

USE OF REMOTE SENSING AND GIS TO ASSESS THE ANTHROPOGENIC IMPACT ON FOREST FIRES IN NAHR IBRAHIM WATERSHED, LEBANON

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ABSTRACT

The Mediterranean forests are exposed yearly to several forest fire events threatening the social, economical, ecological and living conditions of human being. The majority of these fires are of anthropogenic origin. The Nahr Ibrahim watershed (NIW) represents a typical example of the Lebanese areas having abundant forest surface (38.23% of its surface) but suffering recently from forest fires. The preservation of these natural resources is a priority for the continuity, stability and prosperity of the country. Several methods were applied to evaluate the potential forest fire risk in order to identify hot spots and reduce the potential damage. In this context mapping forest fire risk is a priority and a preliminary tool for the prevention of catastrophic fire events and development of sustainable forest management plans. The use of remote sensing and GIS provided the solid base for similar studies such as the forest fire risk map done for Lebanon at 1:200.000 scale. Therefore, the need for more detailed analysis at the watershed level arises. In this study a comparative analysis was conducted at a large scale (1: 50.000) on the NIW to assess the effect of several natural factors (climate, topography, vegetation and soil conditions) on forest fire risk. A combination of natural and anthropogenic factors (urban settlements, roads and zones with agricultural activity) provided better understanding of the impact of anthropogenic activities on forest hazards and forest resources conservation. The results show that forest fire in high risk zones is aggravated by anthropogenic activities: an increase from 5% to 38% was detected. In areas of moderate risk the increase goes from 7 to 25%. On the other hand, areas with low risk zones noticed a significant decrease when the anthropogenic activities were incorporated. Areas with very low risk have almost vanished.

Keywords: remote sensing, forest, fire, risk, natural factors, human pressure, Mediterranean forest

INTRODUCTION

Fire is a natural element present in all forest ecosystems and influencing many of its functions such as regulating plant succession and wildlife habitat, recycling of nutrient,

maintaining biological diversity, reducing biomass and controlling insect and disease population. Although fire may destroy individual trees and understory plants, native species historically adapted to fire and had a high regeneration capability. But since *Homo sapiens* first learned how to use fire, this equilibrium was broken and the majority of forest fires have been of anthropogenic origin resulting in several catastrophic problems threatening the life of its main cause (Tishkov, 2004). The negative impacts include air and water pollution, loss of biodiversity, land degradation, desertification, soil erosion, impairment of human health and safety as well as loss of human life.

The Mediterranean region is one of the world's biodiversity hotspots (Alacantara, 2010), where many civilizations over the history relied on its forest resources for their cultural, economical, social and esthetic service. However, every year, fires destroy millions of hectares of these surfaces (Maheras, 2002).

In Lebanon, one of the smallest Mediterranean countries (10,452 km²), with a forest cover representing 13.4% of its total surface (FAO, 2010), this problem is well pronounced with the dry and hot climate in the east (ACS, 2006). Furthermore, many studies agreed that forest fires in Lebanon occur so frequently: an amount of 70600 forest fire events took place between 1994 and 2004, with an average of 1200ha of forested area burned annually (Mitri, 2010).

In this context, understanding forest fire risk (FFR) and the behavior of such risk when exacerbated by the anthropogenic activities is extremely important for reducing fire frequency and damage. It is a prerequisite for any sustainable forest management planning. This can be simply done by analyzing different factors that influence forest fires using FFR maps (FFRM) (Jaiswal *et al.*, 2002). For this purpose, geographic information system (GIS) and remote sensing (RS) techniques were used successfully. In this regard, only one previous study was done by Faour *et al.* in 2006, to assess FFR on the national Lebanese scale at 1:200000. But a FFRM at the watershed level using high resolution source data is still lacking in the country and can improve forest management and necessary prevention measures.

The present study shows a typical example of assessing natural and hazardous FFR, and the effect of anthropogenic activity on a selected watershed from Lebanon. It is considered as a pilot study that can be applied on other Lebanese watersheds.

