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Joint use of remote sensing and GIS for monitoring and inventorying forest fires: case of the Saida province, Algeria

Arabi Zohra[1,2*] and Chalane Fatiha[3]

[1] Department of Sciences of Nature and Life, Faculty of Natural Sciences and Life, University of Ibn Khaldoun, Tiaret, Algeria
[2] Laboratory of Geomatics and Sustainable Development (LGEO2D), Tiaret, Algeria
[3] Department of Sciences of Nature and Life, Faculty of Natural Sciences and Life, University of Moulay Tahar, Saida, Algeria

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ABSTRACT

The forest fire is in the wilaya of Saida, the major factor in the destruction of forest ecosystems already weakened by the extreme conditions of drought. This situation is explained by the nature of the main dominant forest species, which are extremely fragile and combustible in the face of fire. The present study attempts to demonstrate a synthetic mapping model on susceptibility to forest fires under a geographic information system (GIS) and remote sensing. For this, several factors favoring the initiation and propagation of fires were taken into consideration such as: slope, NDVI vegetation index, combustibility and density of vegetation. After combining these factor maps using the two-by-two principle, a forest fire sensitivity map was produced. The forest fire vulnerability map obtained shows four (04) classes of fire sensitivity: very low, low, medium, high and very high. The results show that more than 16,4% of the total surface area of the study area has a very high sensitivity to fire and that more than 69,04%) is sensitive to this phenomenon.

Key words : *Sensitivity to fires, G.I.S, Remote sensing, NDVI, Tafrent Forest, Algeria.*

Introduction

Forest fires are a global problem leading to the disappearance of forests and the destruction of ecological heritage. In the Mediterranean Basin, fires annually ravage between 600,000 to 800,000 ha of forest land (Rowell and Moore, 2000), according to FAO (2001), these fires are mostly of human origin, whether by accident, by negligence or intentionally. In Algeria, these fires are considered the most destructive factor of the Algerian forest, they destroy 37,500 hectares annually (D.G.F, 2020). Fires cause the destruction of forest ecosystems and the disappearance of forest species (Hani *et al.,* 2020).

Abréviations

D.G.F. General Directorate of Forests
FAO. Food and Agriculture Organisation
B.N.E.D.E.R. National Bureau of Studies for Rural Development.
A.N.R.H. National Agency for Hydraulic Resources

In the wilaya of Saida, the forest heritage covers an area of 157,289 ha, either a recovery rate of 23.5% compared to the total area of the wilaya which is 676,540 ha. The main species are: *Pinus halepensis*, *Quercus ilex*, *Tetraclinis articulata* and others. Forest fire is the most devastating factor in the degradation of the forest ecosystem in this region, as the results established over ten years show an average annual loss estimated at 2265.74 ha. To follow the evolution of this devastating phenomenon and characterize areas with high sensitivity to fire, remote sensing is an essential spatial tool for developing more precise maps of the progression of fires and damage estimates from satellite images. The use of Geographic Information Systems (GIS) is proving to be an adequate choice for monitoring forest fires Bordin, 2002; Erten, 2004; Xu *et al.*, 2005; and in their prevention Dagorne *et al.*, 1995; Esnault, 1995; Missoumi *et al.*, 2003; Haddouche *et al.*, 2011; Souidi *et al.*, 2017).

The main objective of this work is the development of a synthetic mapping methodology for the monitoring of burnt forests and to draw a map of potential sensitivity to forest fires through the application of innovative techniques such as remote sensing and 'Geographical Information system (GIS) the one hand and the collection and statistical analysis of data in the form of fire reports for a period of 30 years (1988, 2018). The results of the data collected from the DGF are expressed in graphic and cartographic forms.

Materials and Methods

Region of study

The study focuses on the Tafrent state forest in the wilaya of Saida (Figure 1). It covers an area of around 8444 ha. The study area fits into the space bounded in longitude by 0.6 ° W to 0.15 ° E and in latitude by 35.02 ° N to 34.9 ° N. It is characterized by a semi-arid climate with cool winters with a dry period of more than 6 months extending from the month of May to the month of October (Arabi *et al.*, 2014).

Experimental design

Sensitivity mapping of forest fires is an essential step for the development of a plan to fight against these fires at various horizons (short, medium and long) term and this through a division of the study area into zones homogeneous according to their degree of potential sensitivity to forest fires. The joint use of remote sensing and GIS is the only means of early prevention against this phenomenon, these tools will allow better management of this problem by the implementation of corrective measures according to the particularity of each area.

