IJPAES
INTERNATIONAL JOURNAL OF PLANT, ANIMAL AND ENVIRONMENTAL SCIENCES
Volume-8, Issue-3 July-Sept-2018 Coden:IJPAJX-CAS-USA, Copyrights@2018 ISSN-2231-4490
Received: 24th June-2018 Revised: 25th July-2018 Accepted: 28th July-2018
DOI:10.21276/Ijpaes http://dx.doi.org/10.21276/ijpaes Research Article

ASSESSMENT OF FOREST FIRE RISK IN THE WATER SHED OF DAMOUR RIVER - LEBANON

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ABSTRACT: Forest fires are still considered as the biggest danger facing the Lebanese forests. The frequency and intensity of these fires are a real threat to the forest ecosystem sustainability, human life, ecosystem services and nationaleconomy. Fires occurring at the end of summer and followed by rainy seasonstriggeracceleratingsoil erosion.According to the forest fire maps produced by the Association of Forest Development and Conservation (AFDC)in 2007and that of Balamand in 2016, a large area of Lebanon is threatened by fires. Damour Watershed, with its forest coverage area of 32% was selected for this study due to its repetitive forest fire problems. This significant percentage of forests cover requires an appropriate management plan tailored for watershed preservation and restoration. Anticipation of the factors influencing the occurrence of fires and understanding the dynamic behaviors of those fires are critical aspects of management and preservation in the studied watershed. A particular evaluation of forest fire problems and decisions on solution methods can only be successful when a fire-risk-zone map is available. In this study, the geographic information system (GIS) and remote sensing resources were used to combine different forest-fire-causing factors anddelineate forest fire risk zones in Damour basin, one of the greenest watersheds of Lebanon.In the process, the influence of factors (i.e. climate, topography, vegetation and soil conditions) on forest fire occurrence was assessed and ranked.In order to test the findings, a comparative analysis was made with the actual records of fires for 3 years. The remote sensing forest fire risk model of the study area was found to be in strong agreement with actual fire-affected sites.
Key words*:* Forest fire, Remote sensing, Watershed management, Influencing factors.

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INTRODUCTION
Fire is an ecosystem disturbance that has short and long term impacts on ecological processes. It has an omnipresent role in land management and it is a frequent visitor to watersheds throughout the world [1].In many cases, forest fire is a part of the ecosystem natural processes, but it becomes a risk when its frequency or its intensity destroys the forest beyond the normal and threatens men and their activities. Therefore, to reduce the frequency of fire and minimize the damage, responsible authorities should be prepared, and a fire-risk map would be a much needed tool. Forest fire risk zones are locations where a fire is likely to start, and from where it can easily spread to other areas.

A precise evaluation of forest fire problems and decision on solutions can only be satisfactory when a fire risk zone mapping is available [2]. In Lebanon, forest fires are still major natural hazard problems. According to the Ministry of Environment's forest fires database, 129 fires occurred in 2007 resulting in 585 ha of burned forest areas [3]. Moreover, forest fires were catastrophicin 2007- 2008 and have destroyed the vegetative cover of over 4,200 ha of Lebanon's landscape[4]. The reason behind the forest fire ignition can be attributed to the negligenceof the local community and the authorities' mismanagement,more than by the well-known edaphic factors such as aspect, land cover, slope gradient and evapotranspiration.These factors were used for mapping of the forest fire prone areas in Lebanon [5]. Furthermore, the general public through its lifestyle or livelihood activities represents an important initiator of forest fires, mainly due to the lack of understanding of the importance and value of forests and of the negative impacts of fires [4]. Therefore the damages from those fires were large and they reduced large amounts of the forest cover in a relatively short period of time. The increasing in forest fires events also raised concern at the national and international levels that they could lead to total eradication of forests if radical steps were not taken to solve the problem [6]. The effects of this forest destruction have led to forests fragmentation and loss of the forest ecosystem services, which in turn has had a devastating impact on the livelihoods of local communities. Satellite remote sensing has opened up opportunities for qualitative analysis of forests and related ecosystems at all geographic and spatial scales[7]. According to Souidi[8], special attention needs to be given to the water stress conditions of the vegetation, while the special knowledge of this stress remains a scientific challenge. Understanding the behavior of forest fire, the factors that contribute to making an environment fire prone, and the factors that influence fire behavior are essential for forest fire prevention[9].In this context, the aim of this research is to better understand forest fire risk and to anticipate the behavior of fires by using a well-defined methodological approach, and by applying advanced assessment techniques. The above was tested by analyzing different factors that influence forest fires making use of forest fire risk (FFR) maps ([2], [10]). Such maps will help forest department officials prevent or minimize the risk of fire initiation and propagation within the forest and be better prepared to initiate preventive measures before the fire and take proper action when fire breaks out[11]. The objectives of this study is to (1) evaluate the capability of RS and GIS techniques in detailed forest fire risk mapping and management, (2) estimate the percentage of area burned within the watershed caused by different natural factors and mismanagement, (3) estimate the burn severity and ground check the burn severity map, and (4) based on field survey,develop recommendations to mitigate the potential forest fire risk.

