Celsius degree, the lowest fire risk occurrence when compared to another place. Two other places accounted for 23% and 22% have very high risk and medium risk respectively.

Precipitation: This considers the amount and timing of rainfall so it has a big impact on reducing the heat from the sunlight of a particular area because it moistens the fuels and soil. The layer indicated 31% area has the lowest precipitation is in the high elevation region where the amount of rainfall was less than 56 mm (very high risk). In contrast, there was 28% area has the highest precipitation that higher than 60 mm and they are in the low elevation region.

Solar radiation is the amount of heat from the sun that a particular region can receive and it contributes to forest fire risk. The huge solar radiation in a long time can make the temperature getting higher, dry fuels and water evaporation process will happen in the trees. The data showed 3% area had more than 12700 kJ m^2/day were on the top of the mountain (very high risk), top mountain area had a very high risk than other places when making a comparison.

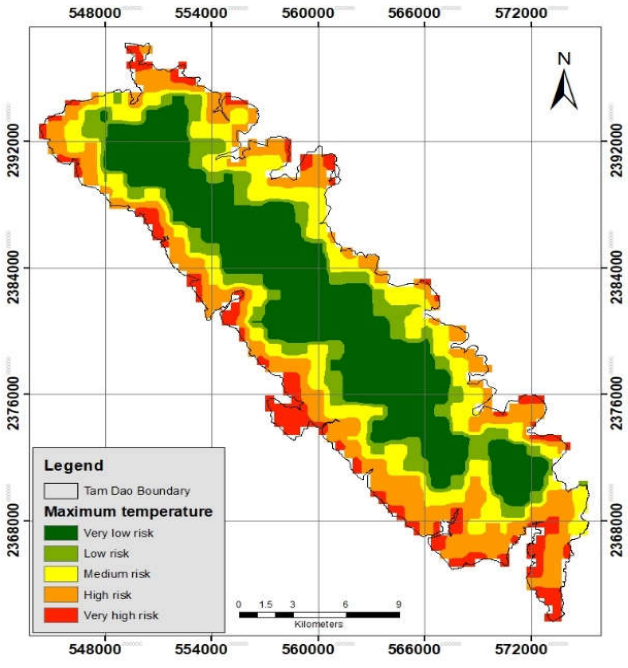

Figure 2. Maximum temperature-based fire risk zone layer

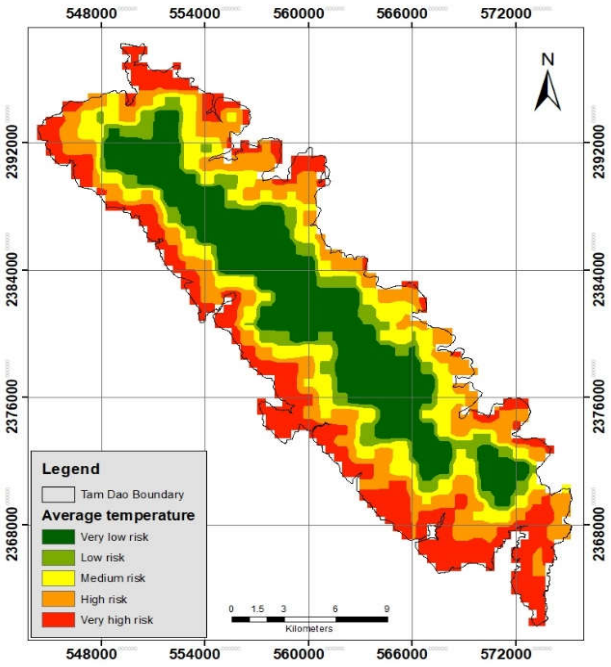

Figure 1. Average temperature-based fire risk zone layer

Wind speed is one of the variables that affect wildfire's behavior, it supplies additional Oxygen for the fire so it will consider how big the fire is, further dry potential fuels, and make the fire spread at a faster rate. It showed 5% area had wind speed faster than 1.9 were on the top of the mountain (very high risk of fire) while 65% area has wind speed less than 1.6m/s where is located in the lowest elevation region.