GENERAL CHARACTERISTICS OF THE STUDY AREA

The study area is the Nahr Ibrahim watershed (NIW), located in the occidental part of Jbeil casa and covering an area of approximately 326 km² (Figure 1). It comprises forest (38.23% of its total surface), agricultural land and residential areas. It is characterized by an obvious biodiversity and classified as an international heritage site (Bou Saab *et al.*, 2007). It is considered as a diversified landscape in terms of geology (Dubertret, 1953), climate (CAL, 1977; 1982) and topography representative of Lebanese environments. But such an important area has recently witnessed forest fires, making it a typical pilot area for study.

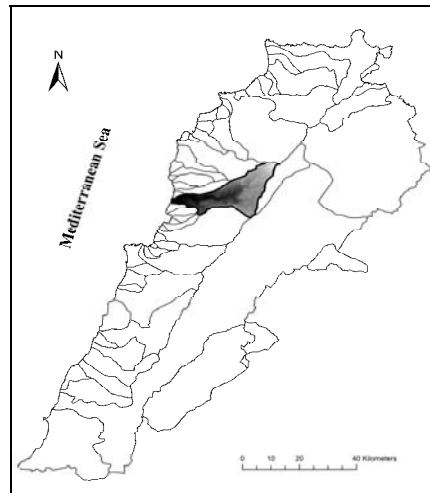


Figure 1. Location of the study area.

FOREST FIRE CONTROLLING FACTORS

Many researchers mapped FFR zones using several natural (vegetation, topography, climate) and anthropogenic factors (proximity to roads, agriculture and urban settlements) (Chuvieco & Congalton, 1989; Jaiswal *et al.*, 2002; Limin *et al.*, 2006; Faour *et al.*, 2006; Erten *et al.*, 2006; Garcia Strino, 2007). In this research, a new approach is integrated, where a combination of elements previously mentioned and other new factor (soil) are used. Then, by assigning relative weights to various factors according to their abilities to ignite a fire, the FFR zones were delineated. Furthermore, since this research focuses on the role that humans can play in such risk, two FFRM will be generated:

- Natural FFRM (NFFRM) where natural factors are combined.
- Forest fire hazard map (FFHM) where natural and anthropogenic factors are combined.

Modeling will be done without taking into account the large amount of potential forest fire caused by human intended action (arson) which is difficult to predict in any form.

MATERIALS AND METHODS

Materials used

In this research, laboratory and field materials were both used.
 Laboratory Materials provided from the CNRS.
 Land cover map scale 1/20000 (CNRS, 2006).
 Soil Map of Lebanon scale 1/50000 (Darwish *et al.*, 2006).
 Topographic map of Lebanon scale 1/20.000 (DGGA, 1963) (Directorate General of Geographic Affairs).
 Climatic Records from the CAL and LARI (CAL, 1977; 1982; LARI, 2010)
 GIS software.
 Aerial photos of the year 1965 (Mission C 002/60) provided from the DGGA.
 Satellite images from the Ikonos TM sensor of the year 2005 with 0.8 m resolution.

Field devices

Global Positioning System tool (GPS).
Data manipulation for FFR assessment.

Each of the forest fire controlling factors has several elements that contribute to the fire risk in the NIW (Figure 2). Thus for each factor, corresponding elements were extracted using GIS techniques: slope, elevation, aspect, fuel type and density, texture, organic matter content, and wind speed. Average maximal temperature for the fire season was calculated according to the Isohyethal method (Fetter, 1994).

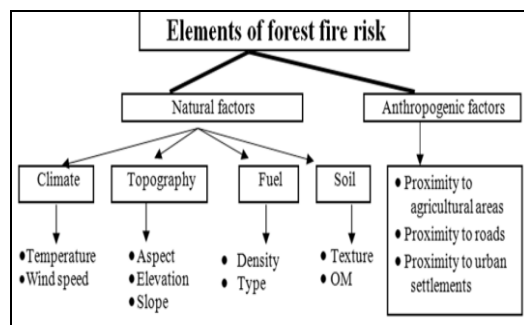


Figure 2. Forest fire controlling factors.

Figure 3 represents the different tools used in the FFR assessment and the generated materials.