MATERIAL AND METHODS

Study Area

The study area in NahrDamour Watershed (NDW) is located in the occidental part of Chouf Casa in Lebanon. It covers an area of 333km2and it falls respectively between the following longitudes and latitudes: 35 26 33.66°E - 33 42 01.09°N; 35 34 34.83°E - 33 36 35.72°N; 35 46 02.32°E - 33 48 55.54°N [12]. The elevations in this watershed range from 0to 2000 m. In Damour watershed, the agriculture land cover represents 30% of the total area[13] followed by herbaceous vegetation (22%), forests (20.5%) dominated by *Pinus* and *Quercus*species and the rest are shrubs (13%) . This watershed is in danger due to the (1) land degradation in vegetation cover and accumulation of soil sediments from soil erosion causing a deterioration ofwater quality and decrease in rivers discharge, , (2) increase in population in the coastal stretch accompanied by an exacerbation of the harmful impact on the environment and (3) lack of resources management plans linked to the absence of any governmental solutions.

Physical Characteristics

In Damour watershed, the slope is sharp and steeply dipping seaward, with a gradient from east to west between 50-75 m/km (Figure 1). Abu El-Anin[14] classified the area into coastal plain, deeply incised valleys and highlands. This division depends on different altitudes, surface relief and rock mass distribution. Jurassic rocks constitute the major rock formation of the area, with Cretaceous rocks making the major rock bodies in this watershed. They occupy an area of about 304.5 km^2, which represents 91.6% of the total area. The dominant types of soil in this watershed were determined from the soil map of Lebanon established by Darwish[15& 18] at a scale of 1/200 000. The soil structure is mainly sub-angular blocky with a medium, sandy-clay texture. Soilsare enriched with organic matter (Figure 2) and have a weakly basic pH value (7.7) [16]. The climate is Mediterranean with annual precipitation rate ranging from 700 mm to 1400mm (Figure 3). The watershed enjoys a relatively moderate wind speed (10-20 km/h), which is almost dominantly from the West and Southwest directions. According to Na'ameh[17], the average annual rate of evapotranspiration in the watershed is 580 mm. Figure 4 shows the Map of ETP for Damour Watershed. The maximum temperature variation oscillates between 15 and 20° C in winter and between 28 and 35° C in summer [16].

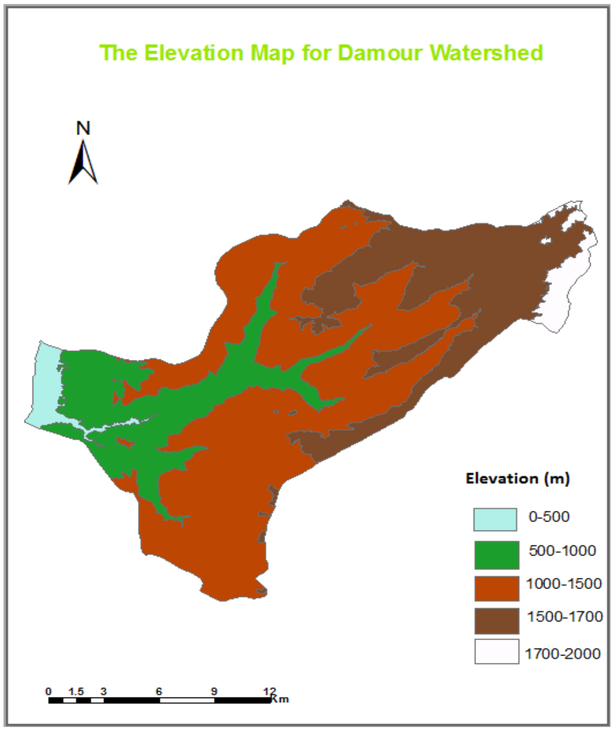

Figure 1: Elevation Map of NDW.

