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IDENTIFICATION OF FOREST FIRE RISK ZONES IN THE SARTAK WATERSHED, KURDISTAN REGION, IRAQ: GIS AND REMOTE SENSING APPLICATIONS

Sarkawt Ghazi Salar[1]

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Key words: AHP; Forest fire; Risk assessment; Geomorphology; Kurdistan Region; Iraq

ABSTRACT

The study area is located SE of Darbandikhan town, which is about 158 km far from the Sulaymaniyah city. In the present study, Analytic Hierarchy Process (AHP) based model and multiple parameter analysis are applied to identify forest fire risk zones in Sartak watershed using Geographic Information System (GIS) and Remote Sensing (RS) techniques. Satellite images are used to generate vegetation, roads, settlements and farmland maps. Slope gradient, slope aspect and elevation maps are derived from Digital Elevation Model (DEM). Whereas, the Tropical Rainfall Measuring Mission (TRMM) data is used to build up mean annual rainfall map of the study area. Forest fire risk zone map was delineated from the scored and weighted layers of all influencing factors on forest fire (vegetation, slope gradient, slope aspect, altitude, rainfall, distances from settlements, roads, international border and farmlands). As a consequence, the study area is classified into five forest fire risk classes. 16.16% of the total area falls in the category of very high risk, followed by 25.37%, 24.51%, 19.01%, and 14.95% in the categories high, moderate, low and very low, respectively. The results help and enable the institutions concerned with forests to set up appropriate fire-fighting infrastructure for the areas more prone to fire damage and exploit the geological and geomorphical situation of the study area to build a natural protection area.

تحديد مناطق مخاطر حرائق الغابات في حوض سرتك – إقليم كردستان – العراق: تطبيقات نظام المعلومات الجغرافية والتحسس النائي

سركوت غازي سالار

المستخلص

تقع منطقة الدراسة في الجزء الجنوب الشرقي من مدينة دربنديخان، التي تبعد حوالي 158 كم من مدينة السليمانية. في هذه الدراسة، تم الاعتماد على تطبيق طريقة التحليل الهرمي AHP و تحليل عدة عوامل متغيرة لتحديد المناطق الأكثرعرضة لخطورة حرائق الغابات في حوض سرتك باستخدام تقنيات نظم المعلومات الجغرافية والاستشعار عن بعد. تم رسم خرائط الغطاء النباتي والطرق والمستوطنات والمزارع بالاعتماد على مرئيات الاقمار الصناعية. تم اشتقاق خرائط الانحدار واتجاه الانحدار والارتفاعات من على نموذج الارتفاع الرقمي (DEM). في حين استخدمت بيانات TRMM لبناء خارطة المعدل السنوي للأمطار لمنطقة الدراسة. تم تحديد خريطة مناطق مخاطر حرائق الغابات من الطبقات المعلوماتية الموزونة والمدرجة لجميع العوامل المؤثرة على حرائق الغابات (الغطاء النباتي، والانحدار، والجانب، والارتفاع، وهطول الأمطار، والمسافات من المستوطنات، والطرق، والحدود الدولية، والأراضي الزراعية). نتيجة لذلك، صنفت منطقة الدراسة إلى خمسة فئات من مخاطر حرائق الغابات. تقع 16.16٪ من إجمالي المساحة ضمن فئة المخاطرالعالية جدا ، تليها 25.37 و 24.51 و 19.01 و 14.95٪ ضمن فئات المخطر العالية، المعتدلة، المنخفضة

[1] Department of Geography, College of Education, University of Garmian;
e-mail: sarkawt.ghazi@garmian.edu.krd

والمنخفضة جدا على التوالي. هذه النتائج تساعد المؤسسات المعنية بالغابات في إنشاء البنية التحتية المناسبة لمنع ومكافحة الحرائق في المناطق الأكثر عرضة للضرر واستغلال الاوضاع الجيولوجية والجيومورفولوجية لبناء وجعل منطقة الدراسة منطقة محمية طبيعية.

INTRODUCTION

Vegetation is an important factor in geomorphology (Istanbulluoglu and Bras, 2005). Numerous studies demonstrated the influence of vegetation on surface geomorphological processes. Gyssels and Poesen (2003) focused on the impact of vegetation characteristics on soil erosion rates by concentrated overland flow, whereas, Puigdefábregas (2005) revealed the role of vegetation patterns in structuring runoff and sediment fluxes in drylands. Moreover, Saco *et al*. (2007) and Branealeoni *et al*. (2003) investigated the relationships between geomorphology and vegetation patterns. Whereas, Zhou *et al*. (2008) produced a vegetation cover map to quantitatively evaluate soil loss by erosion. Ruiz-colmenero *et al*. (2013) revealed that soil degradation is a cumulative process, which depends on factors such as crop management, vegetation cover, climate, topography and soil physical properties. In addition, Fox *et al*. (2006) studied the forest fires impact on soil erosion and runoff process due to destruction of vegetation cover after a forest fire.

Forest is a major natural resource, which plays an important role in maintaining natural ecological balance. The health of a forest in any given area is a true indicator of the ecological conditions, habitat composition and species richness prevailing in that area (Pourghasemi *et al*., 2014). According to Jaiswal *et al*. (2002), forest fire risk zones are locations where a fire is likely to start, and from where it can easily spread to other areas and fire is the greatest enemy of standing vegetation and wild animals. Chuvieco and Congalton (1989) defined the fire risk as the union of two components of fire hazard and fire ignition. The overall risk depends on the fuel and its susceptibility to burn (i.e., hazard) and on the presence of external causes (both anthropogenic and natural) leading to fire ignition (Vadrevu *et al*., 2009). Forest fires can cause substantial damage to natural resources and human lives regardless of whether it is caused by natural forces or human activities (Dong *et al*., 2005). Fox *et al*. (2006) stated that forest fire impacts the earth's surface degradation through soil erosion and runoff processes. The frequent occurrence of fires is one of the prime contributors to the problem of forest degradation. Specifically, fires are among the greatest threats to standing vegetation and wild animals (Jung *et al*., 2013). Forest fires are considered to be a potential hazard with physical, biological, ecological and environmental consequences. Forest fires constitute an ongoing threat in areas with an urban wild land interface (Soto, 2012). According to Keane *et al*. (2010) and Freitas *et al*. (2017), the increasing of human activities, developments and human settlement comes an increased risk to human life and property as severe wild fires become common.