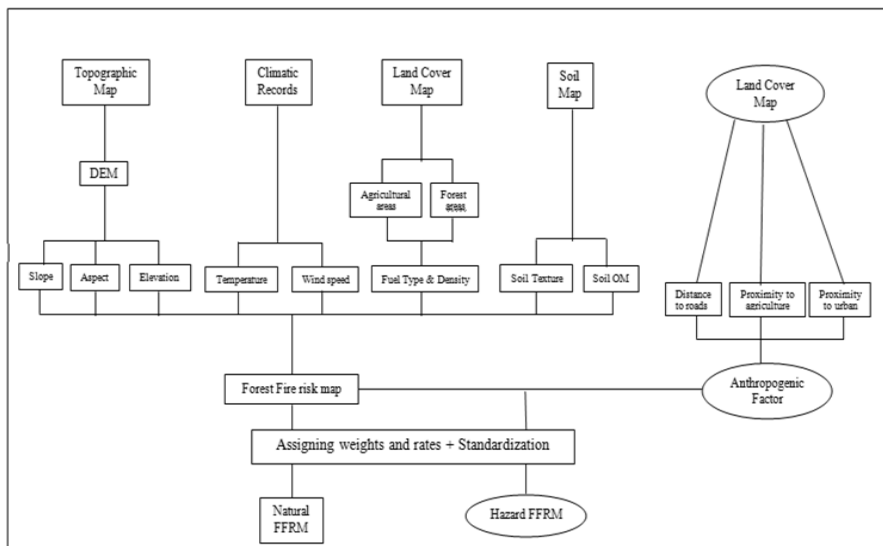


Figure 3. Different tools used in the production of the FFRM.

Method of analysis of the FFR

The factors described previously have not all the same effect on FFR in the NIW. Some factors bring higher risk, while others have less influence. Thus a chart based methodology inspired by the model proposed by Shaban *et al.* (2000) and implemented in Darwish *et al.* (2010) was adopted to evaluate the weight of each factor affecting N & HFFR in NIW. This method is based on the calculation of the total effect that each factor can produce on other factors to calculate its weight. The classification was operated as follow: a factor having a major effect on another one was attributed a weight of 1.5, of 1 for a moderate effect and of 0.5 for a minor effect. Hence, to produce the N & HFFRM two scenarios were followed:

- In the first FFRM scenario, only the natural factors were considered.
- In the second HFFRM scenario, the anthropogenic factor was mapped separately then added to the FFRM. Figure 4 shows a schematic presentation of different effects between the different factors influencing FFHM.

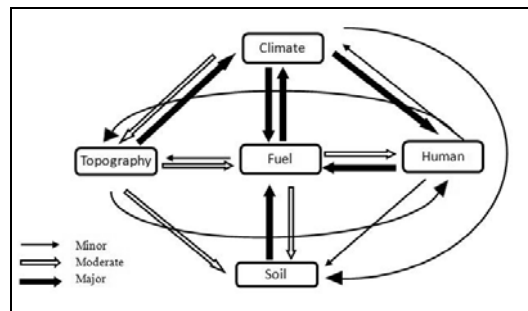


Figure 4. Methodology to evaluate the weight of different factors affecting HFFR.

For example, the fuel type has a major effect on climate, two moderate effects (one effect on the soil and one effect on the anthropogenic factor) and one minor effect on the topographic factor. Thus the fuel weight is: $1(1.5) + 2(1) + 1(0.5) = 4$. According to Figure 4, the climate is the most influencing factor due to the high number of effect that can produce on the remaining factors. Finally, the final weight for the two maps was expressed in percentage. Table 1 shows the total weight for each factor.

TABLE 1

Calculation of the Weight of Different Factors Affecting HFF

Effect Factors	Major	Moderate	Minor	Total	Weight (%)
Climate	2(1.5)	2(1)	-	5	27.78
Topography	1(1.5)	2(1)	1(0.5)	4.5	25
Fuel	1(1.5)	2(1)	1(0.5)	4	22.22
Human	1(1.5)	-	3(0.5)	3	16.66

Sub-factors weighting

The weight of the agricultural cover was distinguished from the forest factor according to the rate of the calculated divisions. For the other factors the weight was equally divided between the different elements. For example, the three topographic factors were given an equal weight ($25/3=8.33$). Having established these weights, the divisions were rated from 1 to 2 (very low to very high) to evaluate their influence. The rate of agricultural and forest factors were assessed following the Lebanese NAP (2003). And the other factors were given a rate according to their capacity to ignite a fire. Table 2 represents the weight of each factor and the rate of the corresponding divisions.