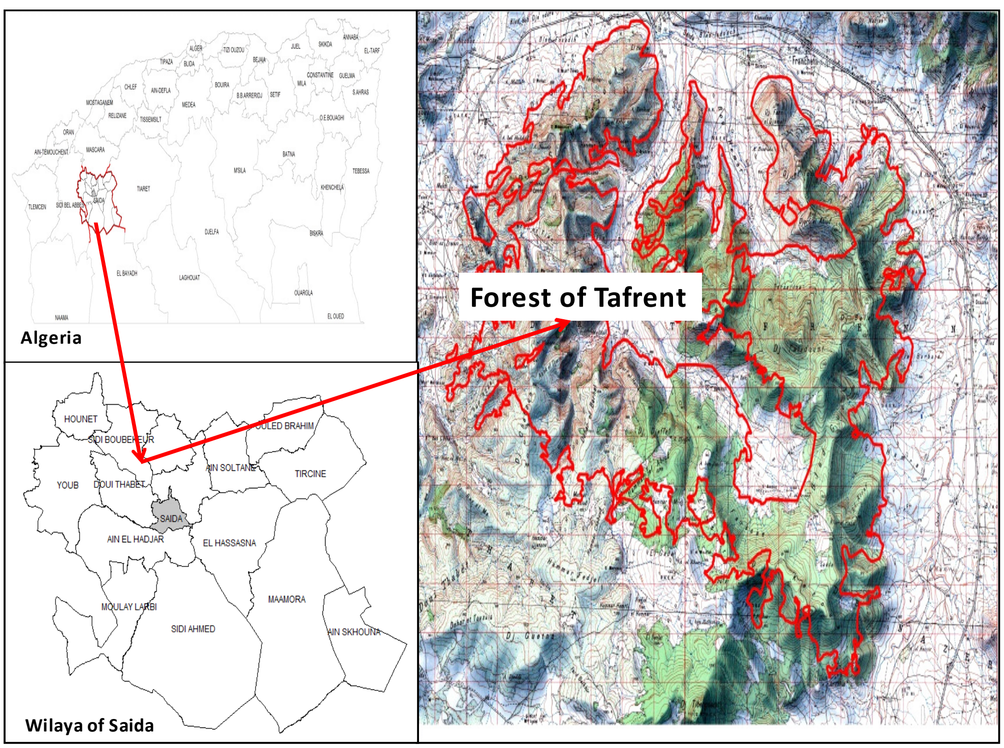

Fig. 1. The location of the study area

The model chosen for our study area is borrowed from those proposed by Erten, 2004; Xu *et al.,* 2005; Faour *et al.,* 2006; Haddouche *et al.,* 2011; Smail *et al.,* 2017; Talbi *et al.,* 2017; Belgharbi *et al.,* 2018, but changes were made to this model to make it suitable for our study area (Figure 2). This choice is justified by the simplicity of its application because it does not require too much data.

Collecting information on fires

The study focuses on the analysis and processing of data collected from the Directorate General of Forests over a period of 30 years (1988-2018) in order to properly choose the key factors that act directly on the degree of the fire. First, the data collected was structured in an Access database. Among the parameters taken into consideration in the analysis: the areas most burned during this period, the causes of fires, the distribution of fires by species and the nature of the terrain: slope, exposure and topography.

Identification of burnt areas

The identification of burnt areas or areas that recorded a high frequency of fire during this period is the key step in the study which can ensure a good start. It was done on the basis of historical data and satellite images in order to be able to geographically locate these areas. This makes it possible to accurately calculate the surface areas of the burned areas.

The study area is covered by the scene acquired by the Landsat satellite - 8 OLI and TIRS bands in 2018. The scene is downloaded free of charge from the USGS website. We produced a colored composition from the combination of the three channels TM5, TM 4 and TM 3. Channel 3 being in the green, channel 5 in the near infrared and channel 4 in the red. This step was done by the ENVI 4.5 software. We performed the same operation but with old and time-spaced Landsat satellite images (1988, 2007, 2013), but this time the colored compositions was made by the three channels TM4, TM3 and TM2.

The visualization of the different colored compositions will make it possible to clearly define the various existing themes on the ground in the following colors: vegetation in red, bare ground in light, agglomerations in blue-gray, water bodies in dark, fires in dark gray.

A geometric treatment of the different images has been launched which consists in minimizing the distortions due to the geometry and also in rendering the images in the same cartographic projection as the topographic map. The procedure consists of selecting more than twelve (12) points (crossing of roads, crossing of tracks, towns, wells, etc.) on the topographic map at 1/50000 previously set in its projection system (UTM: Universal transverse