Many researchers like Chuvieco and Congalton (1989), Jaiswal *et al*. (2002), Dong *et al*. (2005), Fox *et al.* (2006), Kalabokidis *et al.* (2011), Liu *et al*. (2012) and Amalina *et al.* (2016) have studied forests fires through models to identify and map the risk zone using Geographic Information System (GIS) and remote sensing (RS) techniques. Verde and Zezere (2010) state that wildfire prevention is a vector for model development, driving efforts for a better prediction of those conditions that favor fire spread, or to allow for a quicker wildfire detection. New technologies of geo-informatics (e.g., global positioning systems, digital mapping, GIS, and spatial decision support systems) and electronic data capture and transmission of information from remote locations (e.g., remote sensing, remote automatic weather stations, automated detection sensors, etc.) have strong potential to contribute to more effective organization for environmental protection (Kalabokidis *et al*., 2011).

Plantation and natural forests preservation and protection have been taken into consideration and received visible interest by Kurdistan Regional Government (KRG), but the forest fire may undermine these efforts in the study area, which has been subjected to many forest fires in the past years. The objective of the present study is to delineate forest fire risk zones in Sartak watershed through integration of GIS and RS techniques. The forest fire risk zone mapping enables the decision makers to avoid and control forest fire with proper treatment.

THE STUDY AREA

Sartak watershed is located within the eastern side of middle Sirwan river basin as a sub-basin near Iraq – Iran boarder. It lies between longitude (45° 30' – 45° 55') E and latitude (34° 30' – 34° 55') N, about 80 Km southeast of Sulaimaniyah city and 33 km south of Halabja town (Fig.1). It covers an area of more than 26.5 Km^2. It is located in a semi-arid climate zone with a mean annual rainfall of 667 mm. The study area is surrounded by several mountains like Bamo and Khush, which are crossed cut by Sartak gorge. The highest elevation of the watershed is located at the eastern part (1629 m a.s.l.) and this altitude decreases toward southwest where the elevation reaches (453 m a.s.l.). In addition to presence of many settlements, there are farmland and agriculture activities in the area. It is a touristic area that attracts huge number of tourists annually during spring season due to its attractive natural scenes. Forest comprises important natural resources in the study area and fire forms a real problem and risk on the forest. Hence, the goal of this work is to identify the forest fire risk zone.

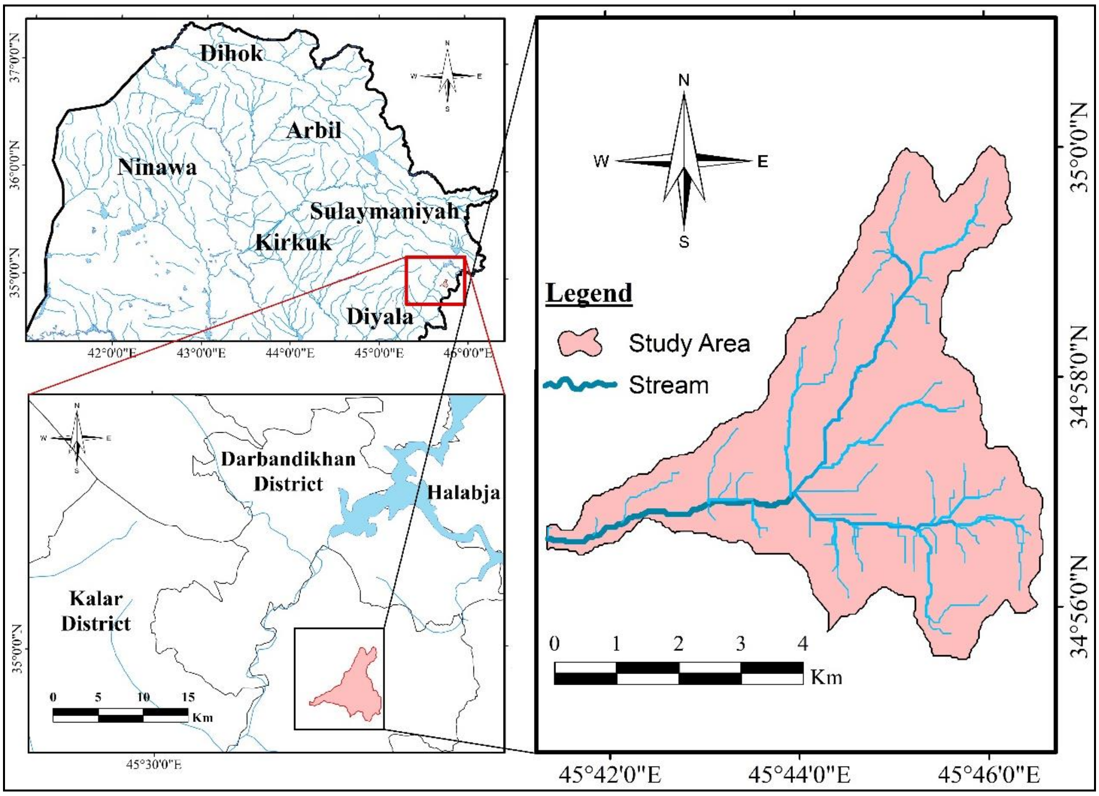

Fig.1: Location map of the study area

MATERIALS AND METHODS

▪ **Work procedure**

In the present study, a GIS and RS-based model and multiple parameter analysis has been applied to identify forest fire risk zones in Sartak watershed. In order to reach this objective, five main steps have been done:

– **Step 1:** Gathering available information about the subject, depending on literature review and field work, in order to identify the factors influencing forest fire risk zone. This review revealed the influence of 8 main factors: vegetation, slope gradient, slope aspect, elevation, settlement, road, farmland and rainfall.

– **Step 2:** Collecting available and necessary data about the study area, represented by ASTER GDEM (30 m resolution) and a set of Landsat images, which were acquired in 1984, 2013, 2015, 2016 and 2017 as shown in Fig. (2) and Table (1).