TABLE 2

Weight and Rate for Different Factors Affecting HFFR

Factor	Weight	Sub-factor	Weight(a)	Divisions	Rate (b)	PA (a x b)
Climate	27.78	Temperature (T)	13.89	T<20	1	13.89
				20<T>22	1.50	20.83
				22<T>24	1.75	24.30
				24<T>26	2	27.78
				T>26	2	27.78
		Wind speed (W)	13.89	W<3.5	1	13.89
				3.5<W>5	1.25	17.36
				5<W>6.5	1.5	20.83
6.5<W>7.5	2.0			27.78		
Topography	25	Slope	8.33	0-9	1	8.33
				9-20	1.25	10.41
				20-31	1.5	12.49
				31-43	1.75	14.57
				43-63.33	2	16.66
		Aspect	8.33	SW	1.75	14.57
				ES	1.75	14.57
				NW	1	8.33
				NE	1	8.33
		Elevation	8.33	0-500	2	16.66
				500-1000	1.75	14.57
				1000-1500	1.5	12.5
				1500-2000	1.25	10.41
2000-2650	1			8.33		
Anthropogenic factor	16.66	Proximity to houses	5.53	Less than 100m	1.75	9.4
				More than 100m	1	5.53
		Proximity to roads	5.33	Less than 100m	1.75	9.4
				Exceeding 100m	1	5.33
		Proximity to agriculture	5.53	Less than 100m	1.75	9.4
				More than 100m	1	5.53

Cont. TABLE 2

Calculation of the Weight of Different Factors Affecting HFF

Factor	Weight	Sub factor	Weight (a)	Divisions	Rate (b)	P A (a x b)
Fuel	22.22	Agriculture	6.80	Field crops in small/medium fields	1	6.80
				Field crops in large fields	1	6.80
				Abandonment agriculture land	1	6.80
				Olives	1.5	10.2
				Vineyards	1	6.80
				Fruit trees	1	6.80
				Citrus fruit trees	1	6.80
				Protected agriculture	1	6.80
		Forest	15.42	Dense pine forest	2	30.84
				Dense broad leaved wooded land	1.75	26.985
				Dense mixed wooded land	2	30.84
				Clear coniferous forest	2	30.84
				Clear broad leaved wooded land	1.75	26.985
				Clear mixed wooded land	1.75	26.985
				Scrubland	1.5	23.13
				Scrubland & dispersed bigger trees	1.5	23.13
				Burnt wooded land	2	30.84
				Dense grassland	1.5	23.13
				Clear grassland	1.5	23.13
Soil	8.34	Texture	4.17	Clay	1	4.17
				Clay loam	1	4.17
				Loam	1.5	6.25
				Loamy sand	1.5	6.25
				Silt clay loam	1.5	6.25
				Sandy clay loam	2	8.34
				Sandy loam	2	8.34
	8.34	OM	4.17	0-2	2	8.34
				2-3.97	1.75	7.29
				3.97-5.9	1.5	6.25
				5.9-8.5	1	4.17

The product assessment (PA) is equal to weight times rate. The product assessment given by the GIS software varies between 47.9 (corresponding to the lowest risk) and 152

(corresponding to the highest rate of risk). This interval is divided into 5 classes to which the class of zero risk was added as shown in Table 3.

TABLE 3

Classes of Risk in the NIW

Class	PA	Categories
I	0	Zero
II	47.92-62.53	Very low
III	62.53-77.15	low
IV	77.15-91.28	Moderate
V	91.28-106.38	High
VI	106.38-121	Very High

Method of analyzing the trend of urban expansion

Social statistics during field survey with local community confirmed the following fact: a high number of urban settlements as well as roads have highly increased during the last forty years. For this purpose digitizing of the road network on aerial photos of the year 1965 and satellite images of the year 2005 was operated on a representative small area (15.63 km²) from this watershed.

