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Research paper

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Combining AHP with GIS for mapping the vulnerability to forest fire risk

Kahina Loumi[1] 0000-0002-3840-8306
Ali Redjem[1, ✉] 0000-0001-8527-397X

[1] Urban Techniques Management Institute, City, Environment, Hydraulic, and Sustainable Development Laboratory, M'sila, University of M'sila, Algeria
✉ Corresponding author: kahina.loumi@univ-msila.dz

Summary

This article deals with the problem of forest fires in the province of Tizi Ouzou this tragic phenomenon which has always struck the region and which often causes degas at the same time human, social, economic, ecological and sanitary. The methodology applied to the Tizi Ouzou region aims to study the vulnerability of its territory to forest fires. The AHP-GIS integration greatly facilitates this work because in this study several qualitative and quantitative criteria come into play. The construction of this structure was based on the construction of a grid of criteria applied to the entire area of The study, using geomantic operations as integrating and generating tools. To choose the most vulnerable area, a geographic information system (GIS) was combined with an analytical hierarchy process (AHP) in order to analyze several criteria, such as land use, climatological condition and Topography. The AHP was applied to determine the importance weights of each criterion. to assess the vulnerability of areas, a simple additive weighting method was used. Each criterion was evaluated with the aid of AHP and mapped by GIS. The main advantage of such an approach is to facilitate the analysis of complex data in the form of graphical representations. In particular, this is an essential decision-making tool for elected representatives of local authorities. These results can be used effectively to plan fire control measures in advance and the methodology suggested in this study can be adopted in other areas too for delineating potential fire risk zones.

Keywords

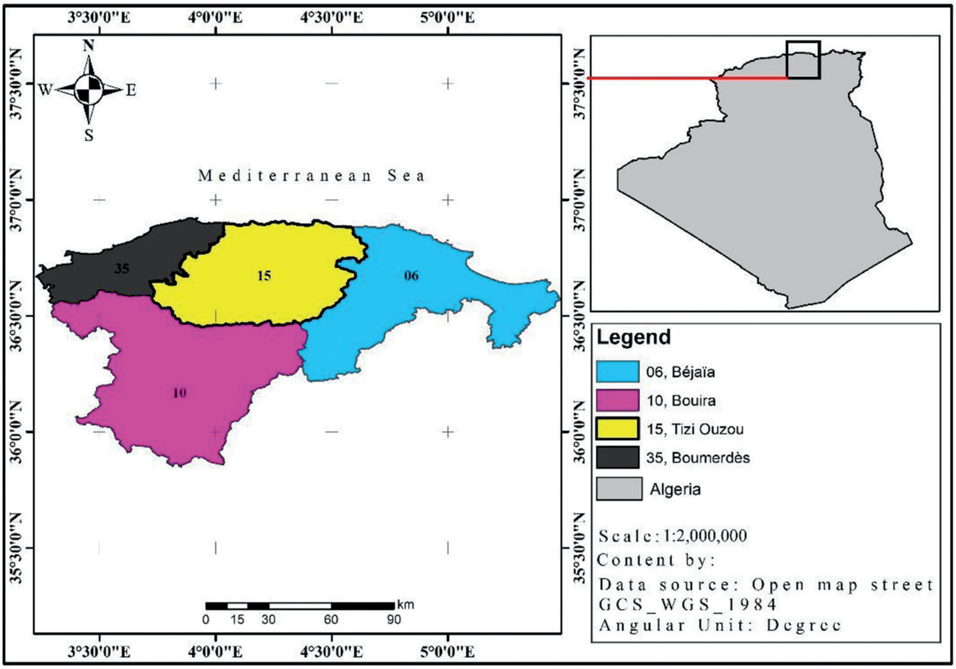
forest fires • AHP-GIS integration • Tizi Ouzou region • risk • decision-making

1. Introduction

Protected areas, which play a significant role in maintaining environmental balance, are found in forests in developing regions [Bonan 2008]. Although extremely important, forest cover loss in these regions is occurring at an alarming rate [Uusivuori et al. 2002]. Over the past decades, forest cover loss has been attributed to forest fires, rapid economic development, agriculture, logging, and human population growth [Ajin et al. 2015]. Globally, about 30% of tropical forests were degraded by logging and fires between 2000 and 2012 [Coomes et al. 2017].