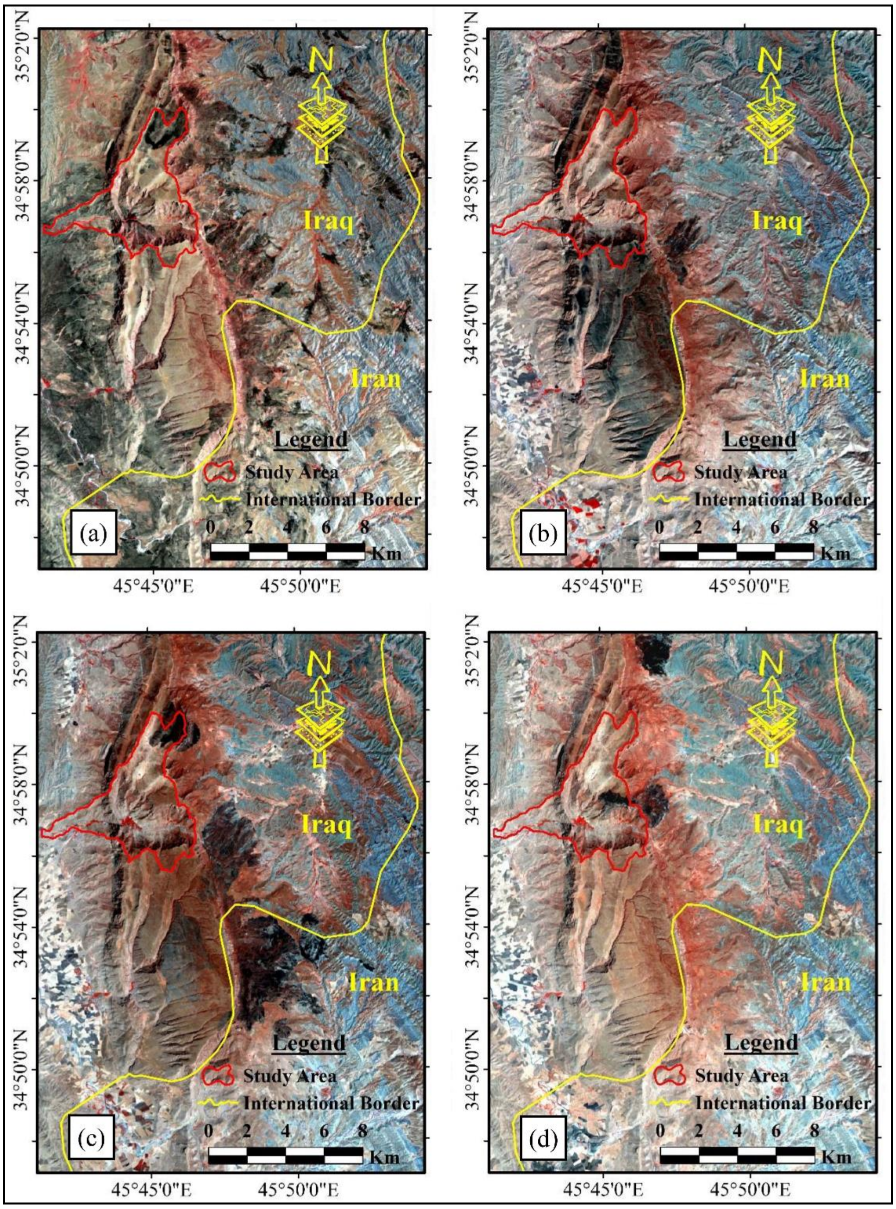

Fig.2: Color composites of Landsat images; **a)** 1984 RGB-432; **b)** 2013 RGB-532; **c)** 2015 RGB-532 and **d)** 2017 RGB-532

Table 1: Data used in this study and their sources

Data	Source	Thematic Layer	Resolution
Landsat Images for: June 2016 10/ 07/ 1984 12/ 09/ 2013 17/ 08/ 2015 21/ 07/ 2017	USGS https://lpdaac.usgs.gov	Vegetation	30 m
		Settlements	30 m
		Roads	30 m
		Farmlands	30 m
		International border	30 m
		Burnt area	30 m
DEM	USGS	Slope gradient	30 m
		Slope aspect	30 m
		Elevation	30 m
TRMM Data	NASA	Rainfall	0.25°

– **Step 3:** Building thematic map for each factor from the Landsat image acquired in 2016.

– **Step 4:** Weighting, ranking and reclassifying each thematic map by integrated GIS and RS techniques using AHP method.

– **Step 5:** Mapping forest fire risk zones through overlying of the generated 8 thematic maps within GIS environment.

– **Step 6:** Validating the results with actual fire occurrence map compiled from Landsat images acquired in 1984, 2013, 2015 and 2017.

DATA PROCESSING

The identification and mapping of forest fire risk zone involve integration of the mentioned eight influencing factors as input data including vegetation, topography (slope gradient, slope aspect and elevation), rainfall, proximity to settlements, roads, farmland and international border. Each factor is mapped, ranked, weighted and reclassified as follow:

- **Vegetation Cover**

The main factor affecting the spread of a forest fire is the type and characteristics of the vegetation (Chuvieco and Congalton, 1989). Dong *et al.* (2005) and Guglietta *et al*. (2015) stated that fuel represents the material available for fire ignition and combustion. Vegetation cover in the study area is extracted from Landsat 8 image using normalized difference vegetation index (NDVI). Landsat image of 2016 (Table 1) is downloaded from USGS Earth Explorer website (http://earthexplorer.usgs.gov/). NDVI is useful index that reflects vegetation condition (Liu *et al*., 2012). NDVI index is calculated on the basis of the following equation:

$$NDVI = (NIR - RED)/ (NIR + RED) \quad \ldots\ldots\ldots \; 1$$

Where NIR (band 4) and RED (band 3) values are the infrared and red portion of electromagnetic spectrum respectively. In the present study the NDVI map is built using ArcGIS 10.3 and then the vegetation cover is extracted through NDVI values (Fig.3). The values of NDVI range from (-1) to (1) and its values for the vegetation cover in the study area is (> 0.2). According to NDVI values and vegetation density, the vegetation cover is classified into low, medium and high classes. The first class is highly sensitive, whereas the second and third classes are relatively less sensitive to burning.

- **Rainfall**

Rainfall is another important influencing factor on forest fire due to its effect on fuel moisture and soil moisture (Pourtaghi *et al*., 2014). The higher rainfall values contribute to high moisture in fuels, thus they represent a negative indicator of fire spread, whereas, low amounts of rainfall account for high fire potential (Vasilakos *et al*., 2009 and Vadrevu *et al*., 2009). We have used the mean annual rainfall for the period 1998 – 2017. Its values are ranging between (540 – 580 mm) increasing northward. It is classified into 5 classes (Fig.4).