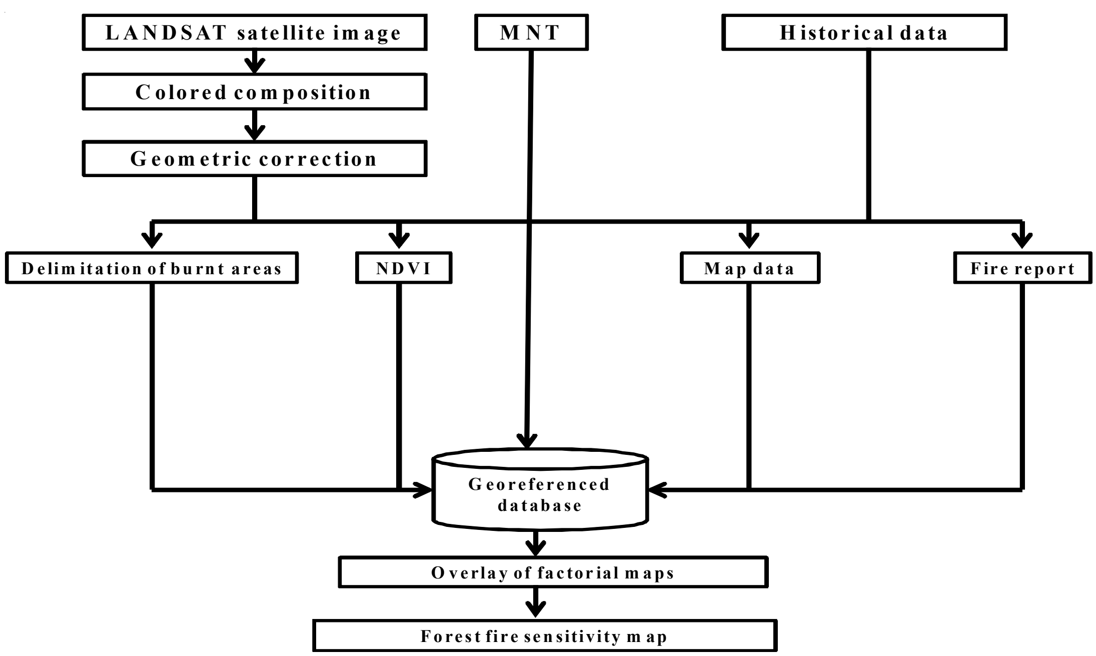

Fig. 2. Flow chart showing all the steps of the study

Mercator, geodesic system: W.G.S, 1984). The polynomial model used is of degree 2, while the interpolation is of the "nearest neighbor" type. The latter preserves the dynamics of the image and therefore adapts better to our purpose. In addition, it makes it possible to draw cartographic areas representing the burnt areas.

Potential sensitivity to fires

We took into consideration in our study the sensitivity analysis of Five parameters which are vegetation density, fuel types, gradient and slope exposure, and evapotranspiration. According to Faour *et al.* and 2006; these factors affect the conduct of forest fires.

Vegetation Index

The NDVI (Normalized Difference Vegetation Index), proposed by Rouse *et al.* in 1974, is a potential source of information for vegetation mapping. It remains the most widely used index, the reasons for this historical "popularity" are mainly due to its simplicity of calculation compared to other indices. Two channels are used for the calculation the red (R) and the near infrared (NIR) since which the contrast between the ground and the vegetation is more accentuated. The channel ratio provides values between (-1 and 1). The delineation of the classes of potential sensitivity of the vegetal covering to fire was made by thresholding the NDVI in order to refine the zoning.

NDVI = PIR – R/ PIR + R

Combustibility

The combustibility makes it possible to assess the part of the risk linked to the power reached by the fire because it is strongly linked to the composition and the quantity of combustible biomass (Faour *et al.,* 2006). The land use map established by the B.N.E.D.E.R in 2012 was georeferenced to extract only the study area, and then it was vectorized and classified according to the most dominant plant species on which we can define the degree of combustibility.

Slope gradient and slope exposure

The steep slopes promote the spread of fire and prevent firefighting interventions (Talbi *et al.,* 2017). The slope was extracted from a digital elevation model (DTM) with a resolution of 50 m. The slope classes were selected based on their frequency of occurrence and their spatial distribution. As for the exposure of slope, is closely linked to the rate of drying and the spread of fires (Talbi *et al.,* 2017).

Evapotranspiration

Areas with high evapotranspiraton are favorable to the start of fire. Slopes exposed to the north have higher evapotranspiration values compared to those exposed to the south, the southern slopes are drier and more bare (Souidi *et al.,* 2010). The evapotranspiration map was taken from the average annual evapotranspiration map of northern Algeria established by ANRH in 2002. Only two classes were taken into consideration for our study area.

Weighting of the various parameters according to their impact on the sensitivity to fire

The methodology adopted consists of a synthetic mapping of potential sensitivity to forest fires arising from the superposition of several thematic maps called factorial maps, namely: the map of the slopes and their exposure, the map of the dominant plant species, the map of evapotranspiration, the NDVI map. All these maps were given in the form of classes according to their potential sensitivity to fires. Five sensitivity classes have been identified: very low, low, medium, strong and very strong. The parameters for evaluating the degree of sensitivity to forest fires are summarized in the table (Table 1).

The spatial analysis based on the crossing and superposition of the different factor maps relating to the parameters described above allows the production of the map of potential sensitivity to forest fires. The superposition of the layers took place according to the principle of two by two which consists in superimposing two thematic maps to establish a new map, on this same map new polygons are created as well as a new attribute table is installed (Arabi, 2016). This technique is carried out via the decision matrix (Table 2) which made it possible to propose a decision tree facilitating the establishment of the final map.