Forests are among the most productive ecosystems in the world as they provide essential services that support key sectors (agriculture, energy, water, mining, transport and urban sectors) [FAO 2018], helping to maintain soil fertility, protect watersheds, to provide habitat for a wide range of species and to reduce the risk of natural disasters, including floods and landslides, and also to slow climate change by absorbing carbon dioxide released by burning fossil fuels through photosynthesis [Gupta et al. 2012]. Unfortunately, the world's forests have always been exposed to several disturbances, themselves strongly influenced by climate change on the one hand, such as fires, droughts, landslides, the spread of invasive species and infestations [Thom et al. 2016]. Insects, on the other hand, are threatened by the expansion of agriculture, timber production, firewood collection and other human activities. All these factors have affected the vulnerability of forests to the various risks they face, especially in terms of frequency, severity, duration, and timing of disturbances [Seidl et al. 2017, Canelles et al. 2021]. For example, increased fuel loads, longer fire seasons and more severe weather conditions could result. Today, forest fires are the most common hazard threatening forest wealth and the entire forest system. This phenomenon has dramatically increased in recent decades (wildfires destroy an annual value of 10 million hectares worldwide), due to socio-economic problems and climate change. Lightning causes less than 10% of fires worldwide. However, 90% of forest fires are of human origin [San-Miguel-Ayanz et al. 2017]. Some of the most common causes of fires include criminal acts, private and agricultural forestry, irresponsible behavior, littering, reigniting fires, etc. In Algeria, the forest area destroyed by forest fires has increased significantly in recent years. In 2021, a series of fires separately ravaged 89 thousand hectares of forest, fruit trees and olive trees in several northern regions (a total of 71 fires in 35 states) [Forest Wildfires 2023]. Indeed, 19 forest fires, including eight major ones, were recorded in several municipalities of the state of Tizi Ouzou, with a death toll of 69, including 28 soldiers and 41 civilians, and 12 injured, in addition to the destruction of dozens of homes [Forest Wildfires 2023], this has subsequently caused environmental, economic, and social disruption. Our interest in this study is to map the vulnerability of the state of Tizi Ouzou to the risk of forest fires through the integration of geographic information systems and the multi-criteria hierarchical GIS-AHP method. The cartography obtained makes it possible to locate the zones exposed to the risk to help to set up prevention and control programs in a more precise way in the face of forest fires. The state of Tizi

Ouzou is in the North of Algeria; it extends over an area dominated by mountainous ensembles. The Algerian north (the Tell Atlas) is the region in which most of the fertile and arable land and wooded structures are found, unlike the arid lands of the highlands or the arid expanses of the Sahara. It is a region located between the coast to the north and the highlands to the south, which extends over part of northwestern Tunisia.



Source: Authors' own study

Fig 1. Location map of the state of Tizi Ouzou

2. Material and research methods

In this study, a multi-criteria method (AHP) was integrated into GIS software (Arc GIS 10.3) to assess the vulnerability of the state of Tizi Ouzou to the risk of forest fires, this methodology was developed according to the following steps.

2.1. Identification of study criteria

The vulnerability of a territory to the risk of forest fire imposes society-nature interactions, the criteria studied and the sub-criteria are the factors of the natural and anthropogenic environment which influence the outbreak, the spread and the intensity of a fire.

2.2. Map study criteria

The evaluation criteria are identified in relation to the factors that have the greatest impact on the vulnerability of the forest territory of the state of tizi ouzou to the phenomenon of forest fires. Each criterion is therefore linked to several classes. Each evaluation leads to a map representing [Joerin 1995]. These maps were obtained on the basis of satellite images integrated into a database for the creation of a Geo-referenced GIS.

2.3. Weighting of study criteria

The process of calculating the relative importance of each criterion is according to the scales shown in the Table 1.

Table 1. Comparison scale

Scale	Description
1	Equal importance of two elements.
3	One element is slightly more important than the other.
5	One element is more important than the other.
7	One element is much more important than the other.
9	One element is much more important than the other.
2, 4, 6 ,8	2, 4, 6, 8 Intermediate values between two judgments.