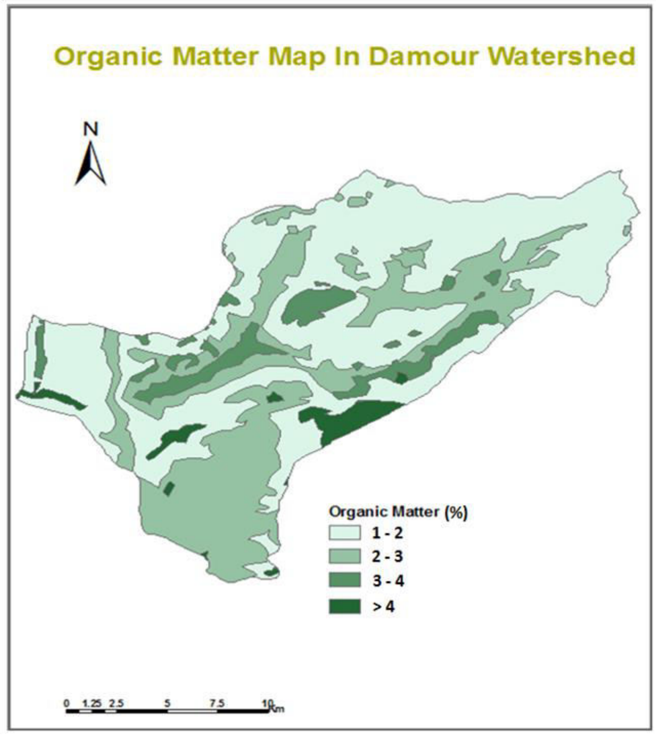

Figure 2: Organic Matter Map for NDW.

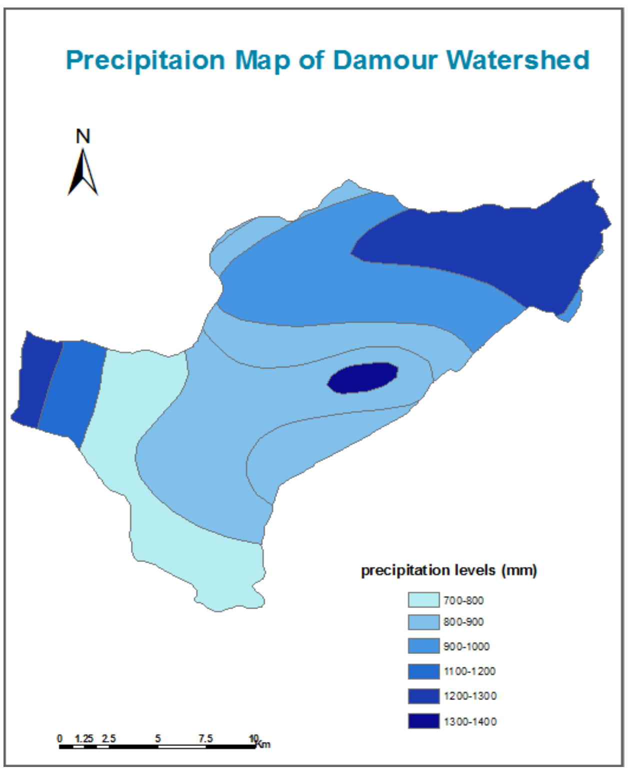

Figure 3: Precipitation Map for NDW.

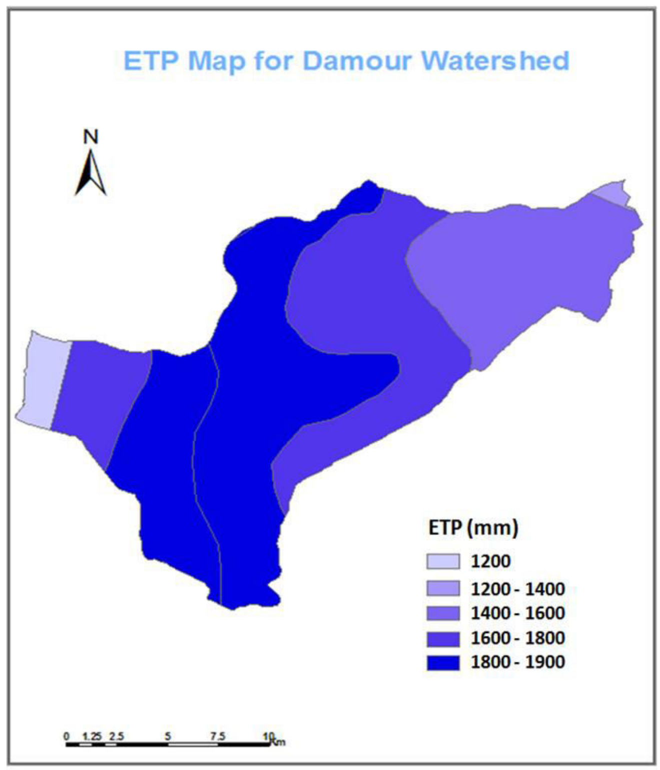

Figure 4: Evapotranspiration (ET) Map for NDW.

Data used

For the purpose of forest fire risk assessment, the team made use of the following materials and tools: (1) Land cover map scale 1/20000[18], (2) Soil Map of Lebanon scale 1/50000[19], (3) Topographic map of Lebanon scale 1/20.000[19] (Directorate General of Geographic Affairs), (4) Climatic Records from the CAL and LARI ([20],[21],[22]), (5) GIS (Geographic information system) software: ArcGIS 9.3 and data manipulation for FFR assessment: (Available Statistical Records from 2003, 2005, 2007 for the fire occurrence in NDW).

