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Risk of climate change impacting on drought and forest fire based on the spatial analysis and satellite data †

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Abstract: Drought is considered a serious disaster after floods and typhoons and is tending to increase frequency and intensity due to climate change on a global scale. In addition, droughts also cause large and small fires that occur daily around the world, damaging the forest, the forest ecosystem and having a significant impact on the economy, society and people. This paper presents the situation of forest fires in U Minh Ha forest of Ca Mau province, which is the last land area in the south of Vietnam. The study used satellite imagery processing, which combined spatial analysis to identify areas of fire sensitivity, in the face of drought risk associated with climate change in the dry season in 2016. AHP hierarchy analysis was performed using factors such as surface temperature, leaf moisture, vegetation cover, vegetation density, distance to water sources, distance to residential areas and the distance to the fire protection works. The results show that in the study area, the zone with average fire sensitivity accounts for nearly half of the forest area and is distributed in the south and southwest. The high fire sensitivity area is negligible. Study results are useful for planning strategies to protect forest resources against the drought risk caused by climate change that is increasing now.

Keywords: AHP hierarchy analysis; climate change; drought; forest fire; satellite image

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1. Introduction

Following flood and storm, drought is regarded as one of the most devastating disasters and is increasing in frequency and intensity due to global climate change. Drought reduces or disables the ability to meet the water needs of people, plants and animals, causing serious impacts on the survival and development of the ecosystem. In the context of global warming today, the impact of drought on forests leading to the risk of fire is the most obvious manifestation. The consequences caused by forest fires appear both immediate and long-term in many ways. Especially in tropical forest conditions, the consequence of forest fires is enormous, specifically including: [3] Forest degradation; Land degradation; Loss of ecosystems and biodiversity; Reducing air quality and causing atmospheric pollution; Demolition of water basins; Economic damage; Influence on life and human health. Forest fire is one of the causes of negative impacts on forests, the environment, ecology, as well as the economy, society and people.

The study area is U Minh Ha Forest, a large wetland ecoregion in the Mekong Delta and the whole country, with many species of flora and fauna. Total natural area is 54,254 ha, in which forestry land is 40,576 ha. The terrain is relatively flat. The soil is often flooded during the rainy season and is affected by alum [3]. The weather in the dry season from 2015 to 2016 is relatively complicated. El-Nino has negatively impacted the area and caused prolonged heat. Water levels in some canals are depleted, causing difficulties for transportation of means and water for forest fire fighting. At the peak of the dry season (March and April 2016) the U Minh Ha forest area was dry on 43,000 hectares with high fire risk, in which the level IV and V alert equivalent to dangerous and extreme levels occupied up to 43,545.5 ha, can occur fire at any time [3].

2. Methodology

2.1. Data

The main data used in the study was Landsat 8 satellite image with 8 spectral bands (band 1-7 and 9) with spatial resolution of 30m; band 8 (panchromatic) with resolution of 15m; and 2 thermal bands with a resolution of 30m (adjusted resolution from 100m). The scene has Paths 126, Row 53 and taken on April 7, 2016 representing near the end of the dry season 2015-2016 in the study area. The data set is free to download from the USGS earthexplorer.usgs.gov website. In addition, the map data of the study area in the shape file format with a scale of 1: 25,000 was also collected for the overlapping calculation.

2.2. Evaluation method

The study was based on the Fire Risk Index (FRI) model [6], which is determined by the sum of the weighted Fi parameters as follows:

$$\mathrm{FRI} = \sum_{i=1}^{n} w_i F_i \quad (1)$$

Where the component parameters were determined for the study area including: type and density of vegetation cover, leaf moisture, surface temperature, distance to residential areas, water supply and fire protection works. These factors are determined from the remote sensing indices and GIS data.

2.2.1. Normalized Difference Vegetation Index

Normalized Difference Vegetation Index (NDVI) represents the density (or freshness) of vegetation coverage on land, which is an important element in research on forest fire [1]. NDVI is calculated from the spectrum of visible and near-infrared light that is reflected by vegetation. Fresh plants absorb most of the visible light, and reflect much of the near-infrared light. Sparse or poor vegetation reflects more visible light and less infrared light.. The formula for calculating this index is as follows:

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{VIS}}{\mathrm{NIR} + \mathrm{VIS}} \quad (2)$$

Where NIR is near-infrared band corresponding with Landsat 8 band 5; VIS is visible band corresponding with Landsat 8 band 4. The calculated NDVI for 1 pixel always ranges from -1 to +1. Zero (0) means no vegetation, and nearly +1 indicates the highest possible density of green leaves [5].

2.2.2. Normalized Difference Water Index

Bo-Cai Gao (1996) proposed Normalized Difference Water Index (NDWI), which uses the wavelengths 0.86 and 1.24 μm to determine vegetation humidity. NDWI is sensitive to changes in the liquid water content of the vegetation cover, so it can also be called the Leaf Humidity Index. NDWI is less affected by aerosol scattering phenomenon in atmosphere than NDVI. The formula of NDWI was given by Gao (1996) as follows:

$$\mathrm{NDWI} = \frac{\mathrm{NIR} - \mathrm{SWIR1}}{\mathrm{NIR} + \mathrm{SWIR1}} \quad (3)$$

Where SWIR1 is shortwave infrared band corresponding with Landsat 8 band 6 with wavelength in range 1.566 – 1.651 μm, It is the electromagnetic wave that absorbs much water.