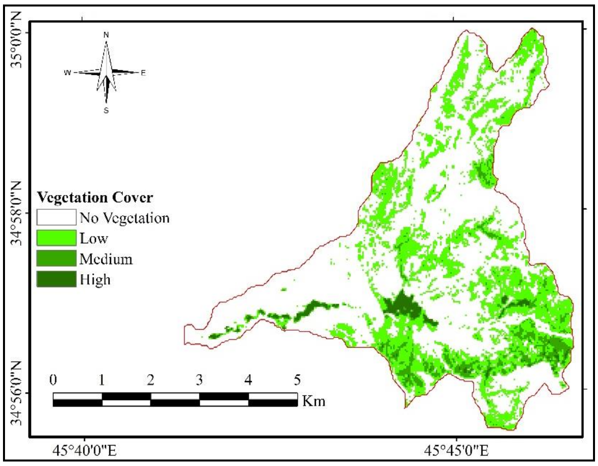

Fig.3: Map of vegetation cover

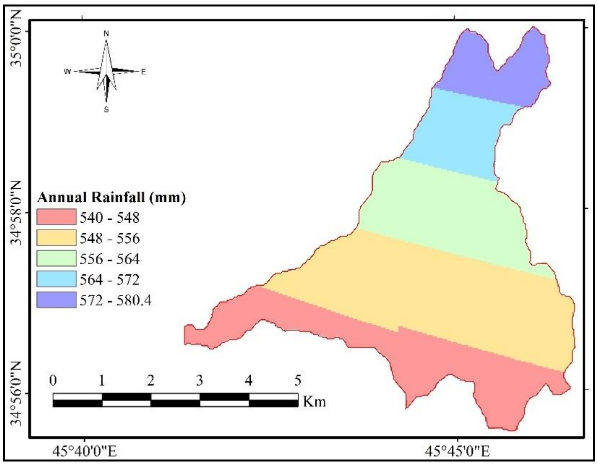

Fig.4: Map of annual rainfall

Climate is greatly influenced by landform and landscape (latitude and topographic features) (Wright, 1961). The highest mean annual rainfall is located in the northern part of the study area with 580 mm/yr and the lowest is in the southwest part with 540 mm/yr. The average annual rainfall is around 550 mm/yr. Darbandikhan Meteorological Station records show that the mean annual air humidity of the area ranges between 24% in July and August and 66% in January, and the mean monthly temperature is between 8.5 and 33.88 °C. Fires frequently take place during the dry period in June, July and August (summer season) due to availability of dry grass at forest floor that provides fuel for ignition.

- **Topographic Factors**

Topography is an important physiographic factor among fire risk factors. it is an important landscape feature in predicting the occurrence and spread of fire (Dickson *et al*., 2006 and Dong *et al*., 2006). It is one of the main factors included in any fire hazard rating system (Chuvieco and Congalton, 1989). Literatures review (e.g., Chuvieco and Congalton, 1989; Liu *et al*., 2012 and Jung *et al*., 2013), revealed that slope gradient, slope aspect and elevation have great role in fire risk rating system. Slope gradient is an important geomorphic factor that impact on forest fire and considered the critical factor. Fire travels most rapidly up-slope and least rapidly down-slope (Jaiswal *et al*., 2002 and Vadrevu *et al*., 2009). Hence, the forest fire flammability has direct proportionality with slope steepness. Liu *et al*. (2012) state that slope gradient influences the spread speed of grassland fire. The grassland fire spread accelerates with slope increase. According to Chuvieco and Congalton (1989), steep slopes increase the rate of spread because of a more efficient convective preheating and ignition by point contact. In the present study, the slope map is classified into five classes which are weighted, scored and reclassified in ArcGIS environment (Fig.5).

Slope aspect plays significant role in the identification and mapping of forest fire risk zones. It has the strongest effects on the most number of fuel model parameters and impacts the weather condition on slope faces, especially, temperature and wind orientation that in turn affect the speed of fire spread (Perry *et al*., 2011 and Pierce *et al*., 2012). According to Pourghasemi *et al*. (2014) and Adab *et al*. (2013), slope aspect directly affects the amount of solar radiation and then the temperature at different aspect is quite discrepant. At the slope aspect that receives more sunlight radiation, the air dryness degree is larger and the probability of forest fire occurrence increases (Hai-Wei *et al*., 2004). In the present study, slope aspect is categorized into four classes; north, east, west and south. Sunlight is mostly reflecting on slopes facing south and southwest sides of the study area (Fig.6). This causes more dryness on ground surface at these areas and hence they are more susceptible for fire spread.

Elevation, on the other hand, is a crucial physiographic variable associated with temperature, moisture and wind (Zhang *et al*., 2014). Fire behavior trends are less severe at higher elevations due to higher rainfall (Verde and Zezere, 2010 and Keane *et al*., 2010). Hai-Wei *et al*. (2004) stated that in mountainous areas with increased elevation and precipitation, the possibility of forest fire occurrence is less due to increase of humidity in association with decrease of air temperature and evaporation. In the present study area, the elevation ranges from (453) m to (1629) m above sea level and is classified into five classes (Fig.7).