Forest Fire Risk Map (FFRM) analysis

DEM (Digital Elevation Model), elevation, slope, and aspect were extracted from the topographic map (scale 1/20000). DEM are created from the interpolation of digitized contour lines. Then the DEM has been used to generate the maps of elevation, slope gradient and slope aspect. Fuel type and density were delineated from the updated land cover map of Lebanon 2005 (scale 1/20.000) using GIS techniques accompanied with field validation for accurate results. Soil depth, texture and organic matter content for NDW were extracted from the soil map of Lebanon (scale 1/50,000). Satellite images were processed, for preparing different thematic maps like land cover, and vegetation mapping etc. using ArcGIS 9.3 software.

Considering all these factors, satellite images were added to a common data base and further processed to produce the Forest Fire Risk Map. The burnt area estimation was carried out using satellite images from years 2003, 2005 and 2007. The statistical data was collected also by visiting burnt areas to produce then a map showing the burnt areas in these years to compare it with the Forest Fire Risk Map. This comparison is made to test the precision and effectiveness of the model, with its different five classes ranging from very low to very high. Figure 5 represents the different tools used in Forest Fire assessment and the generated materials. The data of different factors was extracted from the Topographic, Land cover and soil Maps using GIS software (ArcGIS 9.3). The Data of each factor was gathered in the Attribute table after being a shape file for easy representation as a Map. The product assessment is the common data base of all factors which after processing in the software will generatethe Forest Fire risk Map product assessment data which also will be presented as a Map.

