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MAPPING THE RISK OF FOREST FIRES IN THE SOUK AHRAS MOUNTAINS

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ABSTRACT

Forests fire is the most devastating factor of degradation of the Algerian forest, despite numerous efforts to limit it. Traditional fire prevention and firefighting methods have shown their limitations due to their slowness… , is it therefore useful to adopt new techniques in order to react quickly and effectively. The main objective of this study is to model the «forest fire» risk, in order to produce a risk map, which is indispensable for preventing and informing on fire-vulnerable areas. To achieve this objective, a forest fire risk map was elaborated, on the basis of the scientific methods using geographical information systems and satellite imagery. The adopted approach is an empirical model, involving three parameters controlling the behavior of fire, the topo-morphology of the ground, the combustibility of the vegetation cover and human activity. The study area chosen is one of the most affected areas by this phenomenon (Souk Ahras Mountains). It belongs to the densest forest in Algeria, known for its sensitivity to fire, particularly in relation to its physical conditions (nature of the vegetation cover, climatic conditions (strong Sirocco wind) and socio-economic conditions (high population density).

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1. Introduction.

Fire is not a recent phenomenon (Ouahiba et. al., 2010); it is a natural phenomenon often indispensable for the renewal of forests. But today, it constitutes a risk that is getting worse and worse because of its recurrence. If the forest regenerates normally after a fire, the passage of successive fires can compromise its sustainability. Closely dependent on meteorological factors (wind, prolonged drought), ecological factors (water-content, flammability and combustibility of plant formations), topographical factors (uneven relief) and recently anthropogenic factors.

The risk of fires starting is closely linked to anthropogenic action. Previous analyzes of forest fire statistics have highlighted the issue of pastoral fires, the main cause of fires in certain regions of the far northeast of Algeria. , where fire is the most economical way to regenerate pastures and open impenetrable scrub (Azzedine et al., 2019). Forest fires, in the current context of climate change, are likely to become more frequent and more intense, particularly in countries around the Mediterranean. It is therefore essential to determine the areas at risk in order to put in place a strategy of prevention and

fight against forest fires, which are classified in Algeria among the ten major risks, listed in Law No.04-20 of December 25, 2004,related to the prevention against the major risks and disasters management.

The Algerian forests of the sclerophyll type are vegetal formations which are in continuous fight against drought (several consecutive dry months). They are cyclically exposed to fire. In order to preserve them, it is absolutely essential to understand this phenomenon in all its facets, but above all, it is necessary to clearly identify the areas at risk and their degree of vulnerability in order to optimize measures of control or prevention.

In this article, we got interested in SoukAhras Mountains, which have very good forestry potential and a high sensitivity to fires, as evidenced by the annually burned area and the high number of the registered fireplaces. The main objective of this study is to model the risk of forest fires, in order to elaborate a risk map, which is essential for preventing and informing on the vulnerable areas to fires. The adopted approach is an empirical model, developed by DAGORNE in 1994 (Dagorne & Duch, 1994), involving three parameters that control fire behavior, the topo-morphology of the ground, combustibility of the vegetation cover and human activity.

2. Study Area Presentation.

2.1 Physical Context.

The region of Souk Ahras, the subject of our study, is a Tellian forest region, located in the North East of Algeria. It is part of the mountains of the upper Medjerda, which constitutes the contact zone between the two largest units of eastern Algeria (the Tellian Atlas and the Saharan Atlas) (L.David 1956). It includes an imposing mountain chain to the north-east, south-west, crossed by one of the main Maghrebin valleys, the Medjerda valley in the north and the Mellegue valley in the south.

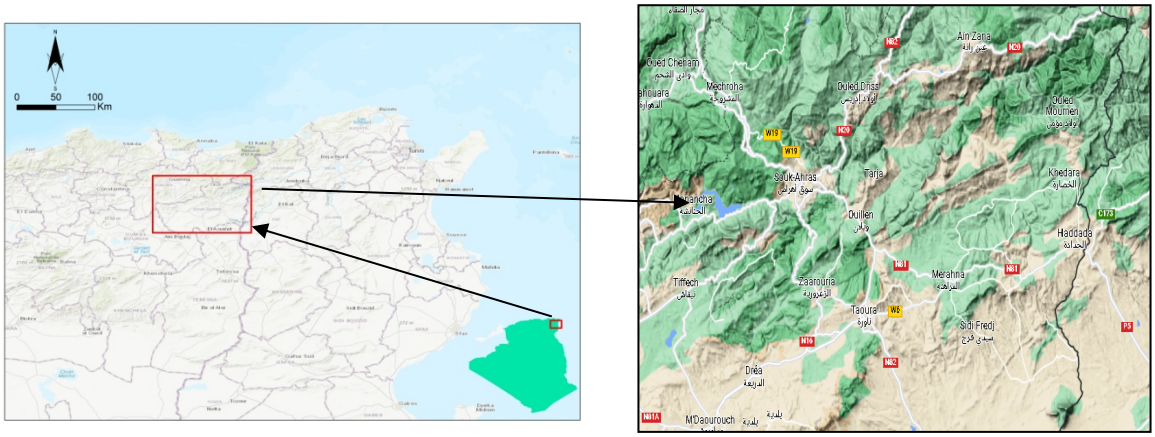

Fig 1. Situation map.