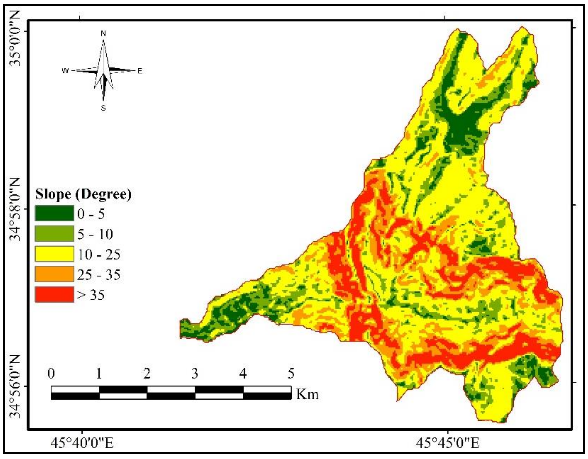

Fig.5: Slope map

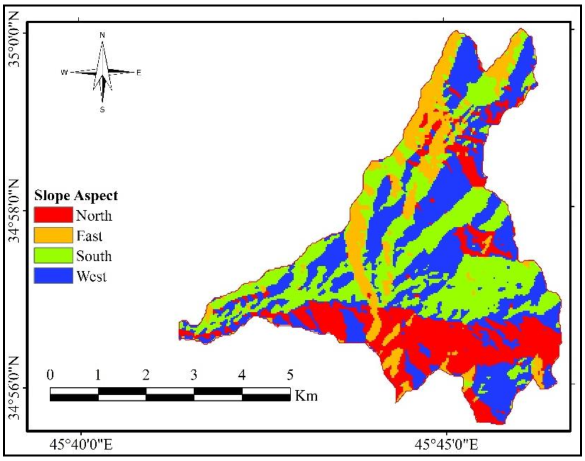

Fig.6: Slope aspect map

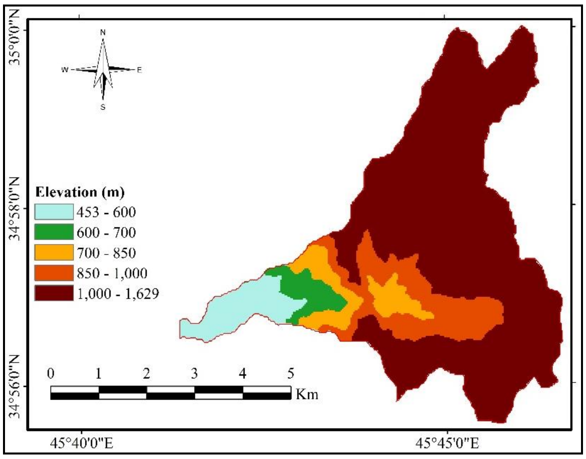

Fig.7: Topographic elevation map

- **Anthropogenic Factors**

Anthropogenic factors mean the role and effect of human, as an agent, on forest fires. Human activities play visible role on forest fire, where human-caused fires account for the most disasters, such as smoking, cultivation, arson, camping, etc. (Liu *et al*., 2012). The fire risk at a particular area, due to human, is based on the distance from anthropogenic structures and activities (Kalabokidis *et al*., 2011). Forest areas near the settlements are more prone and have higher probability for forest fire as a result of higher human activities (Adab *et al*., 2013). Statistical analysis showed that grassland fires occurred frequently nearby the residential point and rarely occurred far from them (Liu *et al*., 2012). In the current study, the settlements are represented by the villages within the study area which are mapped depending on Landsat 8 image and fieldworks. The distances from the villages are calculated, mapped, categorized, weighted, reclassified and ranked on the basis of their impact on forest fire (Fig.8).

Trail and road locations are also important factors in fire hazard mapping (Chuvieco and Congalton, 1989). The probability of forest fire risk increases with decreasing distance from roads. According to Bui *et al.* (2016), forest near roads have higher susceptibility to fires due to increase of human activities. The study area is crossed by many roads connecting the settlements with each other and also leading to Iraq – Iran boarder. In addition, these roads are used by a huge number of tourists during spring. The distance from roads is calculated, categorized into five classes, weighted and reclassified (Fig.9).

Farmland is as an important forest fires causative factor for extracting general forest fire ignition patterns, such as spatial distribution features (Han *et al*., 2003 and Vadrevu *et al*., 2009). It becomes the center of community activity because most of the villagers are farmers (Amalina *et al*., 2016) and hence, forest near farmlands have higher susceptibility to fire (Dong *et al*., 2005). Farmlands map is derived from Landsat 8 image and the distances from farmland are mapped, classified, reclassified and weighted (Fig.10).

International borders have impacts on forest areas through military actions due to possible political conflicts between countries and illegal trades, which may cause forest fires at both sides of the border, such as that occurred during (1980 – 1988) between Iraq and Iran. The war between both countries caused several forest fires in the study area, as recorded in satellites images of that period. Hence, the possibility of forest fire occurrence in areas nearer to the international border between Iraq and Iran is higher. The distances from international border are mapped, classified, reclassified and scored (Fig.11).

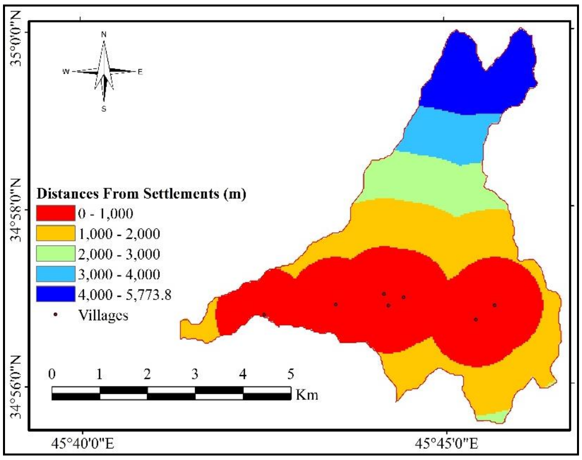

Fig.8: Map of distance from settlements

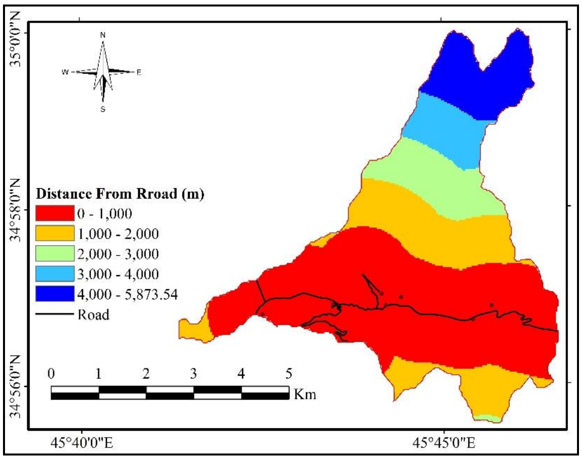

Fig.9: Map of distance from roads

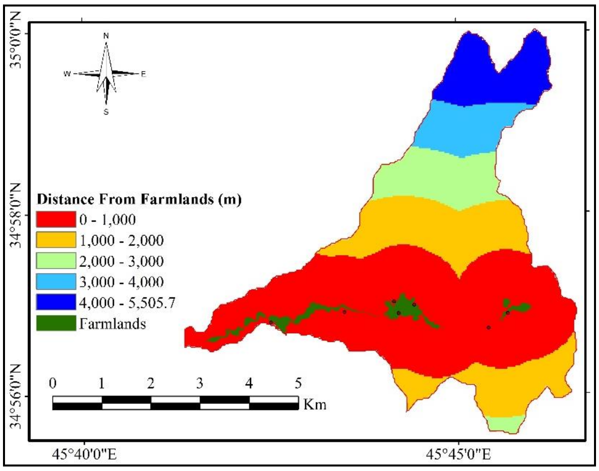

Fig.10: Map of distances from farmlands

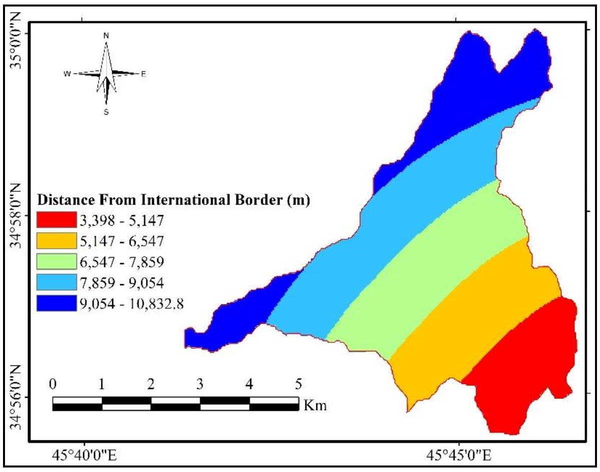

Fig.11: Map of distances from international border

- **Analytic Hierarchy Process (AHP)**

AHP is one of the GIS-based multi-criteria decision-making methods proposed by Saaty (1990) that combines and transforms spatial data (input) into a resultant decision (output). It assists in obtaining an appropriate solution over risk assessment for forest fire risk zone identification. The process involved the structuring factors selected in a hierarchy starting from the overall goal to criteria, sub-criteria and alternatives in successive levels. A verbal scale is used to enable the decision maker to incorporate subjective, experience, and knowledge in an intuitive and natural manner (Saaty and Vargas, 2012). Ratings are provided on a nine-point continuous scale (Table 2).