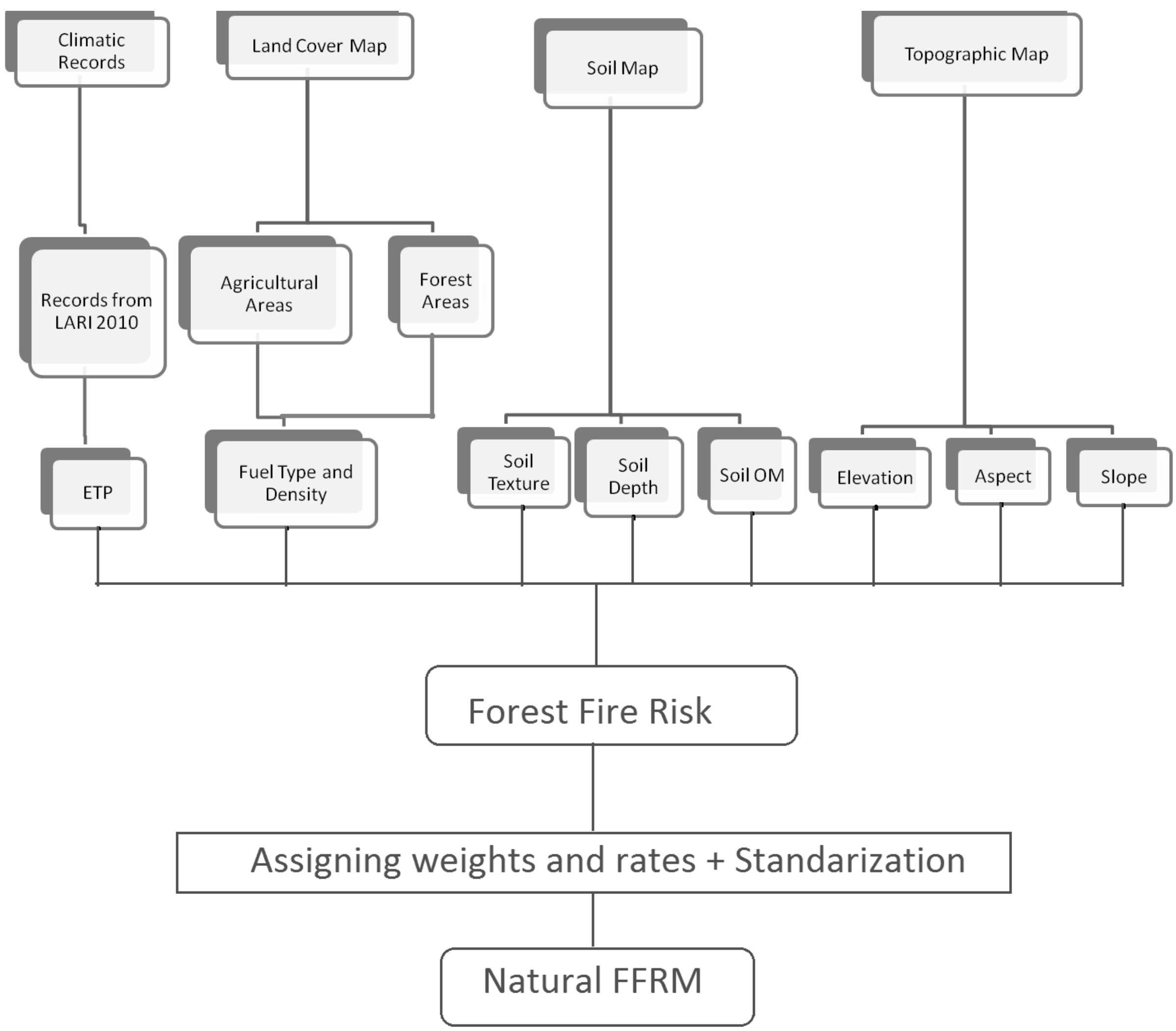

Figure 5 Tools and Materials used for Forest Fire Risk Mapping

Data Manipulation

Forest fire influencing factors give the input information which reveals the parameters favoring the fire risk through computation and other mathematical operations in the subsequent GIS analysis to achieve effective conclusions by indicating the weights in the fire risk in NDW and rating system. After determining the influence of each factor on forest fire risk, the different classes of each factor were given suitable ratings. A higher rating indicates that the factor has a high degree of influence on the fire risk in an area. The method here is based on the calculation of the total effect of each factor that can affect the other factors. The weights are classified consequently, "3" for the factor that have major effect on another one, "2" for a moderate effect and "1" for the minor one.

As for example topography has one major effect on soil, one moderate effect on fuel and one minor effect on climate. Thus the topographic weight is: 3(1) + 2(1) + 1(1) = 6.

The percentages of weights are presented in Table 1. The latter revealed that the climate is the most affecting factor due to its high influence on other factors since it has three major effects. Topography is ranked the second, the fuel is the third and soil factor is the fourth.

During analysis, Climate revealed the highest weight being an important factor which provides the suitable environment for fire propagation. High temperature in high evapotranspiration conditions plus high wind speed all together are the most causative factors for fire spread and behavior. Slope (topography), which does not necessarily influence the probability of an ignition but has a strong influence on the behavior of fire, revealed the second highest weight. The different slope classes were rated according to the likelihood that a fire ignited on the slope will spread. In addition to influencing fire behavior, slope also plays a role in the consequent suppression operation. Fuel type reveals the third highest weight because even though an environment may be favorable to fire, a forest fire cannot occur unless inflammable material is present. Each class of forest type was rated according to its composition of species. Soil reveals the fourth highest weight since organic matter, depth and texture of the soil precondition the soil water holding capacity which can support the vegetation cover during the long dry summer season. The Surface water body, which falls under no fire risk zones, has been masked from the final map.

Table 1: Effects of each forest fire factor that can affect the other factors, with evaluation and calculation of the weight of different factors affecting fire hazard and yielding forest fire risk.

		The affected factors[1]						
	Factors of forest fire risk	Climate	Fuel type	Topography	Soil	Calculation	Total	Weight %
Effect of	Climate		3	3	3	3(3)	9	40.9
	Fuel type	1		-----	3	1(1)+3(1)	4	18.18
	Topography	1	2		3	1(1)+3(1)+2(1)	6	27.27
	Soil	-----	3	-----		3(1)	3	13.63
	Total						**22**	**100**

[1]Major: 3; Moderate: 2; Low: 1

Table 2: The table represents the weight of each factor and the rate of the corresponding divisions.

Factor	Weight	parameter	Weight (a)	Division	Rate[2] (b)	Product assessment (a x b)
Climate	40.9	ETP[1]	40.9	< 1200	1	40.9
				1200-1300	1.25	51.125
				1300-1400	1.5	61.35
				1400-1500	1.75	71.575
				> 1500	2	81.8
Topography	27.27	Elevation	9.09	<500	2	18.18
				500-1000	1.75	15.90
				1000-1500	1.5	13.63
				>1500	1.25	11.36
		Slope	9.09	<10	1	9.09
				10-20	1.25	11.36
				20-30	1.5	13.63
				30-60	1.75	15.90
				>60	2	18.18
		Aspect	9.09	Flat	2	18.18
				North	1	9.09
				Northeast	1	9.09
				East	1.25	11.36
				Southeast	1.75	15.90
				South	1.5	13.63
				Southwest	1.75	15.90
				West	1.75	15.90
				Northwest	1	9.09
Fuel	**18.18**	Agriculture	6.377	Field crops in small/medium Fields	1	6.377
				Field crops in large fields	1	6.377
				Abandonment agriculture land	1	6.377
				Olives	1.5	9.565
				Vineyards	1	6.377
				Fruit trees	1	6.377
				Citrus Fruit Trees	1	6.377
				Protected agriculture	1	6.377
		Forest	11.8	Dense pine forest	2	23.6
				Dense broad leaved wooded Land	1.75	20.65
				Dense mixed wooded land	2	23.6
				Clear coniferous forest	2	23.6
				Clear broad leaved wooded Land	1.75	20.65
				Clear mixed wooded land	1.75	20.65
				Scrubland	1.5	17.7
				Scrubland & dispersed bigger Trees	1.5	17.7
				Burnt wooded land	2	23.6
				Medium Dense herbaceous vegetation	1.5	17.7
Soil	**13.63**	Texture	4.089	Coarse	2	8.178
				Medium	1.75	7.155
				Medium Fine	1.5	6.133
				Fine	1.25	5.111
				Very fine	1	4.089
		Depth	5.45	< 10	2	10.9
				10 – 50	1.75	9.537
				50 – 100	1.5	8.175
				100 –150	1.25	6.812
				>150	1	5.45
		Organic Matter	4.089	< 0.5	2	8.178
				0.5 -1	1.75	7.155
				1.0 – 2.0	1.5	6.133
				2.0 – 3.0	1.25	5.111
				> 3.0	1	4.089

[1]ETP: evapotranspiration. [2]Rate: 1 (Very Low), 1.25 (Low), 1.5 (Moderate), 1.75 (High), 2(Very High).