2.2.3. Land Surface Temperature

Land Surface Temperature (LST) is an important parameter in physical interaction between land surface and atmosphere with the exchange process of water and energy [7, 14]. LST can be measured from 2 thermal infrared band 10 and 11 of TIRS sensor on Landsat 8 satellite (since January 6th, 2014, USGS has recommended to select band 10 only for quantitative analysis because it has short wavelength range with high, distinctive reflection resolution; meanwhile, band 11 has larger atmospheric error [13]. LST (Ts) is determined from the consequence of Stefan-Boltzmann Law as follows:

$$T_s = \frac{1}{\varepsilon^{1/4}} T_B \quad (4)$$

where, TB is at-satellite brightness temperature and ε is emissivity, where they are determined by equations (5) and (6) as following:

$$T_B = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)} \quad (5)$$

$$\varepsilon = \varepsilon_v P_v + \varepsilon_s \left(1 - P_v\right) + C \quad (6)$$

Where L_λ is top of atmosphere radiation (Watts/(m2*srad*μm)); K1 = Band-specific thermal conversion constant from the metadata (K1_CONSTANT_BAND_x where x is band number 10 or 11); K2 = Band-specific thermal conversion constant from the metadata (K2_CONSTANT_BAND_x where x is band number 10 or 11); ε_v and ε_s are emissivities of full vegetation and bare soil; P_v is vegetation fraction, calculated by NDVI.

2.2.4. Land cover

With the same impact of factors such as weather and topography, whether a forest area is prone to fire or not; The rapid or slow spread of fire is highly dependent on the type of land cover and the characteristics of each type - fuel elements in the fire triangle. U Minh Ha forest includes the following types of land cover (according to data on digitized maps of forest status in Ca Mau province in 2015-2016 provided by Ca Mau Forest Protection Department – FPD [3]): Melaleuca forest at the age of 1, 2 , 3, 4, 5; Planted forest without reserve (T0); Acacia hybrid; Agricultural land; Residential; Vacant land; Water.

Each land cover type has different potential threat to forest fire. They will be attributed with a score ranging from highest to lowest based on their effect level on forest fire. This classification is established by multi-criteria analysis and survey on opinions of experts and people with specialized knowledge on this issue. However, surface water (drain, canal, river system) will be researched on distance to water resource

2.2.5. Distance to resident area, water resource, forest fire prevention and fighting works

These are the factors of the socio-economic and management, and for U Minh Ha forest, their importance in the risk of forest fire is not to be ignored. The distance from forest to these three objects will be classified by ranging from near to far and rasterized in ArcGIS. This is a tool used to calculate and assign values (in floating point format) to the distance of each raster cell (the vector will be transformed into a raster) to the nearest source in a straight line. Then, the map layers will be reclassified to assign new value in integer (unique values) and be proceeded to a weighted overlap with other information classes.

2.2.6. Analytic Hierarchy Process AHP and weight assignment

This method subdivides the big problem into several sub-problems (or choices) after considering the effects. Each sub-problem can be divided into several sub-criteria. All of the above components will be graded (or weighted) in accordance with a set of evaluation criteria, or simply to score from low to high depending on the priority, level of impact of that factor over the whole problem or in a sub-problem. Breaking down a problem would be helpful in getting advice and consulting with experts or knowledgeable people in the field of interest to objectively rank priorities for the component issues [8, 9, 10, 11, 12]. The total order method for calculating sets of weights for objects with the formula is as follows:

$$w_i = \frac{t_i}{\sum_{i=1}^{n} t_i} \quad \text{với} \quad t_i = n - r_i + 1 \tag{3}$$

Where wi is the standard weight of variable layer i; ti is primary score of variable i; n is number of variable layers (n=7); ri is the relative rank corresponding with variable layer i synthesized from surveyed opinion. Then, each variable layer is divided into sub-criteria and scored from 1 to 5 (least influential to most influential) using equal interval method due to its simplicity and easy-to-use characteristic [6].

3. Results

To determine weight, the research conducted survey on local forest rangers, Environment Department's students and people with related knowledge to define effect level to fire risk of 7 criteria participated in assessment. The results are shown in Table 1 and 2.

The spatial analysis of the component data layers is performed on ArcGIS software. Each layer will be changed to Raster in integer value before being input to Weighted Overlay tool. If the original raster data is floating point format (continuous value, such as temperature, NDVI, distance…), reclassification must be implemented on a scale of 5. Next we enter the weight (% Influence) for each layer. The value per pixel is multiplied by the weight of the layer containing it before it is added to the pixels of the other layers. The results will show the map that contains all criteria corresponding with fire risk index formula (Figure 1 and 2). The results show that in the study area, the zone with average fire sensitivity accounts for nearly half of the forest area and is distributed in the south and southwest. The high fire sensitivity area is negligible. Study results are useful for planning strategies to protect forest resources against the drought risk caused by climate change that is increasing now.