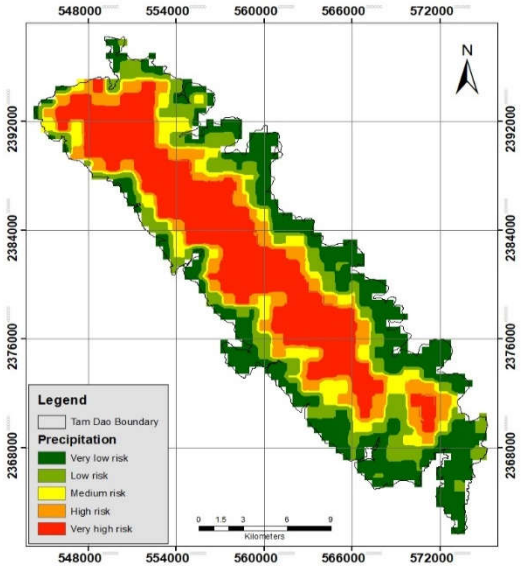

Figure 4. Precipitation-based fire risk zone layer

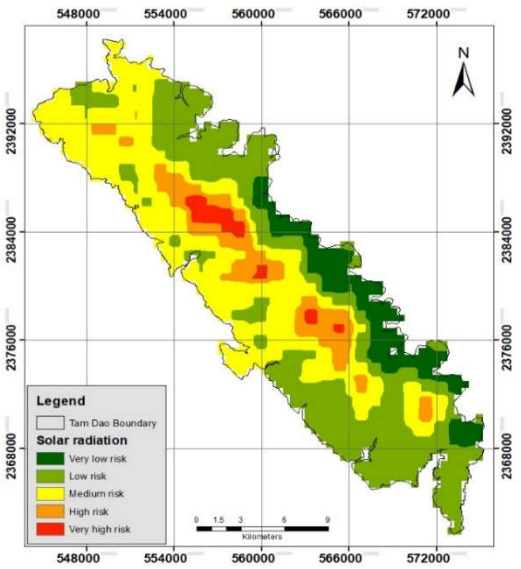

Figure 5. Solar radiation-based fire risk zone layer

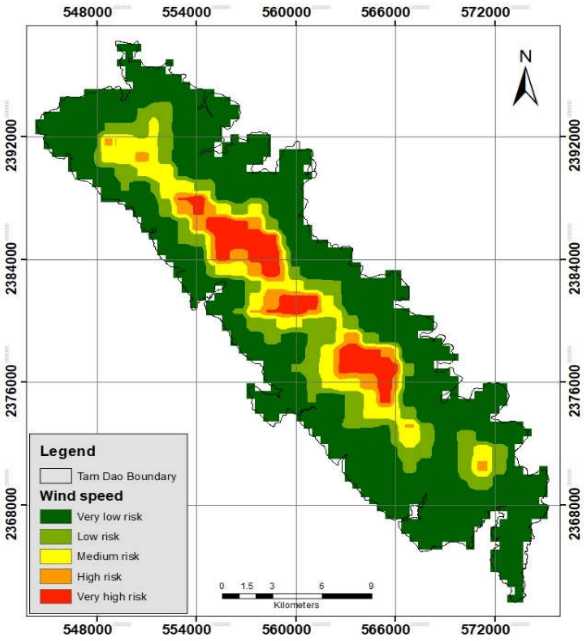

Figure 6. Wind speed-based fire risk zone layer

3.2. Topographic variables results

Elevation: The data showed that 33% area has an elevation higher than 600 meters and the fire spread is lower because of lower temperatures. While 9% area was lower than 150 meters and have the highest fire risk due to a higher temperature.

Aspect: The southern aspect accounted for 28% area and the second-largest was western with 27% area. They are the two most important aspects that will contribute the most to wildfire because they receive much more extreme solar radiation per day so they will dry fuel faster than the northern and eastern sides.

Slope: During the fire season, heavy wind and high slopes play an important role in spreading fire. There were approximately 6% of the area has a slope higher than 40 degrees and this area has the highest fire risk ranking are 4 and 5.

Topographic wetness index: It is affected by water flow areas where water moves deeper into the ground from the land surface and makes the surrounding soil wet in a period. The very high-risk region accounted for 7% area while low and some low-risk rates consider 9% area.

Distance from road: The areas close to the roads have a higher potential of burning than further areas, because of the burning activities of local people. The closest distance was less than 200 meters with 17% area appearing with the very high-risk level.