Factors weighting

The weights of the factors are equally divided between the parameters. For example, the three Topographic parameters were given an equal weight (27.27 /3=9.09). According to the Fuel, the weights were divided according to their percentages; where Forests cover 33.5% of the watershed, where Agricultural lands are less widespread 30%.
Moreover, the weight of the soil is divided among the depth, texture and organic matter according to their percentages respectively; 40%, 30%, 30%. In order to form the risk model all the above parameters were quantified according to their influence in provoking a fire. For this reason, the parameters are separated in classes; first class represent very low fire risk and last class very high fire risk, the divisions were rated from 1 to 2 (very low to very high) to evaluate their influence (Table 2). The product assessment is equal to weight times rate. It's given by the GIS software and it varies between 4.089 (corresponding to the lowest risk) and 21 (corresponding to the highest risk). This interval is divided into 5 classes as shown in table 3.

Table 3: Classes of Risks for Forest Fires in the NDW.

Class	Product Assessment	Categories
I	4 – 9	Very Low
II	9 – 11	Low
III	11 -14	Moderate
IV	14 – 18	High
V	18 – 21	Very High

RESULTS AND DISCUSSIONS

Fire Risk Map in NDW

The overlying/merging of the layer factors together in GIS software results in a map with different polygons indicating the level of risk for forest fire from low to very high (Figure 6). A large part (28.547%) of NDW localized in lower and middle of the basin is characterized as high risk for forest fire. Another significant part of the basin area, where the majority of forests, shrubs are located is attributed to a very high risk (20.5%). A percentage of the area (28.463%) is classified as moderate risk. Moreover, a slightly smaller area (13%) is characterized by a low risk and only a small area (9.48%) has a very low risk. In comparison with the state of forest fires risks study conducted in Nahr Ibrahim watershed (NIW) by Assaker[10]. A larger area (48.66%) classified as high risk was shown in NIW, almost the double of the area of NahrDamour watershed (28.547%) while the very high risk area (20.5%) and the moderate risk (28.463%) in NDW are much larger than that of NIW (5% and 7% respectively). In general, the NIW is characterized by a higher percentage of low and very low risk areas (40%) compared to NDW (20%). As a conclusion, both watersheds seem to be subjected to almost similar high and very high forest fire risk percentages (53.66% NIW; 49% NDW) which reveal the high vulnerability of Lebanese watersheds to forest fire risks. The high vulnerability of the NDW to forest fires could be explained by several endemic biotic and abiotic factors. For instance, the NDW witness a high risk and occurrence of forest fire since evapotranspiration was found to be high (> 1500 mm) in more than 75% of the watershed (Figure 4).In addition to that, the burned areas were shown to be located in zones of a high solar radiation that represent about half of the NDW (31.5% + 17.4% = 49.9%), accordingly the western aspect slopes and flat slope areas are the more receiving higher proportion of solar radiation. Pine forest and dense wooded lands seem to be the most affected vegetation types. Finally, soils with low organic matter content, low depth and medium texture seem to be the sites the most triggering natural forest fires. Areas that showed all these characteristics were classified as high to very high risk in the final fire risk model.