Table 1. Weight for 7 variable layers

Variable layer	ri	ti	wi (%)
Surface temperature	1	7	25,00
Leaf humidity	2	6	21,43
Distance to water resource	3	5	17,86

Distance to forest fire prevention and fighting works	4	4	14,29
Vegetation density	5	3	10,71
Land cover type	6	2	7,14
Distance to residence	7	1	3,57

Table 2. Weight and giving points to sub-criteria

Criteria	Weight %	Sub-criteria	Point	Criteria	Weight %	Sub-criteria	Point
Distance to residence (m)	3.57	0 ÷ 1000	5	Land cover type	7,14	Melaleuca ≥ V, IV	5
		1000 ÷ 2000	4			Melaleuca III, II, I	4
		2000 ÷ 3000	3			Acacia hybrid	3
		3000 ÷ 4000	2			Agricultural land	2
		Over 4000	1			T0, bare land, residence	1
Surface temperature (oC)	25.00	43.5 ÷ 47.5	5	Distance to forest fire prevention and fighting plan (m)	14,29	Over 3508	5
		39.5 ÷ 43.5	4			2631 ÷ 3508	4
		35.5 ÷ 39.5	3			1754 ÷ 2631	3
		31.5 ÷ 35.5	2			877 ÷ 1754	2
		27.5 ÷ 31.5	1			0 ÷ 877	1
Leaf humidity (NDWI)	21.43	-1 ÷ -0.142	5	Distance to water resource (m)	17,86	Over 1279	5
		-0.142 ÷ -0.008	4			960 ÷ 1279	4
		-0.008 ÷ 0.125	3			640 ÷ 960	3
		0.125 ÷ 0.259	2			320 ÷ 640	2
		0.259 ÷ 1	1			0 ÷ 320	1
Vegetation density (NDVI)	10.71	0.396 ÷ 1	5				
		0.259 ÷ 0.396	4				
		0.123 ÷ 0.259	3				
		-0.014 ÷ 0.123	2				
		-1 ÷ -0.014	1				

Table 3. Area of Forest ranking in fire sensitivity level

Level	**Area (ha)**	**Ratio (%)**
1	41.58	0.08
2	39,115.53	73.31
3	14,149.71	26.52
4	46.08	0.09
5	0	0
Tổng	53,352.90	100.00

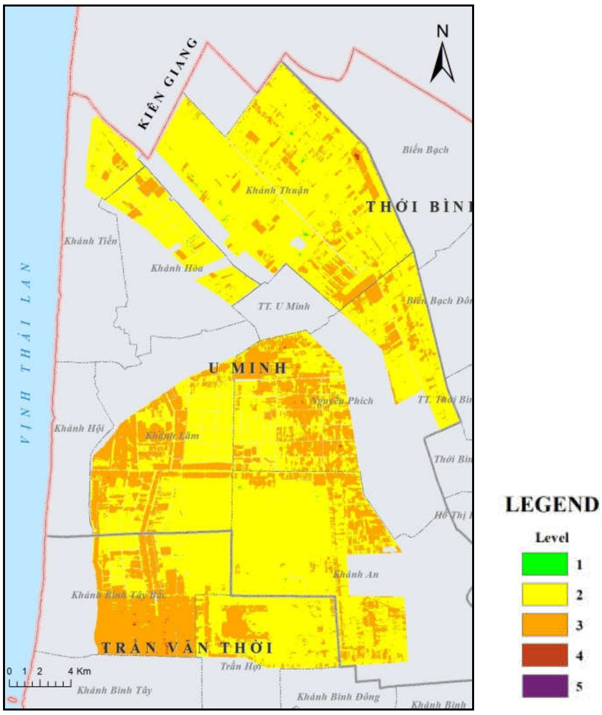

Figure 1. Forest fire sensitivity map of U Minh Ha Forest in dry season 2015-2016

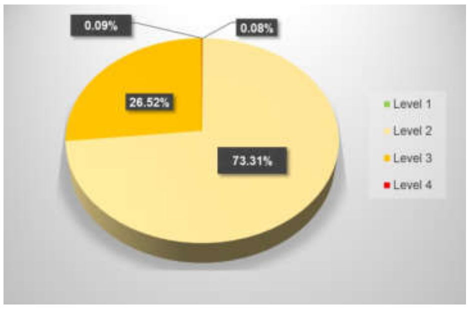

Figure 2. Percentage of area by fire sensitivity level in U Minh Ha forest

4. Conclusion

In the past, forest fire on Melaleuca forest deteriorated peat resources and biological diversity in U Minh Ha Forest. In the future, if the abnormal development of climate and consequences from climate changes continue to take place (salty intrusion, extreme weather), protecting biological diversity of Melaleuca forest's ecology will be difficult such as saline intrusion causing death of Melaleuca forests or forest fires has caused loss of biodiversity. Therefore, understanding the current status of forest fire can help managers to have an overview on the problem, and then they will have further investment in research as well as prevent mesurements in time to protect the forest from the risk of unpredictable climate change.

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