It is characterized by an uneven relief, a climate where the seasons are well contrasted, with particularly long summers (4 to 5 months), dry and hot. It experiences annually a high proportion of fires compared to the rest of the Algerian forest regions and it is its northern part that pays the heaviest burden. Because of its extensive forest cover, it suffers from considerable damage every year, as a result of the recurrence of fires. In addition to its rich and varied vegetation, the northern region has a rough topography, which is a favorable condition for the emergence and continuation of fires during the summer season. These fires further weaken the balance between the available plant resources and the constant wood needs of the inhabitants. This is one of the main reasons for the decline in vegetation, in addition to excessive wood cutting, overgrazing, urbanization and the multiplication of unauthorized waste dumps (Belkaid, 2016).

The region of Souk Ahrasis marked by a rather harsh climate , where summers are hot and winters are cold. Rainfall is erratic both temporally and spatially and averages 1400 mm per place (Mechroha, Ain Zana), but the majority of the area has sufficient rainfall to maintain a good forest cover (700-800 mm).

In general, rainfall decreases from north to south and from east to west, which explains the importance of the vegetation in the north and its scarcity in the south (steppe vegetation).

The forest area of SoukAhras Mountains is 88.938,00 Ha; it is composed mainly by two vegetation formations, the cork oak forest, which is located in the north of the region (Mechrouha, Ouled Driss and Ain Zana), with an area of 21205 Ha, the pine forest, covering a large area of 43625 Ha in the center and south of the region.

The concentration of vegetation, in general, and of the forest in particular in the northern part of Souk Ahras coincides with a high concentration of population and habitat, which directly exposes the natural spaces to a strong anthropogenic pressure. The forest areas are occupied by more than 70% of the population of the wilaya of Souk Ahras, according to the 2017 DPAT (planning department and territory development).

2.2. Brief history of forest fires.

The study and interpretation of the statistics of fires that occurred between 1993 and 2016, highlights the multiplicity and dangerousness of this phenomenon under the particular influence of Man. The exploratory statistical analysis of the past fires in the Souk Ahras region, shows that this part of Algeria is particularly affected by forest fires, which occur mainly in the summer. During the above period, no less than 2923 fires were recorded, covering a total forest area of 18.739,42 hectares.

As for the number of fires, it is marked by an even greater disparity, because, of the total of 2923 fires, 1680 fires, or 57.51% of the total, concern only four forests which are, in this case: Mechroha, Ain Zana, Ouled Moumen and Zaarouria, located north of the city of Souk Ahras.

Each of these forests has a total of more than 300 households, with a maximum recorded by the Ouled Moumen forest (480 households or 16.55% of the total). At the same time, these forests which are very vulnerable, are being increasingly affected by urban expansion.

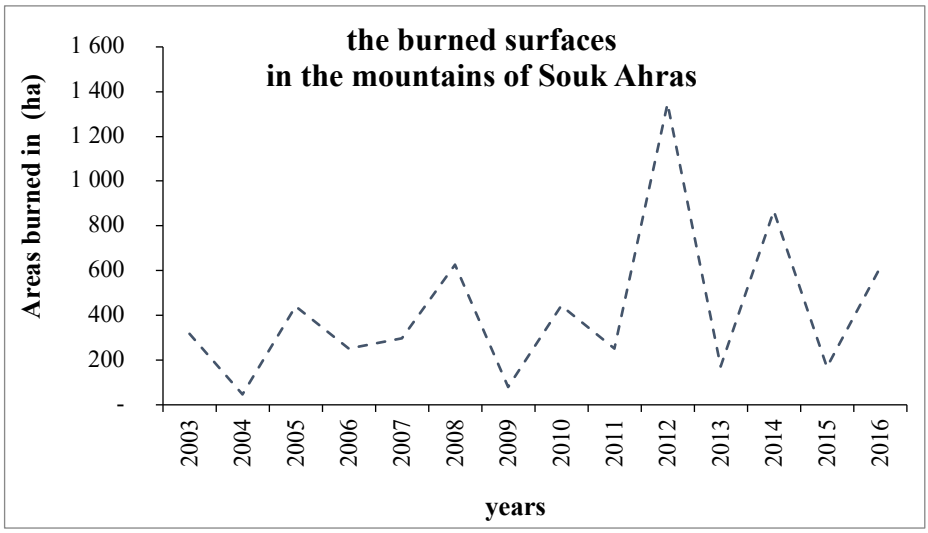

Fig 2. The burned surfaces in the mountains of Souk Ahras.

3. Methods and Tools.

3.1. Methods.

Not all forest formations are exposed to fire in the same way. Their composition, geographical location, proximity to urban centers and management are decisive.

Two large spaces can thus emerge:

- The areas where the risk is greatest and which must be treated as an emergency by protection operations and strict regulations on the use of fire in forests.
- The spaces where the risk is less and where only this last measure will be applied.

The establishment of the fire risk map according to the model put in place by DAGORNE and DUCHE (Dagorne & Duch, 1994) and tested on the forest massifs of the Mediterranean region, takes place according to the stages presented in the flowchart below.