Results and Discussion

The analysis made on the basis of the results of the historical assessment carried out during the period from 1988 to 2018, allowed us to conclude that the most burnt gasoline is the Aleppo pine. The forest fire period lasts more than 07 months, it coincides with the dry season of the study area which lasts

Table 1. Fire sensitivity classes according to each parameter studied

	Evapotranspiration	NDVI	Slope	Dominant essences
Very low	-	0-0.2	0-3%	Other types
Low	1300-1400 mm	0.2-0.4	3-6%	bushes vegetation
Medium	1400-1500 mm	0.4-0.6	6-12%	Shrub vegetation
Strong	1500-1600 mm	0.6-0.8	12-25%	Deciduous trees
Very Strong	-	0.8- 1	>25%	Conifers

from the month of April until the month of October. The fire reaches its maximum during the months of July and August. This analysis gave us a preliminary idea of the burnt areas that were affected by repetitive fires during this period.

The colored compositions of the images made it possible to locate the burnt areas which appear in dark gray (Figure 3). Field trips accompanied by analyzes of historical reports were useful for confirming the location and area of the burned areas and also for taking stationary information such as: The species composition, slope, exposure.

The results from the interpretation of satellite images coincide with the reality on the ground and also with the data provided by the General Directorate of Forests, which shows the interest of remote sensing in monitoring forest fires. Nine map areas representing the most burned areas during the period from 1988 to 2018, were vectorized by the ENVI software, then exported to the Mapinfo. This made it possible to draw up the map of the burnt areas (Figure 4). These areas, which have recorded a large number of fires, are generally located in the northern and northeastern part of the study area near agglomerations and the road network.

The map of the most burned areas between 1988 and 2018 allows clearer conclusions to be drawn on the origin of these fires, since all the burned areas are located near agglomerations and roads, they are therefore easily accessible and subject to fires caused voluntarily. The high frequency of fires and their location in the same sites are indications that further consolidate voluntary acts caused by man. The origin of fires caused by man for the purpose of regenerating rangelands, extension of arable voids, the escape of wild boar, incineration of stubble, search for wild honey, smokers, shepherds (Kezadri, 2019).

Analysis of the factorial maps obtained

The slope exposure map (Figure 5a) indicates that the very strong class is absent and that the strong class occupies 72% of the total forest area, the medium class represents (7%), low (20%) and very low (1%). The vegetation combustibility map (Figure 5b) made on the basis of the dominant species, clearly shows that 52% of the total surface represents a very

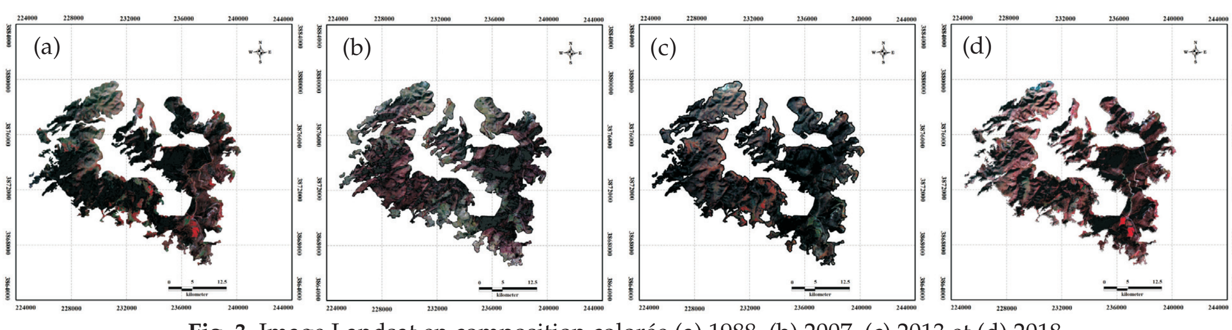

Fig. 3. Image Landsat en composition colorée (a) 1988, (b) 2007, (c) 2013 et (d) 2018.

Table 2. Decision matrix

Essences Slope	Very Low (1)	Low (2)	Medium (3)	Strong (4)	Very Strong (5)
Very Low (1)	1	1	2	3	3
Low (2)	1	2	3	3	4
Medium (3)	2	3	3	4	4
Strong (4)	3	3	4	4	5
Very Strong (5)	3	4	4	5	5