2.4. Verification of the consistency of the study criteria

In order to test the respect of the transitivity of our judgment, Saaty [1990] proposes the following mathematical formula where IC is the coherence index, N the number of elements compared and λmax, a value calculated on the basis of the average of the values of Saaty matrix where λmax is the largest eigenvalue of the n × n reciprocal pairwise-comparison matrix:

$$IC = \frac{(\lambda\text{max} - N)}{(N - 1)}$$

To obtain the average consistency λmax, each column of the non-normalized binary comparison matrix is multiplied by the weight of the associated criterion. The sum of the elements is then calculated for each row. The consistency of each criterion is given by the previous sum divided by the weight of the row criterion. By summing the consistency of each criterion and dividing by the number of criteria, we obtain the average consistency.

The coherence ratio (CR) is calculated by the equation:

$$RC = \frac{IC}{IA}$$

Saaty [1990] defined the Random Index (AI) of a matrix of the same dimension presented in the Table 2. According to Saaty [1990], when it comes to comparing less than 9 elements, a tolerance threshold of 10% is set for this consistency index.

Table 2. Random index by number of criteria

n	1	2	3	4	5	6	7
IA	0	0	0.58	0.9	1.12	1.24	1.32

Source: Saaty [1990]

2.5. Aggregation of study criteria

This operation consists of multiplying each factor layer by its respective weighting coefficient as confirmed in the hierarchical structure according to the AHP method, and the integration of the criteria cards in accordance with their weight on a GIS software by using a method of linear combination of weighting for their aggregation in order to obtain a summary map this analytical method has a very important role in the organization of data and spatial information, their presentation, analysis and interpretation.

3. Results

Wildfires (also known as bushfires or forest fires) are large, uncontrolled fires that can have a devastating impact in rural and urban areas. It can spread rapidly, change the direction of its spread, and even 'jump' great distances as its embers and sparks fly up to be carried by the wind. According to scientific studies, the spread of forest fires depends on the terrain, the available fuel (vegetation or wood debris) and weather conditions (wind direction, speed and temperature). For that the classes of the under criterion are determined both from the factors that have the most important influence on the spread of fires in relation to the experience of professionals of the fight and also from the bibliography [Burgan and Robert 1984, Van Wagner 1987, Lambert 1977, Sol 1991, Alexandrian 1990, Dupuy 1995, Dupuy 1997]. The judgment is exercised between the following criteria, each criteria is supported by a cartographic representation.

The pair wise comparison of the sub-criteria relating to the criteria applied for our case gave the following results (Table 4, the comparison matrix is normalized so that the sum of all the weights is equal to 1).

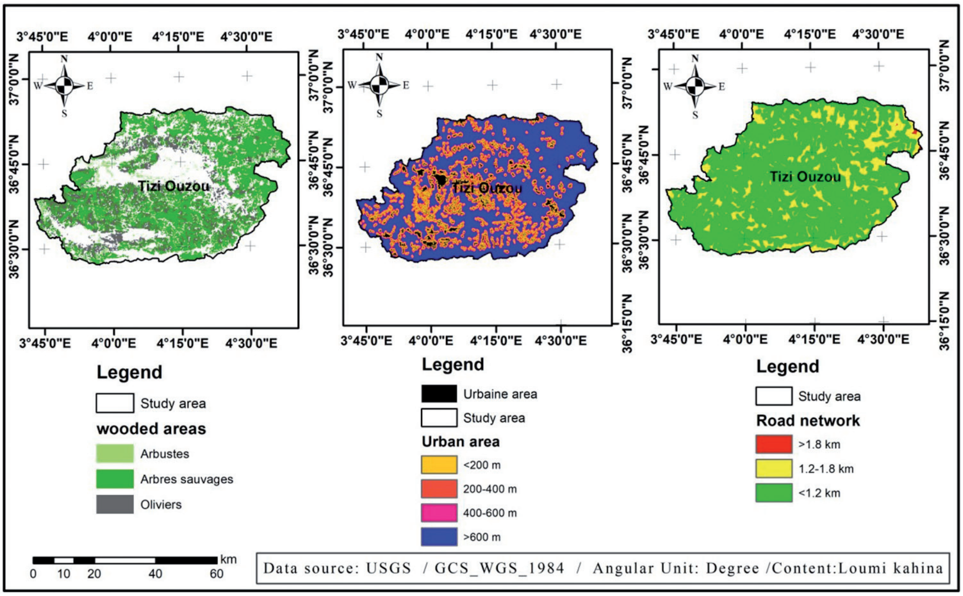
Table 3. Standardization of selected criteria