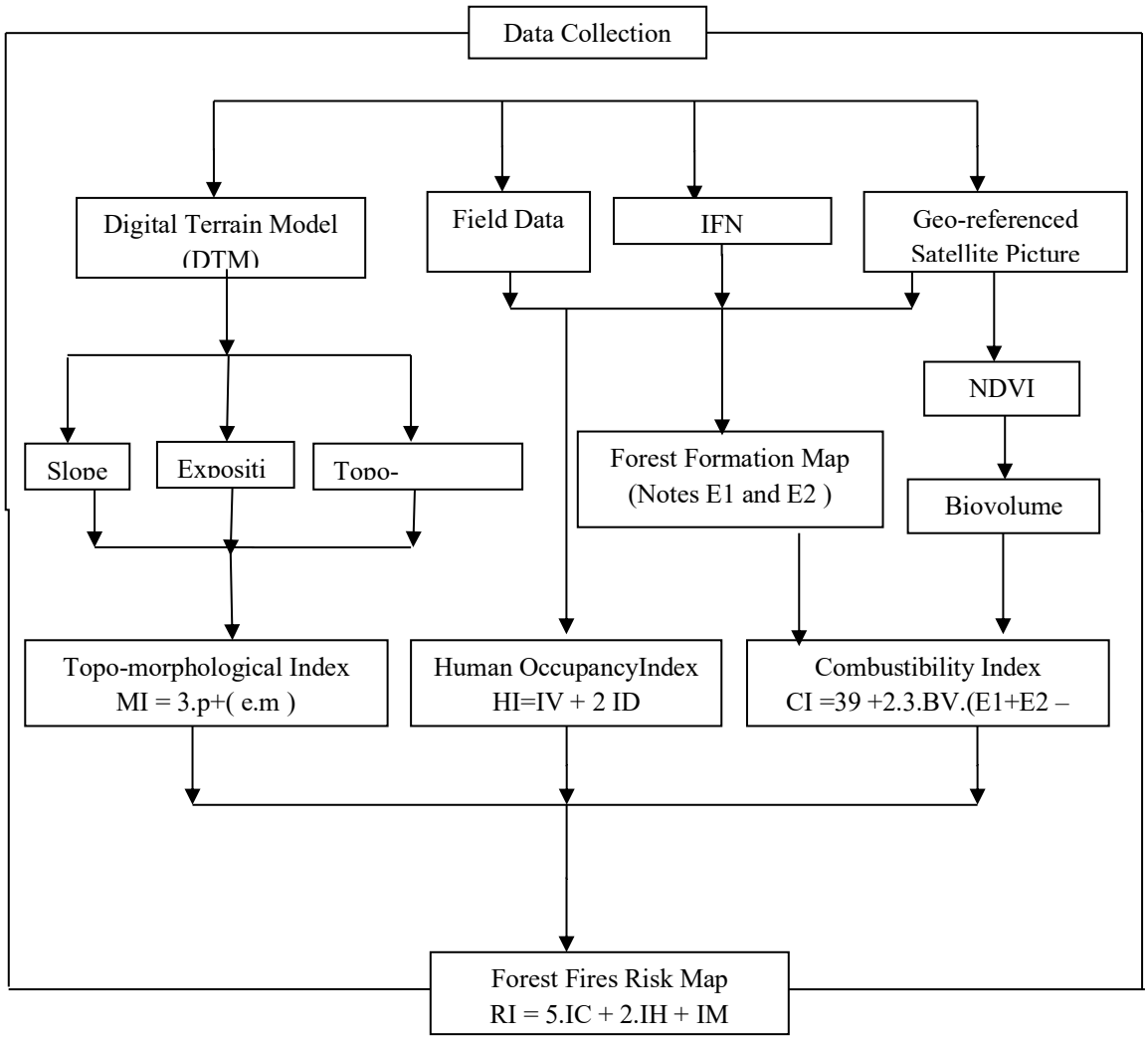

Fig 3. Diagram the applied model.

The model applied involves the three main factors for the assessment of forest fire risk: topo-morphology, combustibility and human activities (Faleh et al., 2012).

The model in question is based on the following formula:

$$\mathbf{RI = 5CI + 2HI + MI}$$

RI: Fire risk index.
CI: Combustibility Index.
HI: Index of human occupancy.
MI: Topo-morphological index.

The characterization of this index is based on the spatial variability of the fire risk, the determination of which is based on the physical parameters involved in the chosen model (Belhadjaissa, 2003).

3.1.1 The Topo-morphological Index (MI).

Three topographical parameters are involved in the model: slope, exposure and topo-morphology. All these parameters are derived from the Digital Terrain Model (DTM)of the region (Khader et al., 2009).

The slope changes the relative inclination of the flames relative to the ground.

Rising fires burn faster on steep slopes. On the other hand, a descendant fire slows down considerably.

The exposure has an indirect role on the progression of a fire, in relation, on one hand, with the nature of the vegetation (rather heliophilic vegetation on the slopes adrets and ombrophiles on the ubacs), and on the other hand, with the dynamics of the wind, a fire spreads more easily on a windward slope than on a downwind slope.

This index is expressed by the following relation:

$$\mathbf{MI = 3s + (m+e)}$$

S : the slope.
M : the topo-morphology.
E : the exposure.