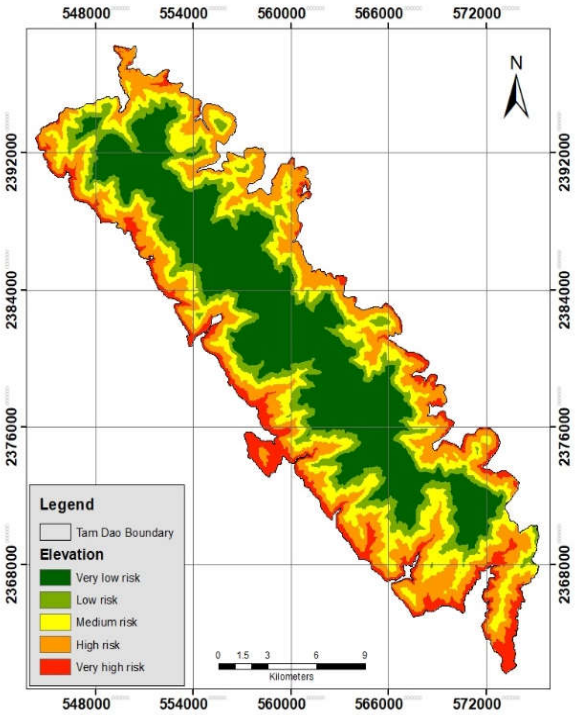

Figure 7. Elevation-based fire risk zone layer

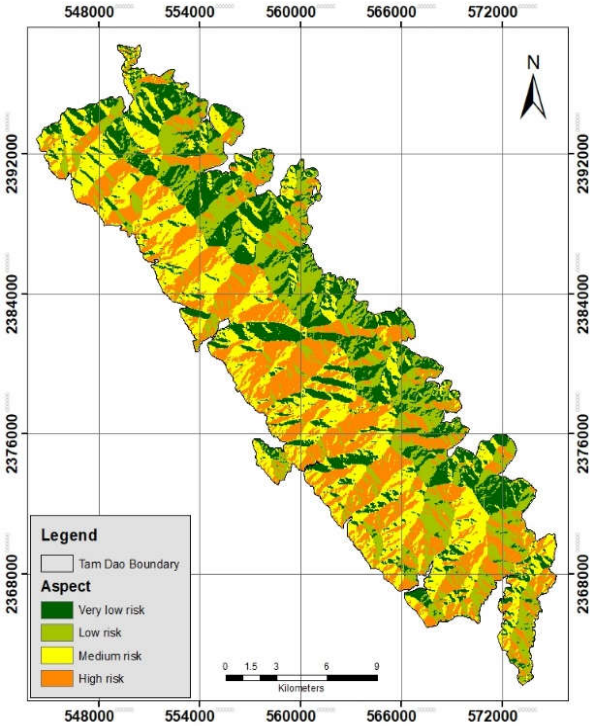

Figure 8. Aspect-based fire risk zone layer

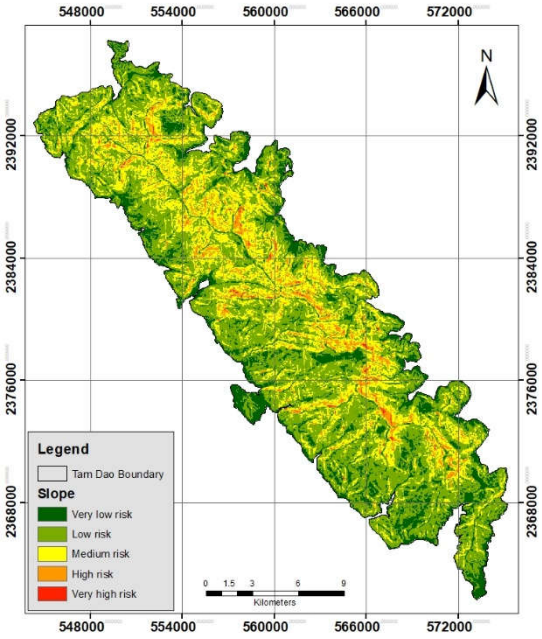

Figure 9. Slope-based fire risk zone layer

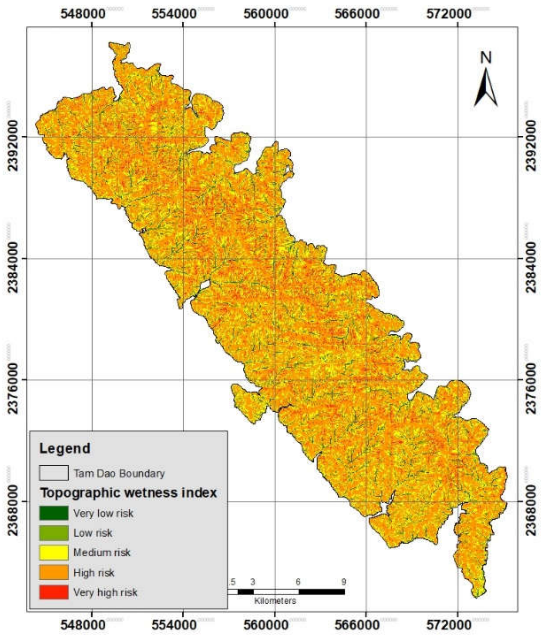

Figure 10. TWI-based fire risk zone layer

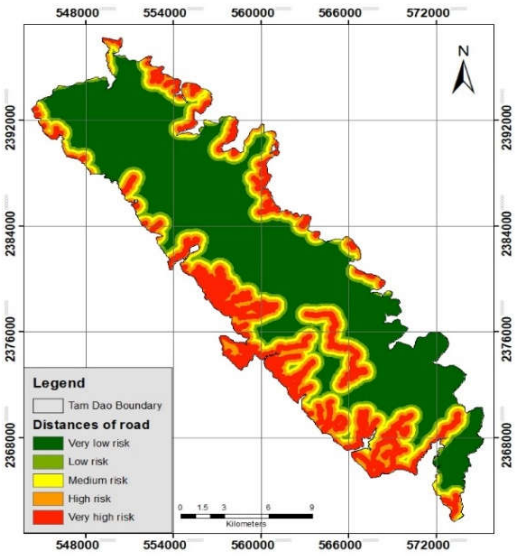

Figure 11. Distances of road-based fire risk zone layer

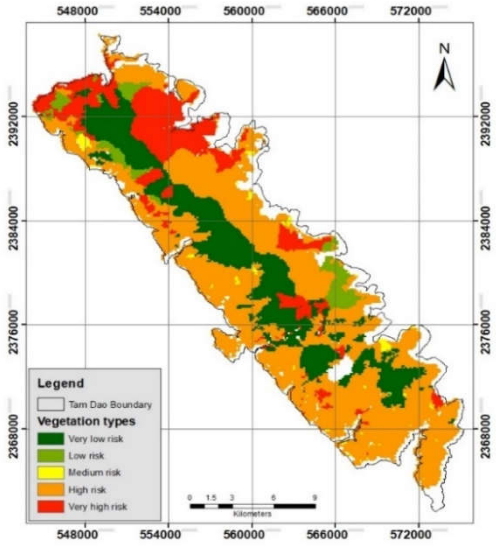

Figure 12. Vegetation type-based fire risk zone layer

Vegetation: 13 vegetation types in Tam Dao National Park and they were classified into 5 groups corresponding to 5 values of fire risk rating ranking based on their flammability. Bamboo trees area accounted for 16% of the area in the highest fire risk, it distributes mostly in the north of the study site. The second dangerous area accounted for 56% area including woody trees, it can be found around the study site where nearby residential areas.

3.3. Forest fire risk zone map results

The forest fire risk zone layer of Tam Dao National Park was the result after using the raster calculator tool to calculate the 11 variable raster layers. The synthesized forest fire risk zone map (Figure 13) showed that very high-risk zones are mainly distributed in the southwest of the study area where are nearby roads and residential areas which accounted for 16% area. The high-risk zone contributes 24% of the total area, mainly distributed in the southwest direction. The medium, low-risk zone, and very low-risk zone accounted for 60% area.