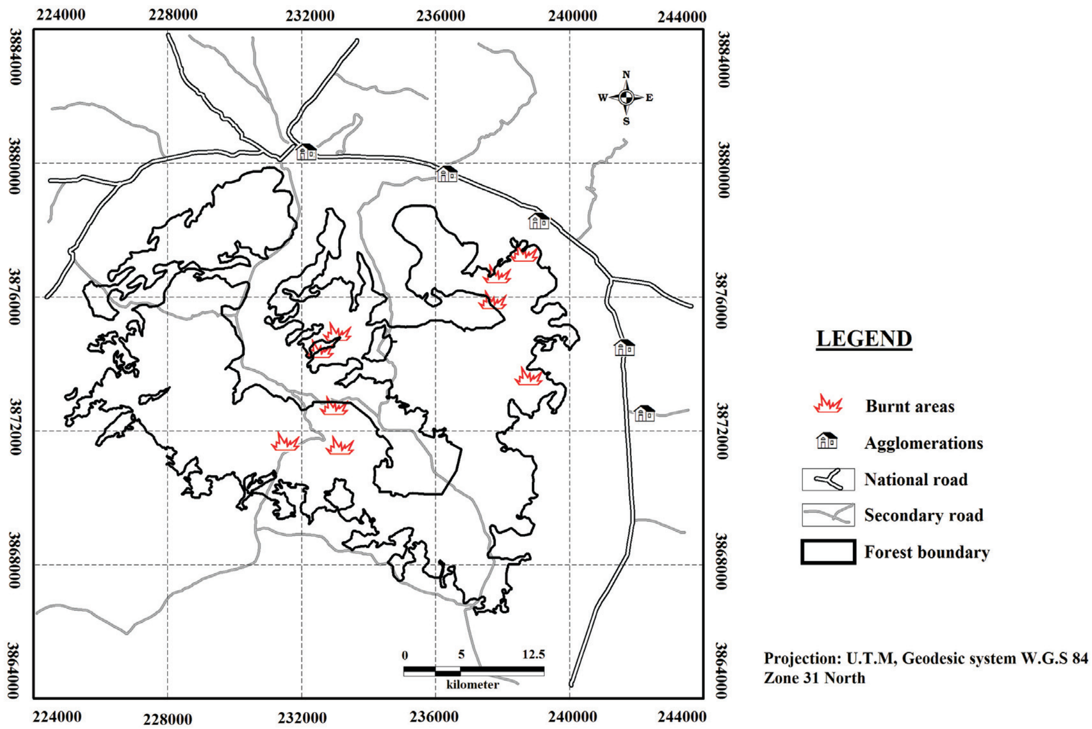

Fig. 4. Carte des zones brulées entre 1988 et 2018.

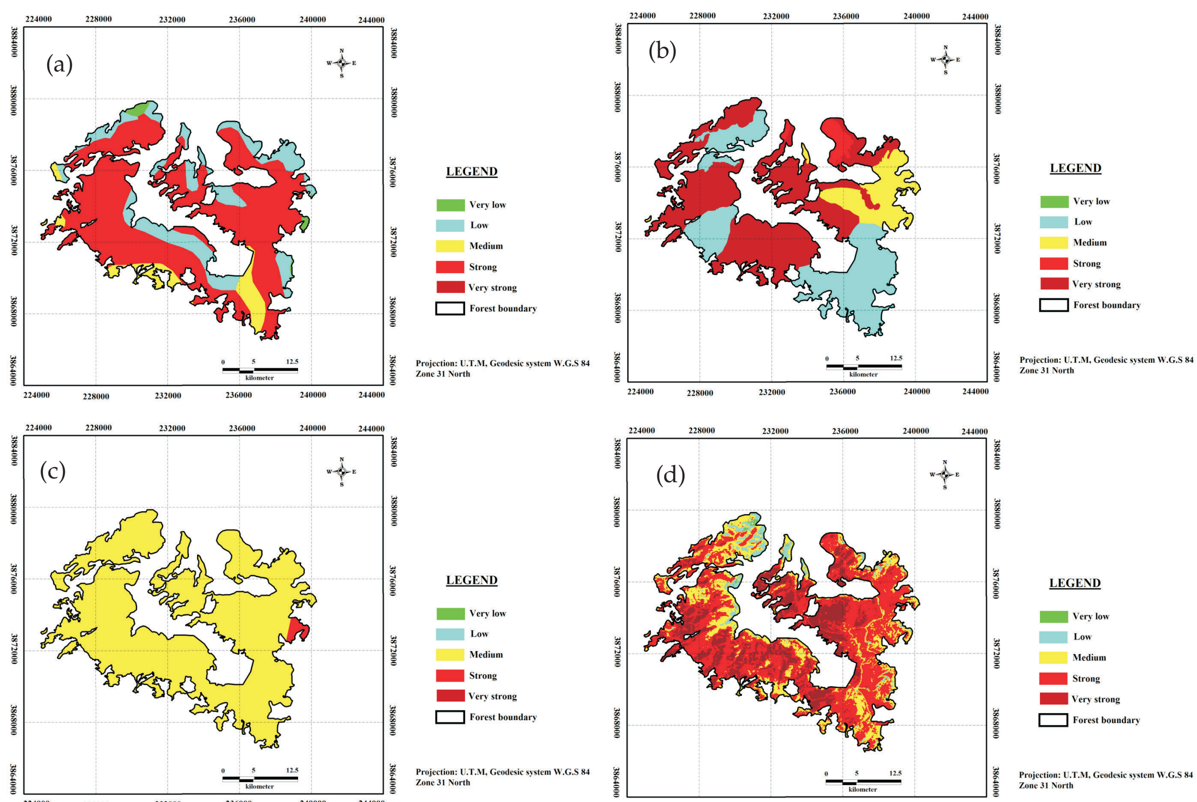

Fig. 5. Factorial maps determining the degree of sensitivity to fires according to each parameter (a) Slope, (b)Dominant essence, (c) evapotranspirationand (d) NDVI