3.1.2 Combustibility Index (CI).

Whatever the causes of the outbreak of forest fires in the Mediterranean region, the best-known characteristic of this forest is undoubtedly its extreme combustibility and its strong sensitivity to fire (Rahmani, 2009).

he type of vegetation is an important factor in predisposing to fire. some plant formations are more sensitive to fire than others: scrub and scrublands are more vulnerable than forest areas (Meddour & Derridj, 2012).

This sensitivity is illustrated by the combustibility index.

This combustibility can only be estimated by an empirical model, based on the experience of fire-fighters to weight the terms of a mathematical expression, whose parameters come from a standardized description of vegetation (Dagorne & Duch 1994).

To estimate combustibility, the model developed by (Mariel, 1995) is adopted; its combustibility index is in the form of:

$$\mathbf{CI = 39 + 0.23BV\ (E1+E2-7.18)}$$

BV: the biovolume of vegetation.
E1: combustibility notes for high woody.
E2: combustibility notes for low woody or herbaceous.

3.1.3 Human Occupancy Index (HI).

The drought is blamed in the outbreak of fire, whereas the opposite is observed in our study region, where the wet and sub-humid part is most affected by this scourge.

The hypothesis on which we must rely is that when the climate does not play the role of fire trigger; it is the human cause that is to be verified.

The anthropogenic parameter is the main term in the human activity index model. The constructions development, in contact with the forest and within the woodlands, increases the sensitivity of these peri-urban areas to forest fires, so that the situation becomes increasingly worrying.

According to the foresters, the fire starts are preferentially located near the access roads (national and communal roads) and more rarely from inaccessible areas. Fire departures are almost always located within 100 m of a habitation or road and most of the time due to human-induced action (recklessness, accident, maliciousness).

Since humans are responsible for most fires (voluntary and involuntary) in forests, it is impossible to model human behavior (Abderrahim & Ali, 2017). The statistical approach developed by J.G. Robin in (Robin et al., 2006) shows a clear correlation between the number of households near a road or houses.

To assess the effect of human influence on forest fire risks, we adopt the following model.

$$\mathbf{HI = NI + 2DI}$$

HI: the human occupancy index.
NI: the neighborhood index.
DI: The human presence index.

- The first parameter (VI) is based on the anthropogenic impact on the near forest neighborhood, over a depth of 100 m.
- The second parameter (DI) takes into account road infrastructure (roads, tracks, trails). However, fire outbreaks are much more frequent near roads and paths of forests.

3.2. The used means.

The basic data of these formulas used by a series of specialized software, allow the drawing up of different maps (layers of useful information), the latter will be superimposed in order to put in place the map of fire risk.

The tools used to develop the fire hazard map are the ENVI software and ArcGIS. The latter was used for the implementation of the Digital TerrainModel (DTM) and for obtaining the slope map, exposures and topo-morphology.

The (ENVI) software (Environment for Visualizing Images)was used to process images for the visualization and analysis of data.

4. Results and Discussions.

The fire risk index, which is the primary objective of this study, is designed as a model that assigns to each parameter a weighting coefficient in relation to its influence on fire propagation.

4.1. Topo-morphology Index (MI).

From the Digital Terrain Model (DTM) that was extracted from the website http://earth data.nasa.gov. The slopes maps and the slopes exposure and altitude maps were elaborated. These three topographic parameters are used in the method to create the topo-morphological index map. The slope plays a very important role in the propagation of fire, the more it is strong, the more the fire moves quickly (Guettouche et al. 2010).

4.1.1. Slopes.

The distribution of the surfaces of the different slope classes shows a predominance of the class (5 to 10%), followed by the class (slope 10 to 25%), a substantial variation which plays a very important role on the degree of fire propagation.

Extreme slopes exceeding 25% are not very representative (0.34%).

Table 1. Classes of slopes in Souk Ahras Mountains.

Types	Classes	Area (Km²)	Percentage %	Notes
Very Low	0-3%	173.66	19.53	1
Low	3-5%	170.07	19.12	2
Moderate	5-10%	346.04	38.91	3
High	10-25%	196.56	22.10	4
Very High	>25%	3.05	0.34	5
Total		**889.38**	**100 %**	

4.1.2. Slope exposures.

The exposure of the slopes plays an important role on the propagation of inflammations (Belkaid, 2016).

As long as it reflects the situation of the slope in relation to the prevailing winds and the sunshine, it influences the progression of fire, therefore, the slopes exposed to winds are more at risk of fires than those which are immune from them.

Table 2. Wind Exposure Classes in Souk Ahras Mountains.

Types	Classes	Area (Km²)	Percentage %	Notes
Very Low	O	72.81	8.19	1
Low	E -NE	182.03	20.47	2
Moderate	N -NO	267.46	30.07	3
High	SW	93.55	10.52	4
Very High	S -SE	273.53	30.75	5
Total		**889.38**	**100 %**	

The study area is characterized by various exposures. The slopes that are most threatened by fires are those exposed to the south and south east, direction of the sirocco. They represent 30.87% of the area of Souk Ahras Mountains.

Moderate risk slopes have N-NO exposure at 30.07%. The latter are of no importance because they receive the wind during the winter period, the low to very low risk classes (slope orientation O and E-NE) represent 28.66% with an area of 254.84 km².

4.1.3. Topo-morphology.

The position in the slope or topo-morphology «T» weights the intensity of the fire according to the position on the relief. The topo-morphology was selected according to the classes of slopes derived from the Digital Terrain Model (DTM).