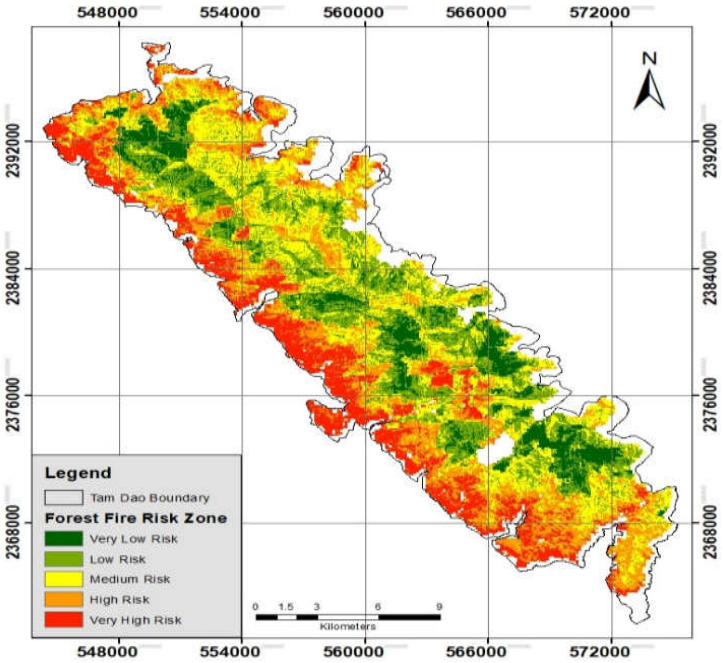

Figure 13. Forest fire risk zone of Tam Dao National

In this study, maximum temperature, average temperature, and solar radiation represent heat. While wind speed represents Oxygen and vegetation symbolizes fuels. Other variables such as precipitation, distances from roads, elevation, aspect, slope, and topographic wetness index also influence forest fire so they were added for a more accurate result. Every environmental factor is important in making forest fire happen, lack of one of them will lead to an imbalance in forest fire assessment and the result will not reliable. As the regulations on forest fire forecasting levels in Vietnam from 2018, there are 5 levels present for forest fire risk so in this study, I followed this to have a unification.

The natural break method for classification variables was a good choice because of its convenience, it arranges a set of values into natural classes so it is different when compared with the manual method which was used mainly in this study. I tested the natural break method for the FFRZ map classification, the result of the most dangerous area was higher than 20% to compare with 16% of it. The result of 20% was not true with the circumstances of Tam Dao National Park. Topographic variables have the second biggest weight index because these variables impact fire ignition and its spread. Climatic variables can make forest fire occur (weight 5) but topographic variables will make it more dangerous after that, which is the reason they were appointed weight 7.

Fire rating level 1 was appointed to F1 and F2 forest types, they are rich and medium secondary evergreen broadleaved forest on soil mountain because very hard to be burned. Fire rating level 2 was appointed to F3, it is a poor natural wood forest in the mountain because of less likely to be burned. Level 3 was appointed to Poor secondary evergreen broadleaved forest on soil mountain (F4) and New plantation on soil mountain (F5) because of medium fire risk. Level 4 was appointed to the Rehabilitation secondary evergreen broadleaved forest on the rocky mountain (F6) and Rehabilitation secondary evergreen broadleaved forest on soil mountain (F7) and New plantation on soil mountain (F8) because of high fire risk. Level 5 was appointed to Mixed wood-bamboo forest on soil mountain (mainly wood) (F9), Mixed bamboo-wood forest on soil mountain (mainly bamboo) (F10), Neohouzeana bamboo forest on soil mountain (F11), Bamboo plantation on soil mountain (F12), Other bamboo forests on soil mountain (F13) because of very high fire risk.

There are a lot of fuels on the study site so it has a great burning potential, Tam Dao National Park has been identified as one of the 6 places that have the most dangerous forest fire in Vietnam. Studies on forest fires in this area, especially applying GIS for mapping are limited, so this study will contribute to the reference source. Research results and methods can be used to compare with other studies on effectiveness or based on real forest fire events to check the accuracy. The study also proposed some forest fire prevention methods to help people and forest rangers refer to develop mitigation plans for human and property damage caused by forest fires.

Using Worldclim 2.0 weather data, the data can be analyzed in GIS and combined with other variables such as topography and type of vegetation, which is convenient for data analysis. It also helps to saves time for data collection in the study area because the manual method will include preparing equipment, installing equipment, and collecting data after years of waiting. The data must then be transferred to analytical tools such as Excel or SPSS for separate analysis. The area of Tam Dao National Park is 368.83 km^2, so we will need to install at least 368 stations for each km^2 to compare with the minimum resolution of WorldClim data is $1km^2$. After that, it takes a lot

of time to import data into analytics while it took about 24 hours for downloading the data from the Worldclim website in this study.

Worldclim data in this study was taken from 1970-2000, so it has less accuracy when compared with weather conditions nowadays other bamboo forests such as the highest temperature, wind speed, and precipitation. The accuracy of the data also depends heavily on the weather variables that influence the sensor of the satellite, while the measurement stations at the study sites will give exact results. The Worldclim data in this study is aggregated over 30 years from 1970 to 2000, the data of one variable will be the average result of 30 years. An average result will not be accurate when compared with daily data at the measuring station. Settlements present the regular appearance of people, which also contributes to the risk of wildfires due to human impact. The activities of local people in Tam Dao that caused forest fires have been recorded. In this study, lack of distance from the settlement is a drawback.

This study has contributed to forest fire risk mapping in Tam Dao National Park with raw data that was taken from WorldClim 2.0 and Aster Global DEM. The results of every raster layer in this study can be used as a reference for other research to make comparisons.