strong sensitivity and 3% a strong sensitivity and 13% an medium sensitivity and that 32% a sensitivity low to forest fires while the very low sensitivity class is absent. The evapotranspiration map (Figure 5c) shows only two class medium (99%) and low (1%) classes. The vegetation density map (Figure 5d) from the NDVI vegetation index shows that 52% of the area of the Tafrent forest represents a strong sensitivity and 22% very strong to forest fires, this is explained by a very dense vegetation cover. The class representing an medium sensitivity also represents 22% of the total forest area. While the low sensitivity class is only 4% and the very sensitive class is absent.

Percentage of fire sensitivity classes for each factor

The Figure 6 allows a comparison to be made according to the degree of fire sensitivity of each parameter studied. The composition and the cover of the vegetation constitute the most favorable factors for fire because the nature of the dominant species and the NDVI are the only parameters characterized by a high percentage of the very strong class which is absent in the other parameters studied. As for the slope, it also records the highest rate in the strong sensitivity class. Finally, evapotranspiration is the least influencing factor on the fire; this is explained by the high rate of the medium sensitivity class.

Forest fire sensitivity map

As for the forest fire sensitivity map (Figure 7), it is a fundamental tool of decision making by rationalizing the use of financial resources on the one hand and guiding the various future programs for better management. the problem of forest fires in the study area on the other hand. It provides a spatialization of this phenomenon hierarchized according to a level of sensitivity which made it possible to divide the study area into five distinct classes by their degree of sensitivity to fires: very low, low, medium, strong and very strong.

Regarding the final result, we notice that the forest fire sensitivity map shows that (16.4%) of the total area of the study area is very vulnerable to fires and that (69.04%) is sensitive, these two classes are found throughout the territory of the study area. While the rest is spread over two classes, an area of the order of (14.35%) is assigned to a medium risk, (0.2%) low, these classes are located in the North-West and South part. –East of the study area.

We note that the low sensitivity class is very reduced due to the absence of cliffs, bare land devoid of vegetation and rocky soils in the study area. As for the medium sensitivity class is located in the center of the Northwestern part of the study area, this class occupies land with a more or less gentle slope and which are covered by less combustible vegetation characterized by shrub strata. and bushy.

We also conclude that the high sensitivity class which dominates the territory of the study area and the very high sensitivity class include steeply sloping land which is covered by a very dense vegetation cover based on flammable species such as *Pinus halpensis, Tetraclinis articulata, Pistacia lentiscus, l'Ampilaudisma mauritanica, Cistus sp, la phyllaire, Calycotome spinosa.* This explains the strong values of NDVI. this zones are located near roads and rural dwellings, so they are subject to strong anthropogenic action as confirmed by Leone, (1994); Marielle, (1999); Faour *et al.,* 2006 Carrega, (2010); Jappiot, (2011), this situation is aggravated by the extension of agricultural land to the detriment of forest land. The presence of the species *Ampelodesma mauritanica*, an indicator species of repeated fires (Smail *et al.,* 2017). The strong presence of shrubs can accelerate the spread of fires, Holidi *et al.,* 2018

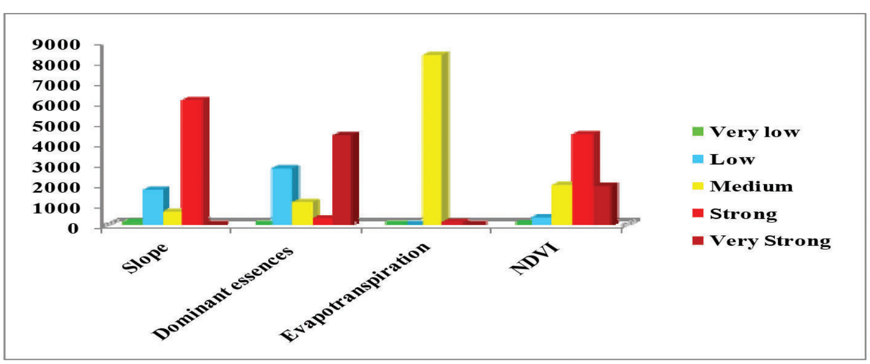

Fig. 6. Percentage des classes de sensibilité aux feux de forêts.

confirmed that the shrub has high risk of fire.

The comparison between the historical data provided by the General Directorate of Forests, the map of burnt areas and the map of sensitivity to forest fires, made it possible to accurately define the main causes that facilitate the outbreak of forest fires. These causes can be summarized in the following points:

- The climatic factor characterized by a long dry period accompanied by winds.