The four classes define the increasingly unfavorable topographical situations for the fight. We have: the plain, low foothills, high foothills and mountains.

Table 3. Topo-morphology classes of Souk Ahras Mountains.

Types	Classes	Area (Km²)	Percentage %	Notes
Low	0-3%	167.84	18.94	1
Moderate	3-12,5%	612.04	69.07	2
High	12,5-25%	106.45	11.97	3
Very High	>25%	3.05	0.34	4
Total		**889.38**	**100 %**	

Depending on the altitude, the fire acts differently based on whether it is flat or has very marked roughnesses.

In the study area, the majority of the land (69.07%) is in the low foothills followed by areas of plains with a slope of no more than 3%. High mountains represent only 11.97%, while very high mountains exceeding 25% are very rare (0.34%).

Table 4. Topo morphology index classes in SoukAhras Mountains.

Types	Classes	Area (Km²)	Percentage %
Low	5-10	188.9	21.24
Moderate	10-15	336.39	37.82
High	15-20	293.41	32.99
Very High	20- 25	70.68	7.95
Total		**889.38**	**100 %**

The map 2 of the topo-morphological index obtained from the combination of natural parameters such as: slope, topo-morphology and slope exposure, shows that more than 40.94% of the surface has natural conditions conducive to fire accentuation, followed by moderately favorable conditions at 37.82%, while unfavorable areas that are risk-free represent only 21.32%.

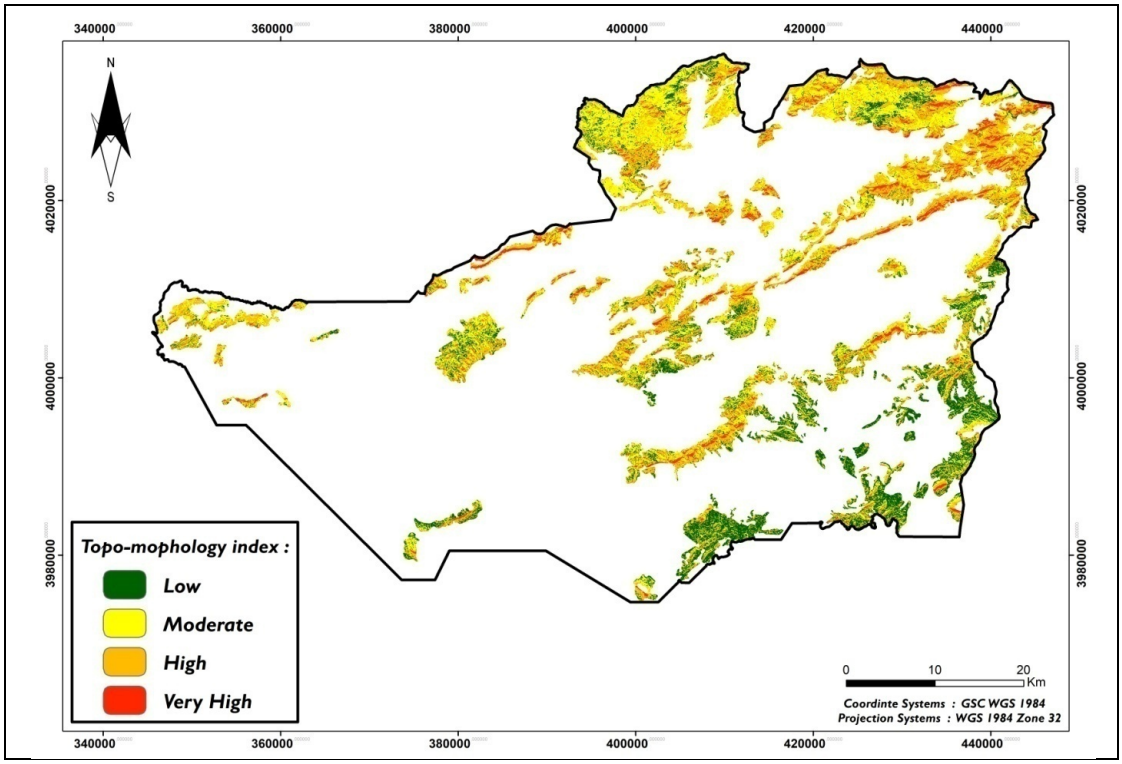

Fig 4. Topo-morphological index.

4.2. Combustibility Index (CI).

Combustibility is related to the quantity of combustible biomass or biovolume, which is an important factor in the extension of forest fires, it is calculated from the NDVI. The normalized vegetation differential index which is obtained by the combination of visible (VIS) and near infrared (NIR) spectral bands: NDVI = (NIR-VIS)/(NIR+VIS).

The recovery rate of the forest formations is between 0 (absence of strata) and 10 (closed canopy strata), so the biovolume is between 0 and 50. The dominant forest formations are taken from the forest formations map, developed in 2007 by the BNEDER (Bneder, 2007) and updated in 2016.

The calorie intensity ratings are between 1 and 7 for the two dominant species: E1 for the high woody and E2 for the low woody or herbaceous, they are taken from the table established by the CEMAGREF (Cemagref, 1990), with the exception of the cork oak which is assimilated to the holmoak.