Table 2: The fundamental scale (Saaty and Vargas, 2012)

Intensity of Importance	Definition
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extremely strong importance

In the present study, AHP method is applied for the identification of forest fires risk zones in Sartak watershed depending on literature review using GIS and RS techniques. The available data and information are utilized as input data in GIS environment. In the current study, the results reported in literature by previous workers are used for selecting the factors influencing forest fires as input parameters for the e.g., Chuvieco and Salas (1996), GIRI and Shrestha (2000), Dong *et al*. (2005), Beverly *et al*. (2009), Vasilakos *et al*. (2009), Verde and Zezere (2010), Guettouche *et al*. (2011), Dimuccio *et al*. (2008), del Hoyo *et al*. (2011), Nasiri (2012), Jung *et al*. (2013), Eskandari *et al*. (2013), Sivrikaya *et al*. (2014), Pourtaghi *et al*. (2014) and Adab *et al*. (2015). These parameters are: vegetation cover, slope gradient, slope aspect, elevation, distance from settlements, distance from roads, distance from farmlands and rainfall. These parameters have been ranked, weighted and reclassified from the point of view of the above authors (Table 3). In this way, the weight of the feature class of individual parameter is assigned at a scale of (1 – 9). The assigned weights are based on the response of thematic layers to forest fire and literature reviews. Most of the of previous workers (97%) considered the forest as the most important layer in forest fire risk mapping and (84) % of them considered slope as the second most important effective factor. Whereas 78% of them suggested that slope aspect is coming after slope in its impact. Settlement and road layers more significantly affect the forest fire than the elevation and farmland layers. Hence, these factors are weighted and scored according to their impact weight (percentage) reported in the literature.

Table 3: Assignment of weight for the feature classes of individual parameter

Parameters	Factor % in Literatures	Weight	Class	Ranking	Risk
Vegetation	97	9	High	5	High
			Medium	3	Moderate
			Low	1	Low
Slope °	84	9	> 35	5	Very High
			25 – 35	4	High
			10 – 25	3	Moderate
			5 – 10	2	Low
			0 – 5	1	Very low
Slope Aspect	78	7	South	4	Very High
			West	3	High
			East	2	Moderate
			North	1	Low
Elevation (m)	63	5	453 – 600	5	Very High
			600 – 700	4	High
			700 – 850	3	Moderate
			850 – 1000	2	Low
			1000 – 1629	1	Very low
Distance from Settlements (m)	75	7	0 – 1000	5	Very High
			1000 – 2000	4	High
			2000 – 3000	3	Moderate
			3000 – 4000	2	Low
			4000 – 5773.8	1	Very low
Distance from Roads (m)	72	7	0 – 1000	5	Very High
			1000 – 2000	4	High
			2000 – 3000	3	Moderate
			3000 – 4000	2	Low
			4000 – 5873.54	1	Very low
Distance from Farmlands (m)	41	3	0 – 1000	5	Very High
			1000 – 2000	4	High
			2000 – 3000	3	Moderate
			3000 – 4000	2	Low
			4000 – 5505.7	1	Very low
Rainfall (mm)	25	1	540 – 548	5	Very High
			548 – 556	4	High
			556 – 564	3	Moderate
			564 – 572	2	Low
			572 – 580.4	1	Very low
Distance from international border (m)	Added to the model by the author	5	3.398 – 5147	5	Very High
			5147 – 6547	4	High
			6547 – 7859	3	Moderate
			7859 – 9054	2	Low
			9054 – 1083.8	1	Very low

RESULTS AND DISCUSSION

- **Fire-risk assessment**

It is well known that forests can absorb atmospheric carbon, maintain a certain degree of humidity in the atmosphere, regulate rainfall, create moderate temperature, retrain soil erosion, etc. Historical burns in vegetated, mountainous topography highlight the profound erosive potential of fire. Disturbance via fire can alter soil, bedrock, vegetation and hydrologic properties and induce geomorphic processes distinct from those occurring between burns (Jackson and Roering, 2009). Hence, spatial assessment of fire risk is very important to reduce the impacts of wild land fires (Pourtaghi *et al*., 2014).

In the present study, the assessment and analysis of the results are important for forest fire risk management; forest fire risk map enables the understanding of forest situation in the study area and becomes a fundamental base for decisions makers for different conditions. Based on equation (2), the forest fire risk map is obtained in GIS environment through integration of the fuel factor (vegetation cover), topographic factors (slope gradient, slope aspect and elevation) and anthropogenic factors (distances from settlements, roads, international border and farmlands).

$$FFRZ = \sum_{i=1}^{n} C_i w_i \quad \ldots\ldots\ldots\ldots\ldots \quad 2$$

Where, C_i: the value of criterion I, where i = list of criteria as in Table 3; w_i: is the weight of the criterion i (see Table 3); n: is the number of the criteria.

Accordingly, the study area is classified into five classes; very high, high, moderate, low and very low risk zones (Fig.12). The results show that the fire risk increases at the middle part. The spatial distribution of forest fire risk zones reveals that the very high and high risk zones are extending along the middle part of the study area, due to integration of high to very high risk weighting portions of the effective factors making this area more prone to forest fire than the other parts of the area. This zone is characterized by low elevation and proximity to human activities (settlements, roads, and farmlands), which are extending linearly from east to west. The exposure and vulnerability of forests to fire increase with high concentration of social-economic wealth and population (Liu *et al*., 2012).