RESULTS AND DISCUSSIONS

Urban expansion

Figures 5 and 6 show the road network for the two selected years. Road network length in 1963 was 22.77 km, while the 2005 network was about 90.68 km. This reflects the increase in number of houses and at the same time pressure and trend of urban expansion observed in the NIW.

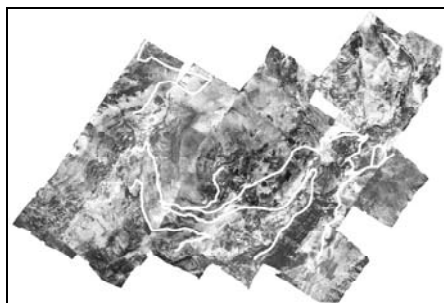


Figure 5. Road density in 1965.

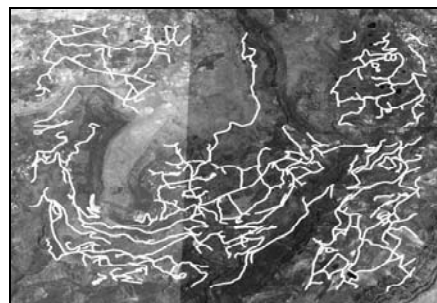


Figure 6. Road density in 2005.

Forest fire risk map in the NIW

The overlaying/merging of the layer factors together in GIS software resulted in a map indicating the level of risk for forest fires from absent or nil to very high (Figure 7).

A large part (48.66%) of the NIW is subject to a high risk for forest fires, localized in the middle to upper part of the basin where the majority of the forest and shrubs is located. In addition, zones with very high risk (5%) are adjacent to these regions. Another part, a bit smaller area (37%) is attributed with a low risk and only 6% with a very low risk. Areas with moderate risk (7%) are areas containing bare rocks where shrubs are found in large quantities. An almost insignificant fraction (2.75 %) is without risk: these are the lakes, river, and urban settlements, fraction almost non observable on the FFRM.

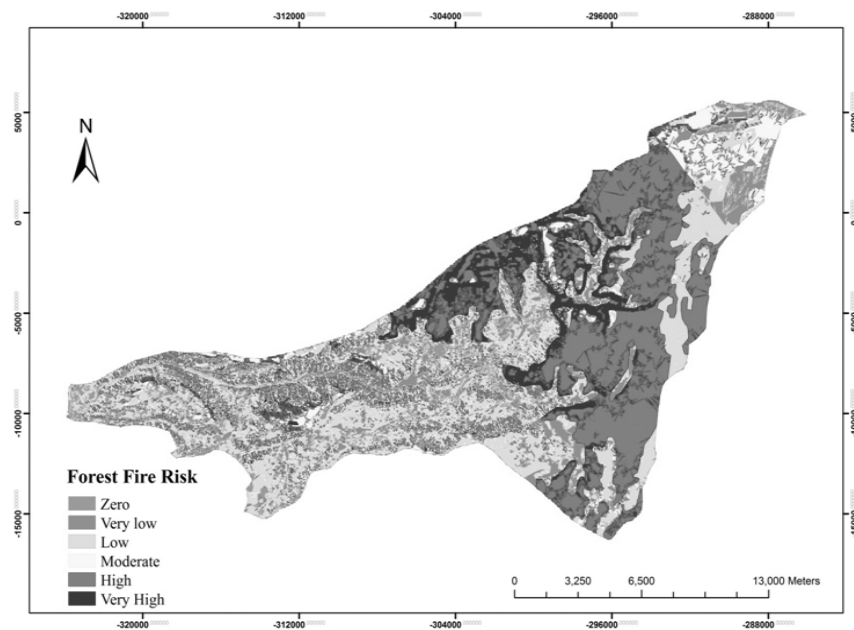


Figure 7. Forest fire risk map for the NIW.