Table 5. Classes of combustibility index in Souk Ahras Mountains.

Types	Classes	Area (Km²)	Percentage %	Notes
Very Low	40 < IC	12.75	1.43	1
Low	40 < IC < 50	197.92	22.25	2
Moderate	50 < IC < 60	312.83	35.17	3
High	60 < IC < 70	140.91	15.84	4
Very High	IC > 70	224.97	25.31	5
Total		**889.38**	**100 %**	

From the combustibility index table and map, it emerges that the high-altitude areas on either side of Oued Medjerda and the Zaarouria Mountains are favorable or very favorable to the fire risk, due

to the nature of their species(the Aleppo pine in the southern part; and the cork and Zeen oak forests in the north) a high calorie intensity (E1= 7). characterizes this type of formation.

The obtainedresults (Table 5 and Map 3) show that 41.15% of the forest area is of high to very high risk, with an area of 365.51 km², followed by the moderate risk areas with 35.17%, and the low-risk areas with 23.68%.

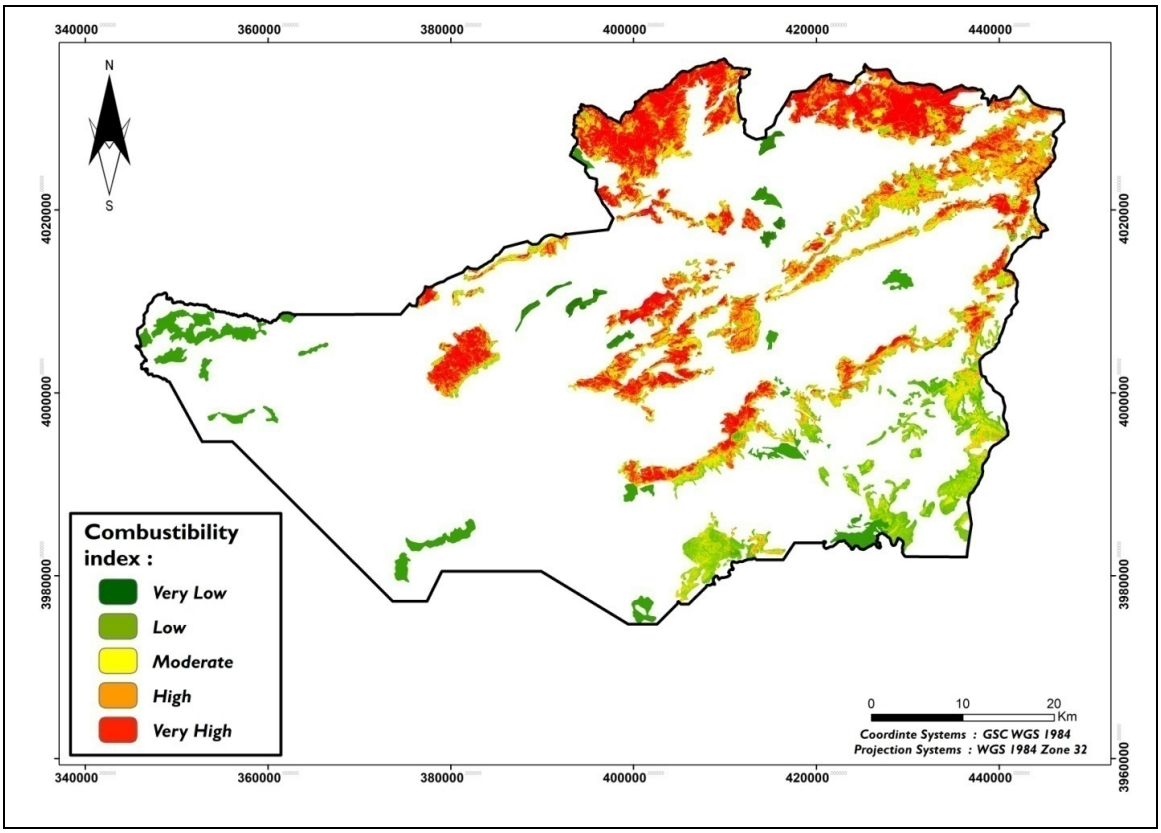

Fig 5. Combustibility Index.

5.3. Human Occupancy Index (HI).

Many human factors contribute to the development of forest fires. Land occupancy in particular has an impact on the "forest fire" risk, due to the development of the forest/habitat interface, following the extension of towns and villages to the edge of wooded areas.

Sellaoua region in 2010 *Sellaoua region in 2020*

Fig 6. Risk linked to housing and road networks.

To assess the human effect on fire risks, the digitalization of the various roads, paths and habitat areas was carried out from Google Earth with a zone of influence of 1000m around each element and finally, the combination of the neighborhood index with twice the human occupancy index according to the above-mentioned formula has given the results indicated in Table 6.

Table 6. Human Occupancy Index HIClasses in Souk Ahras Mountains.