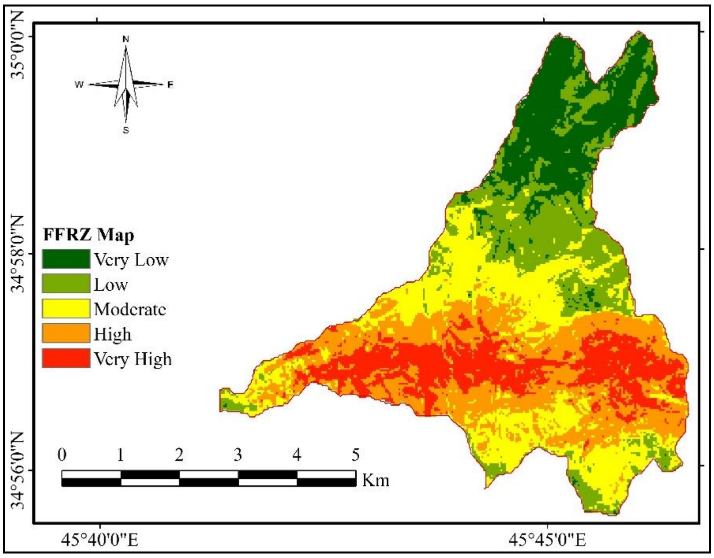

Fig.12: Forest fire risk susceptibility map

The moderate risk zone is lying along both sides of the two previous zones. The area in this zone is characterized by steep slopes, south and west slope aspects with moderate elevation. Furthermore, it shows moderate impact of anthropogenic factors due to increase of distances from settlements, roads and farmlands. The low to very low risk zones are far from human activities. They occupy high altitude, very low gradient, with north and east slope aspect. Hence, the forest density in this zone is denser than the other zones. Table (4) shows the resultant fire risk zones and the corresponding degree of fire risk, where 16.16% of the total area falls in the category of very high risk, followed by 25.37%, 24.51%, 19.01% and 14.95% in the categories high, moderate, low and very low, respectively.

Table 4: Forest fire risk zones

Fire Risk Class	Degree of Fire Risk	Area of Risk Classes (%)	Area of Risk Zones (%)
1	Very Low	14.95	33.96
2	Low	19.01	
3	Moderate	24.51	24.51
4	High	25.37	41.53
5	Very High	16.16	

- **Validation**

In order to validate the results, the actual burnt areas are mapped and correlated with the forest fire risk zones map through a statistical method used by Jensen (2005). In the present study, Landsat images acquired in 1984, 2013, 2015 and 2017 are used to map the burnt area, which reflect the impact of the influential factors (vegetation cover, settlements, slope gradient, slope aspect, road, military actions, elevation, farmlands, and rainfall) on forest fires (Fig.13). Most of the previous researchers checked the extents to which the actual burnt forest areas are located in the very high or high-risk zones drawn in their studies (Jaiswal *et al*., 2002 and Jung *et al*., 2013). The burnt area, in each fire risk zone is mapped and measured (Table 5). The statistical method (Jensen, 2005) is used in the present study to calculate user's accuracy, producer's accuracy, and overall accuracy of the resulted map. The method uses two variables to show the size of burning in the study area. These variables are fire risk level (high to very high-risk zones and other zones) and fire occurrence (burnt forest area and non-burnt forest area). Equations 3, 4 and 5 are used to calculate producer's accuracy, user's accuracy, and overall accuracy.

$$\text{Producer's accuracy} = \frac{\text{Burnt forest areas in high to very high risk zone}}{\text{Total forest burnt areas}} \quad \ldots\ldots \quad 3$$

$$\text{User's accuracy} = \frac{\text{Burnt forest areas in high to very high risk zone}}{\text{Total area of high to very high risk zone}} \quad \ldots\ldots \quad 4$$

$$\text{Overall accuracy} = \frac{\text{Burnt forest areas in high to very high risk zone + Non – Burnt area in other zones}}{\text{Total area of the study site}} \quad \ldots\ldots \quad 5$$

The validation result indicates that the user's accuracy, producer's accuracy and overall accuracy are 49.51%, 38.04% and 45.54%, respectively (Table 6). 61.96% of the actual burnt area is located in moderate, high and very high risk zones, whereas 39.54% is located within low to very low risk zones. These results mean that even areas with a low-predicted hazard were actually burned in the past. Fire hazard is more related to the fuel sources, while fire risk includes both fuel and ignition sources and fire behavior is dynamic (Chuvieco and Congalton, 1989).

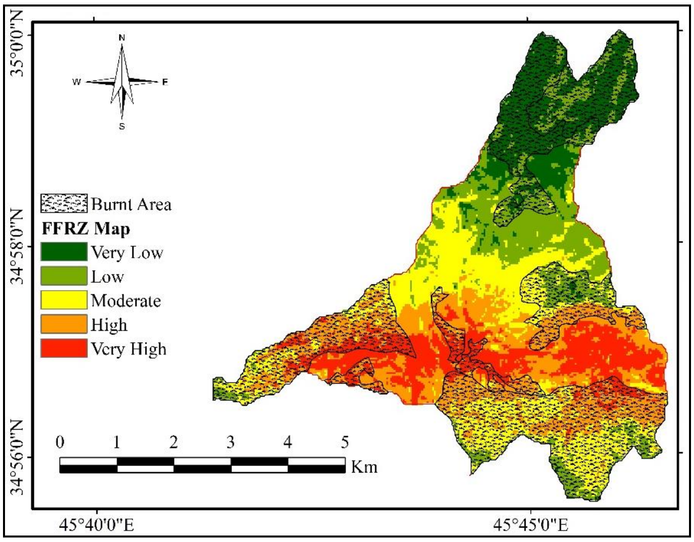

Fig.13: Burnt area in correlation with forest fire risk zones

Table 5: Burnt and non-burnt areas in high to very high risk zones and other zones

Zones	Burnt forest area (Km^2)	Non-burnt forest area (Km^2)	Total Area (Km^2)
High to Very High Risk Zone	5.45	5.56	11.01
Other Zones	8.88	6.62	15.50
Total Area (m^2)	14.32	12.18	26.50

Table 6: User's accuracy, producer's accuracy and overall accuracy

Year	User's Accuracy %	Producer's Accuracy %	Overall Accuracy %
High to Very High Risk Zone	49.51	38.04	45.54

The spatial distribution of the influencing factors is reflected on the results and validation accuracy according to the weight of each factor in the model. The user, producer and overall accuracies indicate that, in addition to forest fire occurrence in high and very high risk zone, forest fire occurrence is probable in lower risk zone. Hai-Wei *et al*. (2004) announced that even if the forest type has low risk, the eventuality for forest fire occurrence can be moderate due to the influence of the other factors such as slope-gradient, slope-aspect and elevation. In this respect, the spatial variation of forests density, which has highest weight (weight 9) and acts as fuel source, is greatly affecting the fire occurrence in areas with high density forests as that happened in the northeast and southeast parts of the study area. The high forest density is matching the burnt areas. According to Chuvieco and Salas (1996), the critical point of these systems is the vegetation layer and the close correlation between the spread and intensity of the fire and fuel characteristics, such as size, plant moisture, compactness, and density. Fire risk models are great approach for precautionary measures for the environmental protection of the forests (Pourtaghi *et al*., 2014). Thus, the results help and enable the concerned institutions to set up appropriate firefighting infrastructure for the areas more prone to fire damage. These results can be applied to early warning, fire suppression resources planning and allocation works.