The slope and type of vegetation are the most important factors influencing the acceleration of the fire.

- It should also be noted that man is the perpetrator, voluntary or involuntary, through the ignorance, unconsciousness or the total neglect of the dangers that this phenomenon causes on the ecosystem, the living environment and the economy.
- The Most surface of the study area is vulnerable to fires to varying degrees

Extreme climatic conditions (high temperature, aridity, long dry period), very rugged relief, dominance of plant species with high combustibility to fire, made the study area very vulnerable to forest fires. This situation is accompanied by strong anthropogenic pressure on the ecosystem which favors the outbreak and spread of fires.

Conclusion

Generally speaking, in terms of forest fire control, the approach taken will undoubtedly give appreciable results which are well traced in the fire sensitivity map in the forest of the Tafrent forest which it would be very judicious to strongly advocate a set of extreme emergency intervention actions, in particular we propose:

- Mobilization of water resources through water points near strong sensitive areas and very strong sensitive to fires.
- Development of forest tracks and firewall trenches to facilitate the operation of extinguishing fires in sensitive to very sensitive areas.
- Strengthening of surveillance and installation of lookout posts,
- Involvement of the local population in prevention actions through information and environmental awareness

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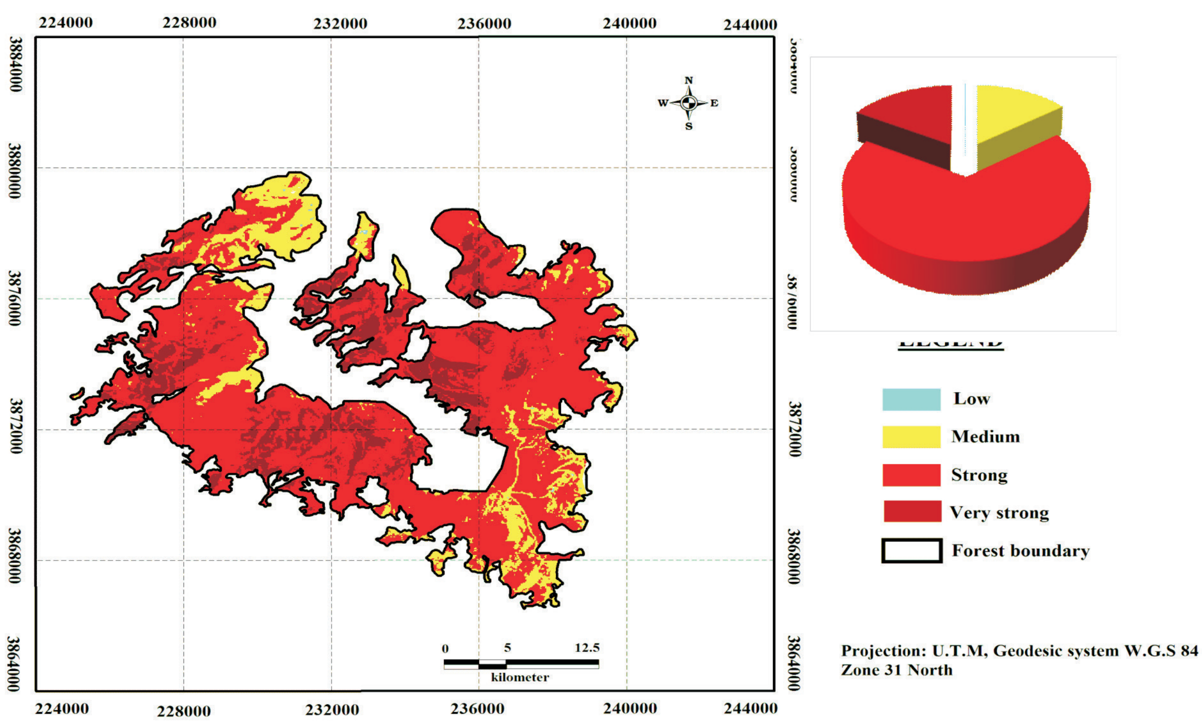

Fig. 7. Map of potential sensitivity to forest fires in the study area

carry out the field work.

References

Arabi, Z., Mederbal, K. and Benaouf, Z. 2014. The state of plant biodiversity in the high plains of Oran (case of the Wilaya of Saida). *International Journal of Basic and Applied Sciences*. [S.l.], v. 3, n. 4, p. 420-425, oct. 2014. ISSN 2227-5053.

Arabi, Z. 2016. Integration of multi-source data into a geographic information system for phytoecological diagnosis and the proposal of a development model "case of the steppe region-Tell region West Algerian interface". Doctoral thesis. Houari Boumediène University of Science and Technology (USTHB) 2016

Belgharb, B., Benabdeli, K. and Mostefai, K. 2018. Mapping the risk of forest fires in Algeria: application of the forest of Guetarnia in Western Algeria. *Ekologia (Bratislava)*. 37(3) : 289-300, 2018. https://doi.org/10.2478/eko-2018-0022

B.N.E.D.E.R, 2012. Land use map of the wilaya of Saida. Scale 1/50000.