Types	Classes	Area (Km²)	Percentage %
Low	5-7	496.19	55.79
Moderate	7-9	189.01	21.25
High	9-12	132.95	14.95
Very High	12-15	71.23	8.01
Total		**889.38**	**100 %**

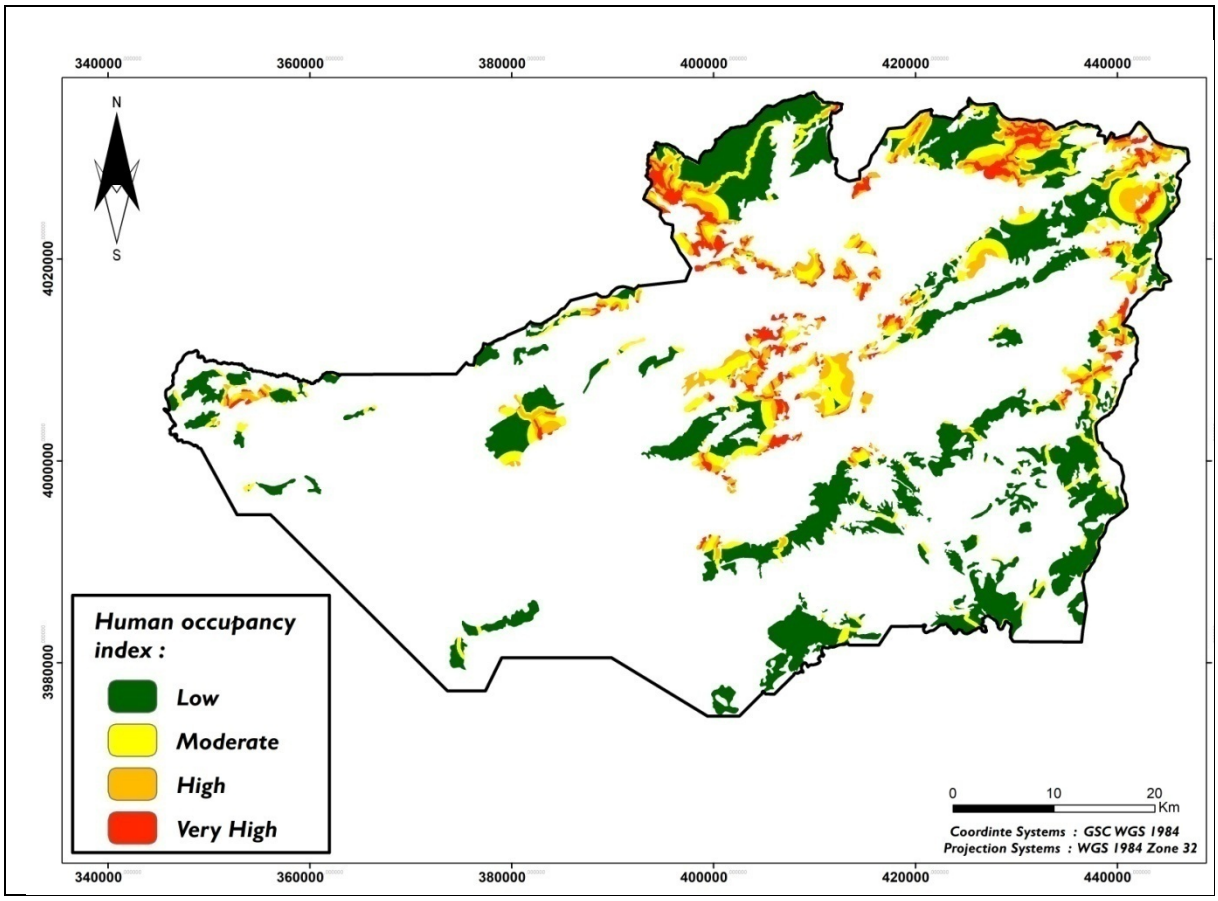

Fig 7. Human Occupancy Index HI.

5. Fire Risk Index Map.

Three layers are superimposed to produce the fire risk index, such as those of the topo-morphological index, the combustibility index and the human index, according to the following formula:

$$\mathbf{RI = 5CI + 2HI + MI}$$

Table 7. Fire Risk Index Classes.

Types	Area (Km²)	Percentage %
Very Low	60.3	6.78
Low	157.34	17.69
Moderate	133.77	15.04
High	234.70	26.39
Very High	303.27	34.10
Total	**889.38**	**100 %**

The results in Table 07 show that the areas favorable to very favorable for the outbreak offire are the most dominant with a percentage of 60.49%. For the other medium and low risk classes, they are around 40.63%.

Most of the high-risk to very high-risk areas are situated in the far north-east and central parts of the region. As for medium and low risk areas, they are situated in the North-West and South 25.16%.