4. CONCLUSION

The happening of forest fires depends on many variables, which play a significant role in the ignition and spread of forest fires. The contribution of each factor in data analyzing the forest fire can not be equal with the others, because some of them have higher influence. Through that, it leads to the different weights that every group of variables was appointed. This research used climatic data of WorldClim 2.0 from 1970 – 2000 so it limited the reliability of the final result, the latest source of data will provide more accurate climatic data.

The FFRZ map showed that 16% area was at the highest risk of fire, 24% area had the high risk, 26% had medium risk, 23% had low risk and 11% appeared with the lowest risk of fire. The methodology and results of this study might be useful for all institutions dealing with a forest fire, help them in wildfire prevention and management. ArcGIS is such a useful tool in forest fire mapping and evaluates the risk in fire season.

REFERENCES

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

2. Ajin, R.S., Mathew, K.J., A.R.R. Menon., Vinod, P.G. (2014). Forest fire risk analysis using geo-information technology: A study of Peppara Wildlife Sanctuary Thiruvananthapuram, Kerala, India. Disaster Risk and Vulnerable Conference.

3. Cuong, C,V., Lamb, D., Hockings, M. (2013). Simple plantations have the potential to enhance biodiversity in degraded areas of Tam Dao National Park, Vietnam. Natural Areas Journals 33(2), 139-147.

4. Erten, E., Kurgun, V., Musaoglu, N. (2002). Forest fire risk zone mapping from Satellite imagery and GIS a case study.

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

6. Quy, N.V., Khoa, T.D., Phu, N.V., Hanh, N.T. (2017). The effect of climatic variables on the risks of forest fire at Vinh Cuu – Dong Nai. Journal of forestry science and forestry No.6, 117-123.

7. Tam Dao National Park. (2013). Geographical position. http://www.tamdaonp.com.vn/index.php/dieu-kien-tu-nhien/vi-tri-dia-ly.html.

8. Torres, F.T.P., Lima, G.S., Martins, S.V., Reis, B.P. (2016). Use Of Geographic Information Systems In Forest Fires Mapping In Southeastern Of Brazil. Australian Journal of Basic and Applied Sciences, 28-35.

9. Tuan, N. M. (2017). Plan for fire prevention during the dry season in Tam Dao National Park, 2017-2018.

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

LẬP BẢN ĐỒ KHU VỰC NGUY CƠ CHÁY RỪNG TỪ ẢNH VỆ TINH VÀ GIS: NGHIÊN CỨU TẠI VƯỜN QUỐC GIA TAM ĐẢO

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[1]Trường Đại học Lâm nghiệp

TÓM TẮT

Vườn Quốc gia Tam Đảo nằm ở phía bắc Việt Nam, nơi nhiều vụ cháy rừng đã xảy ra từ năm 2013 đến 2017. Nghiên cứu này đã ứng dụng GIS trong việc lập bản đồ nguy cơ cháy rừng tại Vườn Quốc gia Tam Đảo nhằm hỗ trợ phát hiện sớm và phòng chống cháy rừng. Các biến môi trường được sử dụng trong nghiên cứu này bao gồm năm yếu tố khí hậu (nhiệt độ tối đa, nhiệt độ trung bình, lượng mưa, bức xạ mặt trời và tốc độ gió) và sáu yếu tố địa hình (loại thực vật, độ cao, độ dốc, hướng phơi, chỉ số độ ẩm địa hình và khoảng cách từ đường). Các yếu tố được biểu diễn dưới dạng lớp raster, được phân tầng thành các lớp để xếp hạng theo cấp độ trước khi được xếp chồng lên nhau để tính tổng điểm. Rủi ro cháy rừng đã được phân thành 5 cấp độ từ rất thấp đến rất cao dựa trên kết quả tính toán. Kết quả cuối cùng cho thấy 16% diện tích nằm trong vùng nguy cơ rất cao, 24% diện tích trong vùng nguy cơ cao, 49% diện tích trong vùng nguy cơ trung bình và thấp và 11% khu vực có nguy cơ cháy thấp nhất. Các khu vực có nguy cơ cháy rất cao phân bố ở độ cao thấp dọc theo ranh giới phía tây nam của Vườn Quốc Gia Tam Đảo. Bản đồ nguy cơ cháy rừng tại vườn quốc gia Tam Đảo sẽ là 1 nguồn tài liệu tham khảo hữu ích trong việc quản lý và bảo vệ rừng trong mùa cháy rừng.

Từ khóa: Biến môi trường, cháy rừng, FFRZ, vùng nguy cơ cháy rừng.

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