Map representing the anthropogenic factor in the NIW

The combination of the three anthropogenic factors with their corresponding weights resulted with a map locating the anthropogenic factor within the area of study (Figure 8). According to Figure 8, the majority of urban settlement is located on the lower part of the basin, explaining the existence of roads in the same zone. Furthermore, the agricultural areas are located in the same region. While only a very little number of urban settlements is located in the upper part of the basin. In this respect, zones with very high risk (in black) are zones located in proximity to urban settlement, roads and agricultural areas. Those with high risk level (dark grey) are in proximity to two anthropogenic factors, and areas with medium level

(light grey) of risk are in proximity to one factor only. The low risk areas (white) are zones distant from all the anthropogenic factors

Hazardous forest fire risk map for the NIW

As previously mentioned, the combination of anthropogenic and natural maps results in a HFFRM. This is illustrated in Figure 9.

A large area (37.88%) of the NIW is found with a very high risk for forest fires. And almost 22% are with a high risk. Besides, 25% represent areas with moderate risk. Zones with a low risk form 11.8% of the total surface of the NIW, and only 0.5% are attributed with a very low risk.

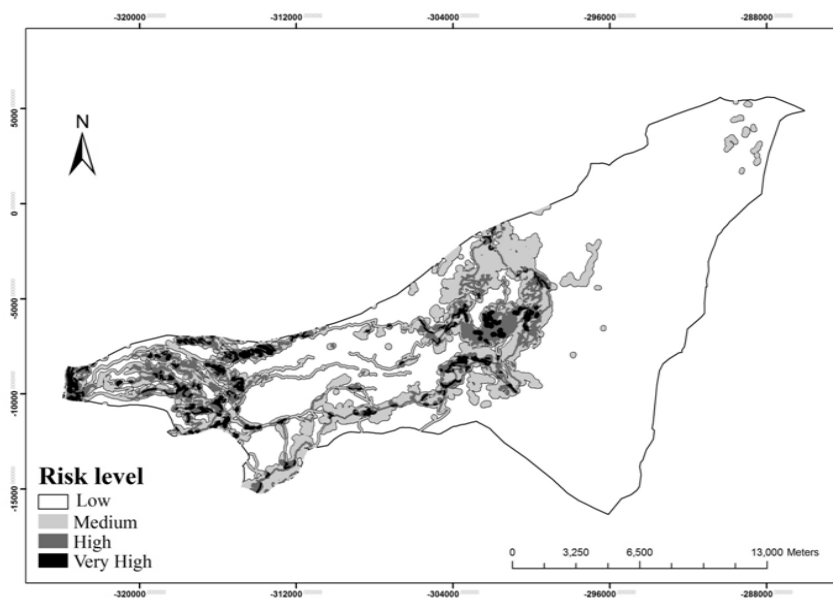


Figure 8. Distribution of Anthropogenic Factor in NIW.

Zones with very high risk in the NFFRM and the HFFRM are zones where factors influencing FFR were combined together. Favorable climatic conditions, fuel type, soil characteristics and topographic nature, in addition to anthropogenic interference, can lead to a higher level of FFR.

Climatic factors: a relatively high temperature (22-26°C) is found in more than 80% of the study area, thus conferring this factor with an additional risk for fire occurrence. Whereas the wind is found with very high speeds for only 53% of the study area, it is localized at high altitudes (> 1000m) thus lowering its effect. As for the exposure, 14% of the NIW is exposed to southern exposure and confined with a higher risk compared to the northern ones.

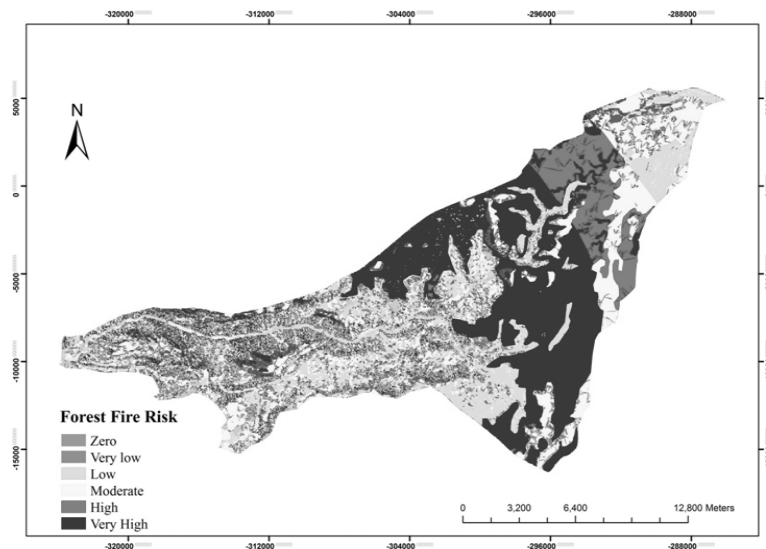


Figure 9. Hazardous forest fire risk map for the NIW.