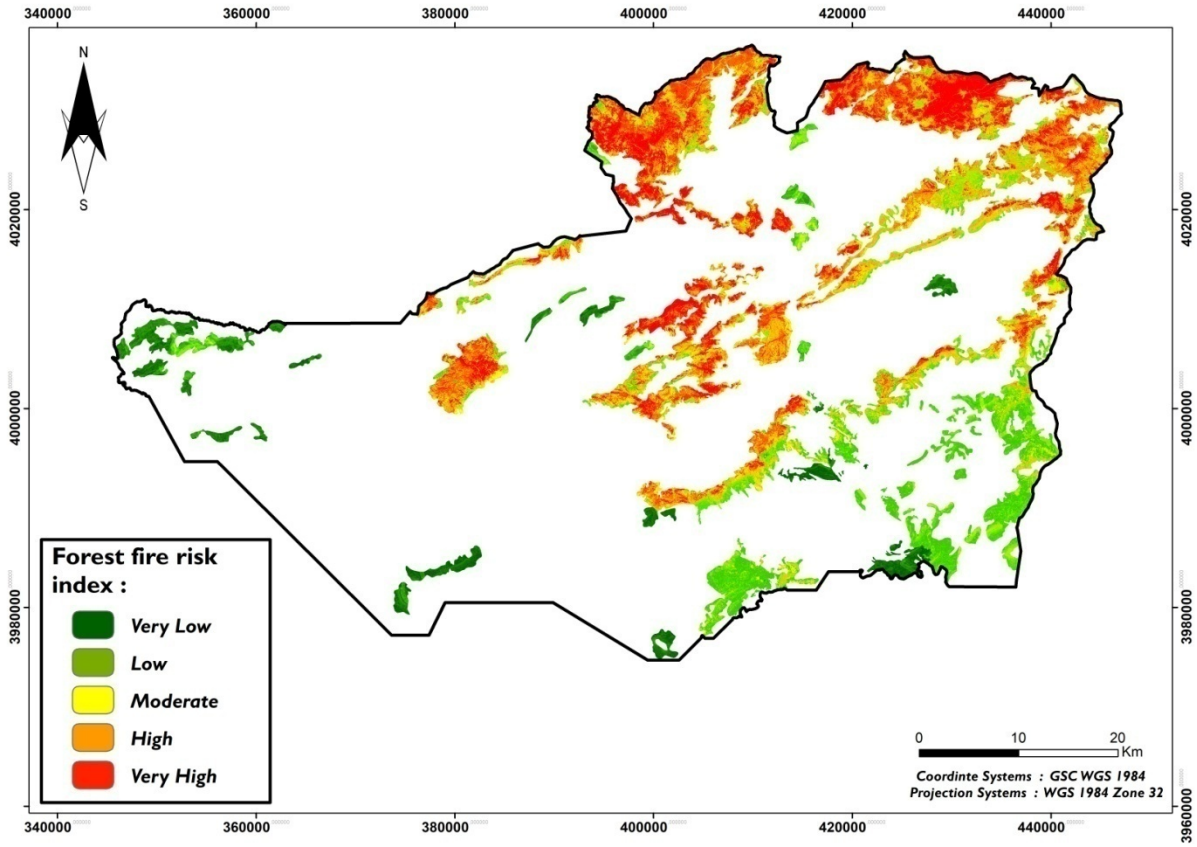

Fig 8: Forest fire risk index.

6. Validation of the Model.

To validate the Dagorne risk model, two approaches are adopted.

- The first is based on a comparison between the fire risk map developed in this work, and the forest fire sensitivity map (2015 forest fire prevention and fighting campaigns), developed by the Souk Ahras Forest Conservation. The results are almost identical:

The affected areas by the fires are the same, depending on the degree of risk, they are located where the rate of afforestation is highest, where the slopes are steep, and where the exposure to the winds is favorable, in addition to a high anthropogenic pressure.

-The second approach, based on the statistical analysis of the data acquired over a 23-year series, also leads to similar results, namely similarity on the level of the burnt areas.

The total burned area during the period (1993-2016) is. 18.739.42 ha. It was unfairly distributed over the study area. The forests located in the far North, representing the massifs located on both sides of the Medjerda, are in the first position with 61.87% of the total burnt area.

The total area burned during the period (1993-2016) is. 18,739.42 ha It was unfairly distributed over the study area. The forests located in the far North, representing the massifs located on both sides of the Medjerda, are in the first position with 61.87% of the total burnt area. Zaarouria Mountains and Souk Ahras hills which dominate the central part of the region, come in the second position with 27.76% and finally, the southern part which represents Oued Mellegue Mountains and Sedrata Mountains with 10.38%.

7. Conclusion.

Forest fire which is a natural phenomenon, becomes a risk when, by its frequency or its high intensity, it damages the forest and threatens man and his activities. The “forest fire” risk depends on many factors: meteorological factors (wind, prolonged drought), ecological factors (water content, flammability and combustibility of plant formations) and topographic factors (uneven relief), factors that we have analyzed to apprehend the risk in Souk Ahras mountains, located in the extreme north-east of Algeria.

The adopted methodological approach is the one of forest fire risk modelling, based on the empirical model developed by DAGORNE Y. DUCHE (Dagorne & Duch, 1994), which involves three parameters based on the calculation of three indices: The combustibility index CI, which takes into account the biovolume and dominant species. The topo- morphological index, which uses three topographical parameters, slope, exposure and altitude. The Human Occupancy Index, which takes into account human activities within the forests and in the proximity of communication routes. It is the most determining factor, but also the most complex to identify and therefore to model.

The results of the superposition of the different topo-morphological layers, combustibility and human actions, showed that the high-risk areas are located in the extreme north of the region of Souk Ahras, and in the center. These regions are particularly marked by the presence of old forests with dense undergrowth, covered by a network of paths and also of fairly important roads, in addition to the presence of scattered rural habitat. The low-risk areas are located in the south (Oued Mellegue) and in the extreme west in the Sellaoua massifs, where the land is mainly used for rangeland, the vegetation is generally steppic with alfa, and Diss.

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