Criteria	Under citerions	Rank	Value	Class
Land use	Wooded areas	1	3	Shrubs
		2	5	Wild trees
		3	9	Olive trees
	Urban areas	1	9	0–200 m
		2	5	200–400 m
		3	7	400–600 m
		4	3	> 600 m
	The road network	1	3	> 1.8 km for 100 ha of wood
		2	5	1.8–1.2 km for 100 ha of wood
		3	7	< 1.8 km for 100 ha of wood
Climatological condition	Wind	1	3	< 9 m/s
		2	7	9–17 m/s
		3	9	> 17 m/s
	Temperature	1	3	< 15 °C
		2	7	15–30°C
		3	9	> 30 °C
	Air humidity	1	3	< 35%
		2	7	35–65 %
		3	9	> 65 %
Topography	Altitude	1	3	< 600 m
		2	7	600–800 m
		3	9	> 800 m
	Slope	1	3	< 10°
		2	7	10°
		3	9	> 10°
	Orientation	1	5	North
		2	9	East
		3	7	West
		4	9	South

Table 4. The results of the pair wise comparison of the sub-criteria

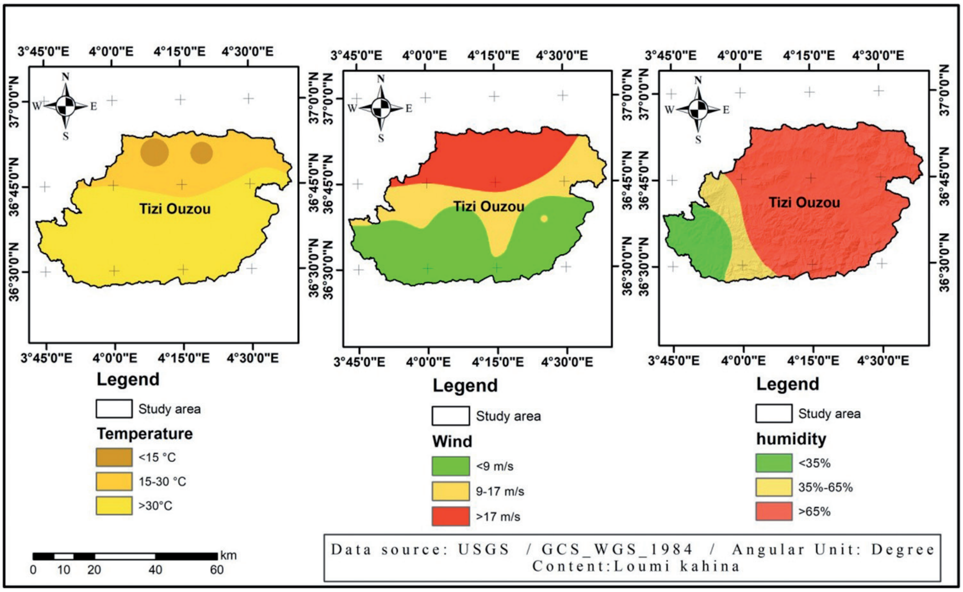
Under criterions	1	2	3	4	5	6	7	8	9	W
1	1	1/5	2	3	2	5	4	4	4	0.17
2	5	1	5	7	5	4	2	3	3	0.30
3	1/2	1/5	1	3	1/5	2	3	3	2	0.09
4	1/3	1/7	1/3	1	1/2	1/2	1/3	1/3	1	0.04
5	1/2	1/5	5	2	1	4	7	5	3	0.18
6	1/5	1/4	1/2	2	1/4	1	5	3	2	0.09
7	1/4	1/2	1/3	3	1/7	1/5	1	1/2	1/3	0.05
8	1/4	1/3	1/3	3	1/5	1/3	2	1	3	0.04
9	1/4	1/3	1/2	1	1/3	½		1/3	1	0.04

Explanations: 1 – wooded areas, 2 – urban areas, 3 – road network, 4 – wind, 5 – temperature, 6 – air humidity, 7 – altitude, 8 – slope, 9 – orientation