- **Geomorphological role in forest protection**

Geomorphology involves analysis of surface features of the earth and those processes that create landforms and landscapes (Costa and Fleisher, 1984). The study and identification of landforms play important role in natural resources management and sustainability. Goudie (2004) stated that the application of geomorphology to the solution of miscellaneous problems, especially, in the development of resources, diminution of hazards, planning, conservation and specific engineering or environmental issues. Applied geomorphology begins with an understanding of the environmental conditions (Costa and Fleisher, 1984).

In the present study, the geology and geomorphology (relief, landforms and drainage network) can play important role in preservation and protection of the forests and prevent post fire implications occurrence (erosion) in Sartak watershed. This is considered as a part of watershed management and natural resources protection. Watershed management is the process of organizing and guiding land, water, and other natural resources used in a watershed to provide the appropriate goods and services while mitigating the impact on the soil and watershed resources (Wang *et al*., 2016). According to Sakellariou *et al*. (2017), the art decision support systems (DSSs) for prevention and suppression of forest fires needs retrieval, analysis, update, edit and prediction models of geospatial (geomorphology, topography, socioeconomic and environmental data), meteorological and satellite data. The geomorphological units that comprise Sartak watershed are units of structural origin (breached anticlines and homoclinal ridges or strike ridges), units of denudational origin (erosional and depositional glacises), units of fluvial origin (fluvial erosional and depositional landforms), units of solution origin (Sartak gorge) and units of anthropogenic origin (Fig.14). Relief of the study area is represented by elevation and slope characteristics previously described, whereas the drainage network is represented by Sartak stream and its branches which have dendritic patterns with three main branches.

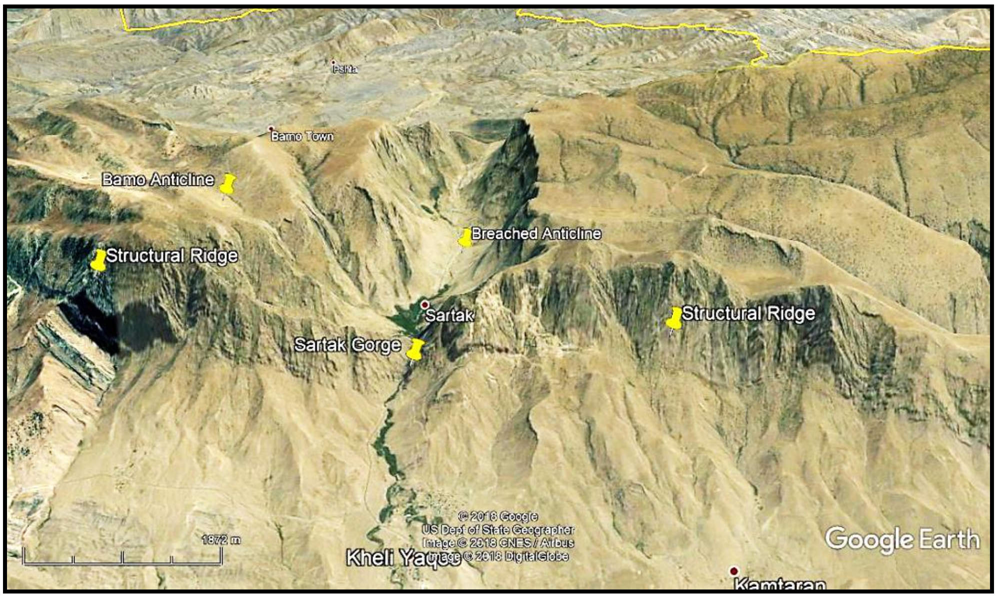

Fig.14: 3D view of Google Earth image shows the relief of the study area

These geomorphological characteristics provide adequate situation to protect and preserve forests. Sartak watershed is an enclosed area within the Bamo mountain range and can be reached through the main road across Sartak gorge. Relief properties are characterized by high altitude and steep slopes. The highly elevated and vertically sloped structural landforms become natural barriers and difficulties that restrict human activities in the study area. These geomorphological situations enable and help easily controlling and restricting human activities in the area as causative factor for forest fires. Moreover, these situations provide fundamental elements to build natural protection zone (National Park) for protecting and preserving the natural resources (forest) and wildlife in Sartak watershed. In addition to landforms and relief, drainage lines can be taken into consideration as breaking the fuel (vegetation) continuity and preventing fire spread. Hence the true natural resource sustainability function in the present area can be obtained.

CONCLUSIONS

- The weighted and scored factors controlling forest fire risk, found in the present study, are vegetation > slope > slope aspect, distance from settlements and distance from roads > elevation and distance from international border > distance from farmlands > rainfall respectively. The integration of these factors in GIS environment, delineated the forest fire risk zones with five classes. 16.16% of the total area falls in the category of very high risk, followed by 25.37%, 24.51%, 19.01% and 14.95% in the categories high, moderate, low and very low, respectively.
- The spatial distribution of forest fire risk zones revealed that the middle part of the study area is more prone to forest fire than the other area, due to integration of high to very high risk weighting portions of the effective factors. This zone is characterized by low elevation and proximity to human activities (settlements, roads and farmlands). The low to very low risk zone is occupying high altitude and very low gradient area. These zones are characterized by higher forest density, north and east slope aspect and are far from human activities.
- The geomorphological situations enable and help easily controlling and restricting human activities in the area as causative factor for forest fires. Moreover, these situations provide fundamental elements to build natural protection zone (National Park) for protecting and preserving the natural resources (forest) and wildlife in Sartak watershed. In addition to landforms and relief, drainage lines can act as factors breaking fuel (vegetation) continuity and preventing fire spread. Hence the true natural resource sustainability function in the present area will be obtained.

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About the author

Dr. Sarkawt Ghazi Salar, Lecturer at the Garmian University, Geography department. B.Sc. degree in General Geology from Sulaimani University in 2001. M.Sc. degree in Hydrogeology from the Baghdad University in 2006. Currently, he has a Ph.D. in Geomorphology at the College of Science/ Department of Geology, University of Sulaimani, Kurdistan/ Iraq. He has more than seven publications.

e-mail: sarkawt.ghazi@garmian.edu.krd