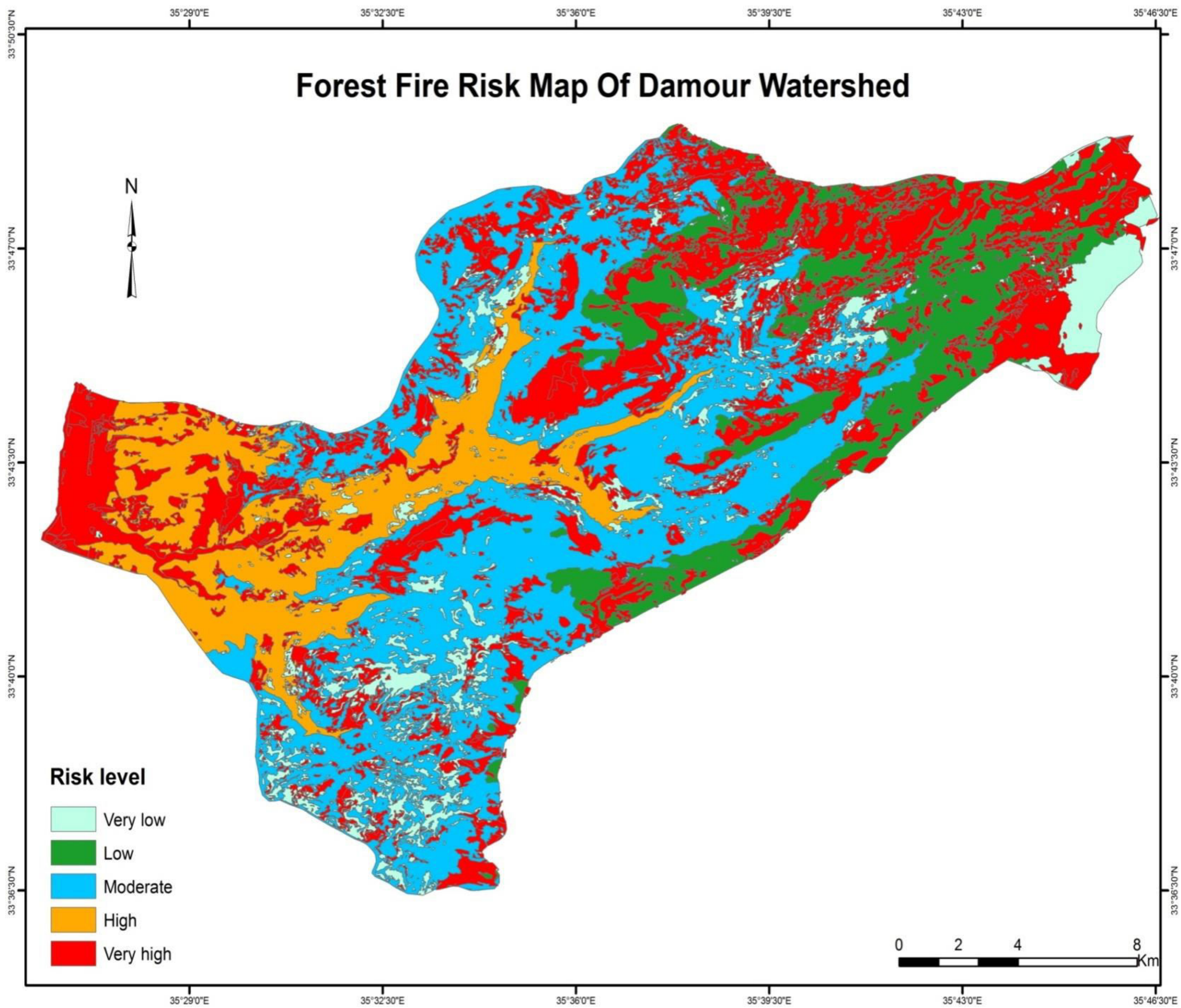

Figure-6 : Forest Fire Risk map for NDW.

Forest fire hazards in NDW

The results in Table 4 reveal that most of the burned area (54.78%) occurred in the very high risk region. The second high percentage of burnt areas was located within the high risk region (33.20%), then (11.5%) for the moderate risk region, and (0.5%) for the low risk region. It is worth noting that no forest fires have been recorded in the area classified in the FFRM as very low risk.

The produced map of burned areas (Figure 7) that occurred between 2003 and 2007 when merged with the data of fire risk map in NDW confirmed the predicted model.Therefore, a good applicability of the model can be considered as possible for the extrapolation to other Lebanese watersheds with the adaptation of classified factors to local physical and pedoclimatic conditions.

Table-4: Actual burnt areas (m2) according to fire occurrences in years (2003; 2005; 2007) comparedto Risk Class Model.

	Fire occurrence/ Per area							
Risk class Model:	**Small burnt area (m^2)**	**Medium burnt area (m^2)**	**Large burnt area (m^2)**	**% of each burnt area**			**Total burnt area in.each risk class model**	**%..of burnt area..in each risk class model**
				% S[1]	**%M[2]**	**%L[3]**		
Very low	0	0	0	0	0	0	0	**0**
Low	0	10900	46975	0	18.833	81.166	57875	**0.5131115**
Moderate	8100	328900	961175	0.6239	25.336	74.040	1298175	**11.509434**
High	35575	990275	2718600	0.950	26.446	72.603	3744450	**33.19776**
Very high	42175	1531200	4605350	0.682	24.781	74.535	6178725	**54.779695**
Total							**11279225**	**100**