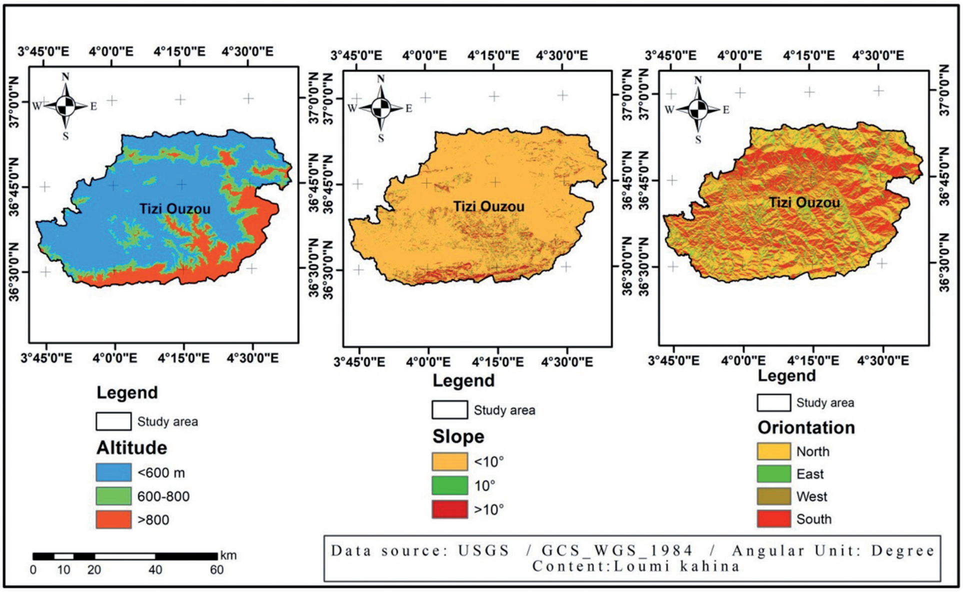
Source: Authors' own study

Fig 2. Land use of the state of Tizi Ouzou



Source: Authors' own study

Fig 3. Climatological condition of the state of Tizi Ouzou



Source: Authors' own study

Fig 4. Topography of the state of Tizi Ouzou

The consistency of criteria must be checked before the application of the cartographic overlay, and after the application of the formulas presented above we find RC < 0.1.

After the superimposition of the geographical data and the maps which represent the criteria of our study by multiplying each layer by its weight obtained by the AHP calculation in GIS software (with ArcGIS interactive maps Builder), we obtained a summary map which represents the vulnerability of the territory of Tizi Ouazou state in the face of forest fire risk.