Topographic factors: a great section of terrain (43-63%) in the NIW is found with a sloping and steep slope. However, 75.85% are located between 1000 and 2650m altitude which contributes in decreasing the forest fires risk.

Fuel factor: the fuel influenced the risk according to different type and density found in the NIW. Hence, 13% of the forest trees are coniferous trees (where 45% are with high density), 31% are broadleaved trees (where 15% are dense), 27% are herbaceous (where 23% are dense) and 36% are shrubs vegetations.

Soil factor: 7.15% of the NIW are soils with a high content in organic matter (5.9-8%) and 53% of the soils have a clay and clay loam texture, thus having a protective and preserving fraction of the water content in the soil to maintain soil water regime and land cover in the dry period.

Anthropogenic factors: 10% of forest surfaces are located within 50m of the roads and 17% are located within 100m of the agricultural areas, allocating for a higher risk. Hence among the 1.15% of urban settlement present in the NIW, 0.54% is an urban sprawl.

COMPARISON WITH PREVIOUS STUDIES

Comparing the results generated in this research with previous ones revealed that areas with low to very low risk in the previous work (Figure 11) shifted to areas of high to very high risk. Whereas areas with high and very high risk still exist but expanded to a larger surface. In addition, in the previous study bare rocks were excluded and considered as a zero risk area, but field survey showed that bare rocks are heavily covered with shrubs aggravating the risk.

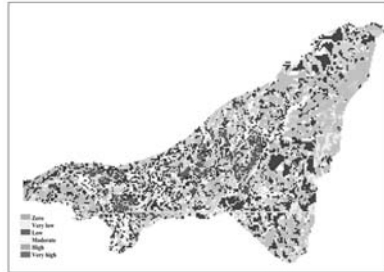


Figure 10. FFRM according to Faour *et al.* (2006).

DATA VALIDATION

Field visit to the NIW, on the 10th of July 2010, accompanied with a Global Positioning System tool made possible the delineation and the exact localization of a burned area in the NIW (Figure 11).

According to the GPS, this zone is located between the geographic coordinates: $34^{\circ}5'54''\text{N}$ et $35^{\circ}51'58''\text{E}$. According to the FFRM this zone is attributed with a very high risk. This helps primarily for data verification and emphasizes on the importance of taking necessary management actions to reduce the possibility of appearance of such risk.

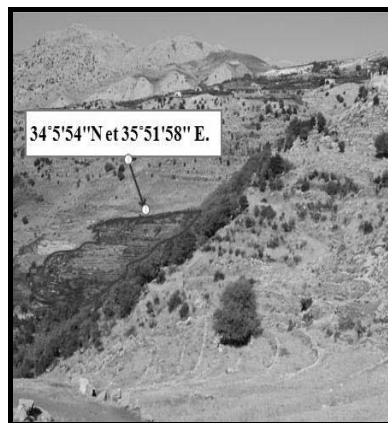


Figure 11. A recently burned area.

CONCLUSION AND RECOMMENDATIONS

This research showed an example of Lebanese areas witnessing forest fires and the optimal tools and methods to assess the natural risk and to quantitatively evaluate how it is affected once the human factor is integrated. For instance, with human interference, areas of

high risk increased 4 times, while areas of low risk decreased by 50% and those with very low risk almost disappeared. Hence, the results given by this research clearly showed an increase in the level of risk which is related to the urban expansion and socio economic activities in this area. This research showed again the reliability, effectiveness and the efficiency of using advanced new techniques in assessing natural risks. Moreover, the use of satellite images made possible the coverage of a large surface and consequently facilitated field work.

This research can be considered as a pilot study and can be applied on other Lebanese regions for a better forest management and preservation.

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