[1]S: small; [2]M: medium; [3]L: large

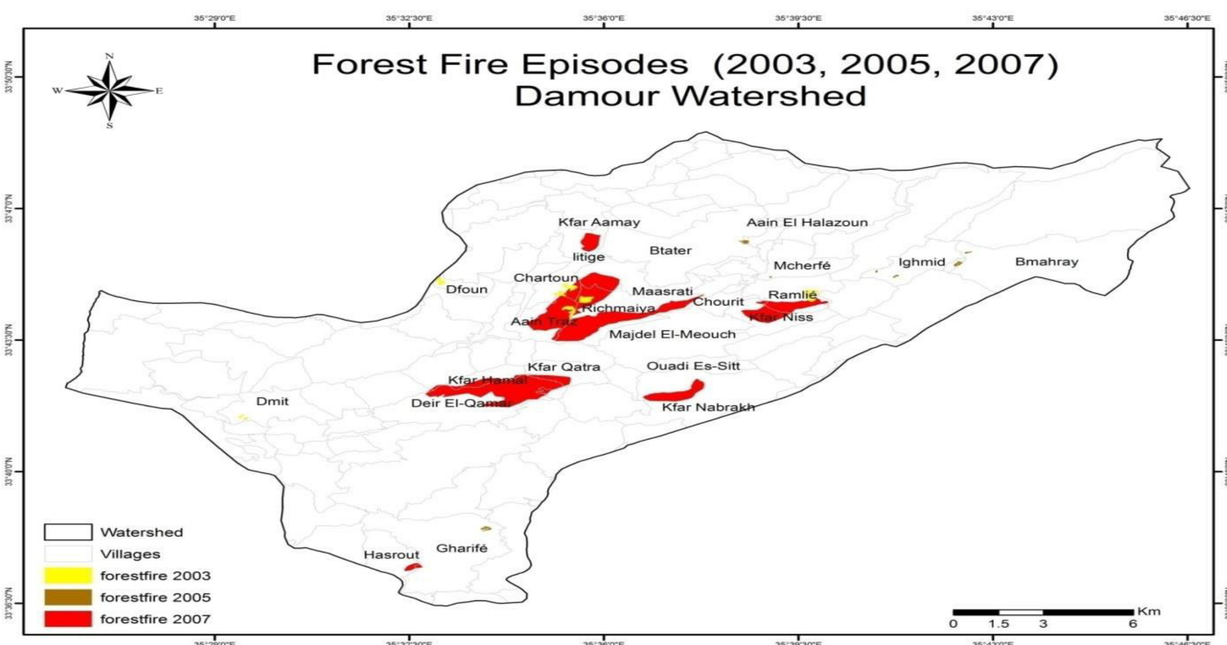

Figure-7: Map of Burnt areas in NDW (2003, 2005, and 2007).

CONCLUSION AND RECOMMENDATIONS

The general objective of this study is to model forest fire risk for NDW in Lebanon.The objective was accomplished since the fire risk model, identified appropriately the very high, high, moderate, low and very low forest fire risk areas. This model showed that: 20.25 % of the surface is under very high risk; 28.457% is categorized as high; 28.463% is classified as moderate risk and 22.48% is categorized as low to very low risk. On the other hand, the fire occurrence and thus the burned areas through years 2003, 2005 and 2007 showed high matchingwith fire risk model where 54.78% of the burned area occurred in the predicted very high risk region.In order to develop the fire risk model, two specific objectives were considered. The specific conclusions are summarized in the paragraphs below.

- To analyze the main factors related to forest fires in the study area, a question is raised, which of these factors are more related to fire through its relationship to burnt areas?

There was a clear effect of evapotranspiration where as it increases the risk increases. Topography has an important effect too. The burned areas are distributed mostly on steep slopes with western aspect and located in mid-elevations. Pine forest and dense wooded lands seem to be the most effected vegetation types. Finally, soils with low organic matter content, low depth and medium texture seem to be the sites the most triggering natural forest fires. Areas that showed all these characteristics were classified as high to very high risk in the final fire risk model.

- To validate the forest fire risk model. A question is raised: How accurate is the forest fire risk model developed in this study?

The validation of the static and fire risk model was successful for the study area, since 54.78% of burnt areas were located in the very high risk category. In summary, the GIS modeling applied in this study allowed the elaboration of an accurate forest fire risk model. Consequently, the obtained results are appropriate to elaborate future prevention strategies in the study area. Moreover, the simplicity of this model allows the incorporation of new variables in order to fine tune the model and improve the obtained results.In this perspective, and according to experimental results and field surveys, the following recommendations could be helpful to prevent the risk and enable sustainable forest management: (1) Establishing control towers with qualified forest guards to insure speedy interventions to combat the fire effectively, (2) securing the existence of vehicle passages to facilitate access for fire vehicles to the forest, (3) organizing training courses and regular simulations for municipal employees to help the Civil Defense, (4) cleaning forest waste, grass and branch remnants of trees aggravate fire, (5) building water tanks in the forests, (6) educating citizens about the negative effects of the fire on the environment and (7) organizing projects to manage forest by products and wood.

ACKNOWLEDGMENT

Special thanks to the National Council for Scientific Research, Centre for Remote Sensing for providing the support and the needed platform for this research.

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INTERNATIONAL JOURNAL OF PLANT, ANIMAL AND ENVIRONMENTAL SCIENCES

ISSN 2231-4490

International Journal of Plant, Animal and Environmental Sciences