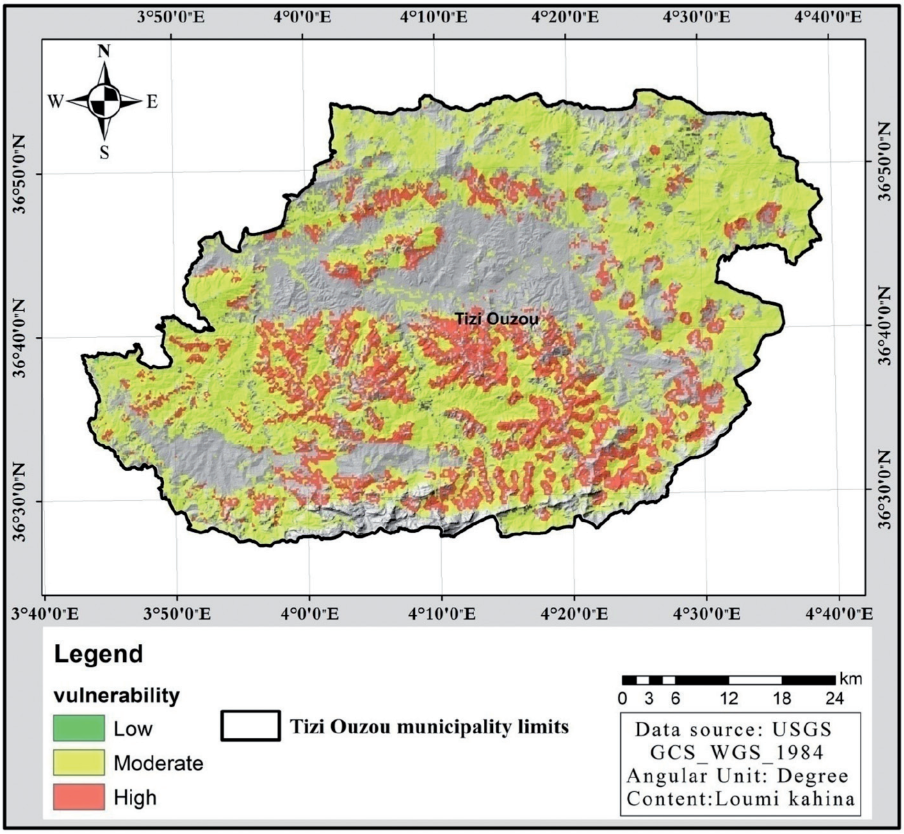


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Fig 5. Vulnerability to forest fire risk of the state of Tizi Ouzou

4. Conclusions

This research document has dealt with the sensitivity of the forest region of the province of Tizi Ouzo to forest fires. This risk is considered to be one of the most important and frequent subjects of particular attention from researchers and decision-makers, especially after the tragic fires that the Wilaya experienced in 2021 and which caused enormous material and human damage, this directly affected the economy, society and the environment too.

The method of analysis used in this study and which relates to the integration of GIS techniques based on satellite imagery to an Analytical Hierarchy Process (AHP) guided us to develop a cartography at 1/200,000 of the whole of the forests of the province of Tizi Ouzou, estimated at 41,489 hectares. This map contains 4 classes according to the level of sensitivity to the risk of forest fire from low to very high. The vulnerability map is considered as an aid tool decision-making in order to put in place an action plan to fight against this danger and to develop prevention and protection plans.

References

Ajin R.S., Ciobotaru A.M., Vinod P.G., Jacob M.K. 2015. Forest and wildland fire risk assessment using geospatial techniques: a case study of Nemmara forest division, Kerala, India. J. Wetlands Biodivers., 5, 29–37.

Alexandrian D. 1990. Analyse des données contenues dans le fichier Prométhée Région Provence Alpes Côte d'Azur. Ministère de l'Agriculture, Entente.

Algeria: Forest Wildfires – Operation Update Report. DREF Operation no. MDRDZ008, Operation update no. 01. Situation Report, Source IFRC, originally published 28.03.2023.

Barmpoutis P., Papaioannou P., Dimitropoulos K., Grammalidis N. 2020. A Review on Early Forest Fire Detection Systems Using Optical Remote Sensing. Sensors, 20, 6442. https://doi.org/10.3390/s20226442

Bonan G.B. 2008. Forests and climate change: forcings, feedback, and the climate benefits of forests. Science, 320(5882), 1444–1449.

Burgan R.E. 1984. Behave: fire behaviour prediction and fuel modelling system, fuel subsystem. https://doi.org/10.2737/INT-GTR-167

Canelles Q., Aquilué N., James P.M.A., Lawler J., Brotons L. 2021. Global review on interactions between insect pests and other forest disturbances. Landscape Ecology, 7, 1–28. https://doi.org/10.1007/s1098 0- 021-01209-7

Coomes D.A., Dalponte M., Jucker T., Asner G.P., Banin L.F., Burslem D.F., Lewis S.L., Nilus R., Phillips O.L., Phua M.H., Qie L. 2017. Areabased vs. tree-centric approaches to mapping forest carbon in Southeast Asian forests from airborne laser scanning data. Remote Sens. Environ., 194, 77–88.

Dampage U., Bandaranayake L., Wanasinghe R., Kottahachchi K., Jayasanka B. 2022. Forest fire detection system using wireless sensor networks and machine learning. Scientific Reports,12, 46. https://doi.org/10.1038/s41598-021-03882-9

Dupuy J.L. 1995. Slope and fuel load effects on fire behaviour: laboratory experiments in pine needles fuel beds. Int. J. Wildland Fire, 5(3), 153–164.

Dupuy J.L. 1997. Mieux comprendre et prédire la propagation des feux de forêts: expérimentation, test et proposition de modèles. Thèse INRA/Univ. Claude Bernard, Lyon I, 272 p.