Bordin, P. 2002. GIS, concepts, tools and data. Ed, Hermes science, Paris. 251 P.

Carrega, P. 2010. Le risque d'incendies de forêt en régon méditerranéenne. Comprehenssion et évolution (The forest fires risk in the mediterranean region : undestanding and evolution. Erchive ouverte HAL – 00470225, version 1-5 Apr2010.

Dagorne, A., Durue, Y., Foucault, B. and Ottavi, J.Y. 1995. De la modélisation à la simulation grâce au système d'information géographique. Rev. Med.TXVI, n°2, pp : 153-158.

Direction Générale des Forêts, 2020. Bilans des feux de forêts.

Erten, E. Kurgun, V. and Musaoglu, N. 2004. Forest fire risk zone mapping from satellite imagery and GIS a case stady. Inst. Infor, Maslak Istanbul, Turkey, 7p

Esnault, F. 1995. Intérêt d'une cartographie des feux de forêts. Rev. Med. TXVI,n°2, pp : 159-163.

FAO. 2001. FAO Meeting on National Policies Affecting Forest Fires: Rome, 28-30 October 1998. Rome, FAO, p. 291-315.

Faour, G., Boukhei, R et Darwish, A. 2006. Méthode globale d'évaluation du risque d'incendie de forêt utilisant la télédétection et le SIG : Cas de Liban. Centre de télédétection, BP. 11. 8281, Beyrouth, Liban. 5(4) : 359-377.

Haddouche, D. and Gacemi, M. 2011. Analyse spatiale de la régénération forestière post-incendie de la forêt de Fergoug à Mascara, Algérie. Spatial analysis of forest regeneration after fire in the forest of fergoug in Mascara. *Algeria Bois & Forets Des Tropiques*. 307 (1): 23-31 (France. CIRAD).

Hani, I., Rached-Kanouni, M., Khamar, H. and Menasri, A. 2020. Study of the dynamics of natural stands of Pinus halepensis in the Beni Oudjana forest (Khenchela, Algeria). *Eco. Env. & Cons.* 26 (3) : 2020; pp. (974-979)

Holidi, M.E., Armanto, A., Halim, P.K.S., Dinar, D.A. and Putranto. 2018. Evaluating of hotspot on various of permanent land use in Ogan Komering Ilir district South Sumatera during 2014-2016. *Eco. Env. & Cons.* 24 (1) : 2018; pp. (223-227).

Jappiot, M., Lampin, C. and Ferrier, J.P. 2011. Modélisation du risque d'incendie de forêt dans les interfaces habitats-forêts. La revue d'Irstea. Article hors-série n° 3.

Kezadri, O. 2019. Contribution à l'étude analytique des feux de forêts de la wilaya de Bouira Décennie : 2008-2018. Mémoire de Master. Université de Bouira, Algérie.

Leone, V. 1994. Les feux de forêts en Italie en 1993. *Rev. Med. TXV*. 4 : 433-434.

Marielle, J. 1999. Evaluation et cartographie du risque d'incendie de forêt à l'aide d'un SIG : exemple d'un massif forestier du Sud de la France in Atelier « les bases de données sur les feux de forêt en région méditerranéenne, utilisation etenseignement ». Tétouan, Maroc.

Missoumi, A. and Tadjerouni, K. 2003. SIG et imagerie Alsat1 pour lacartographie du risque d'incendie de forêt (Sidi Bel Abbes,) TS13 Risk Management, Marrakech, Maroc, 14p

Rowell, A. and Moore, P.F. 2000. Global review of forest fires. Gland: W.W.F/ I.U. C.N

Souidi, Z., Hamimed, A., Donze, F., Seddini, A. and Mederbal, K. 2010. Estimation de l'évapotranspiration d'un couvert forestier en Algérie par télédétection. *Revue Télédétection*. 9(3-4): 164-181.

Smail,M., Oldach E.H. and Dali, M. 2017. Contribution of GIS to the assessment of the risk of forest fires inGouraya National Park, Bejaia. Conference Paper

Souidi, Z., Kattar, S., Bento-Gonçalves, A. and Vieira, An. 2017. Forest fire risk assessment and cartography in Algeria: A methodological approach. Chapter

Talbi, O., Benabdeli, K., Benhanifia, K. and Haddouche, D. 2017. Cartographie des zones de risque de feux de forêt dans la commune de Doui Thabet, Saïda, Algérie. *International Journal of Environmental Studies*. 1-10. 10.1080/00207233.2017.1386434.

Xu, D., Dai, L.M. and Shao, G.F. 2005. Forest fire risk zone mapping from satellite images and GIS for Baihe Forestry Bureau, Jilin, China. *Journal of Forestry Research*. 16 (3) : 169-174.