El Amraoui S., Rouchdi M., Bouziani M., El Idrissi A. 2017. Intégration du SIG et de l'analyse hiérarchique multicritère pour l'aide dans la planification urbaine: étude de cas de la province de Khemisset, Maroc. Papeles de Geografía 63. http://dx.doi.org/10.6018/geografia/2017/280211

Fatih S., Ömer K. 2022. Modeling forest fire risk based on GIS-based analytical hierarchy process and statistical analysis in Mediterranean region. Ecological Informatics, 68, 101537, https://doi.org/10.1016/j.ecoinf.2021.101537

Gupta Anil K., Nair Sreeja S. 2012. Ecosystem Approach to Disaster Risk Reduction. National Institute of Disaster Management, New Delhi, p. 202.

Hossein M., Mohammad M., Biswajeet P., Loke Kok F. 2020. Fuzzy-metaheuristic ensembles for spatial assessment of forest fire susceptibility. Journal of Environmental Management, 260, 109867. https://doi.org/10.1016/j.jenvman.2019.109867

Joerin F. 1995. Méthode multicritère d'aide à la décision et SIG pour la recherche d'un site. Revue Internationale de Géomatique, 5, 37–51.

Kim T., Hwang S., Choi J. 2021. Characteristics of Spatiotemporal Changes in the Occurrence of Forest Fires. Remote Sensing, 13, 4940. https://doi.org/10.3390/rs13234940

Lambert J.L. 1977. Forests fires in Morocco in relation to weather and fuel conditions. Annales de la recherche forestière au Maroc, 17. http://archives.cnd.hcp.ma/uploads/news/015618.pdf

Loumi K. 2021. Croissance urbaine et risque d'inondation cas de la ville de M'sila. Ph.D. thesis, University of M'sila. Algeria. http://dspace.univ msila.dz:8080//xmlui/handle/123456789/29134

Loumi K., Redjem A. 2021. Integration of GIS and Hierarchical Multi-Criteria Analysis for Mapping Flood Vulnerability. The Case Study of M'sila, Algeria. https://doi.org/10.48084/etasr.4266

Lukić T., Bjelajac D., Fitzsimmons K.E., Marković S.B., Basarin B., Mlađan D., Micić T., Schaetzl J.R., Gavrilov M.B., Milanović M., Sipos G., Mezősi G., Knežević Lukić N., Milinčić M., Létal A., Samardžić I. 2018. Factors triggering landslide occurrence on the Zemun loess plateau, Belgrade area, Serbia. Environmental Earth Sciences, 77. https://doi.org/10.1007/s12665-018-7712-z

Lukić T., Marić P., Hrnjak I., Gavrilov M.B., Mladjan D., Zorn M., Komac B., Milošević Z., Marković S.B., Sakulski D., Jordaan A., Đorđević J., Pavić D., Stojsavljević R. 2017. Forest fire analysis and classification based on Serbian case study. Acta Geographica, Slovenica 57. https://doi.org/10.3986/AGS.918

Lukić T., Micić Ponjiger T., Basarin B., Sakulski D., Gavrilov M., Marković S., Zorn M., Komac B., Milanović M., Pavić D., Mesaroš M., Marković N., Durlević U., Morar C., Petrović A. 2021. Application of Angot precipitation index in the assessment of rainfall erosivity: Vojvodina Region case study (North Serbia). Acta Geographica Slovenica, 61–2. https://doi.org/10.3986/AGS.8754

Luković J., Blagojević D., Kilibarda M., Bajat B. 2015. Spatial pattern of North Atlantic Oscillation impact on rainfall in Serbia. Spatial Statistics 14-A. https://doi.org/10.1016/j.spasta.2015.04.007

Martins A., Novais A., Santos J.L., Canadas M.J. 2022. Promoting Landscape-Level Forest Management in Fire-Prone Areas: Delegate Management to a Multi-Owner Collaborative, Rent the Land, or Just Sell It? Forests, 13, 22. https://doi.org/10.3390/f13010022

Parajuli A., Gautam P.A., Sharma P.S., Bhujel B.K., Sharma G., Thapa B.P., Bist S.B., Poudel S. 2020. Forest fire risk mapping using GIS and remote sensing in two major landscapes of Nepal. Geomantic, Natura Hazards and Risk, 11-1.

Saaty T.L. 1990. How to make a decision. The Analytical Hierarchy Process. European Journal of Operational Research, 48, 9–26.

San-Miguel-Ayanz J., Durrant T., Boca R., Liberta G., Branco A., De Rigo D., Ferrari D., Maianti P., Artes Vivancos T., Costa H. et al. 2017. Forest Fires in Europe, Middle East and North Africa 2017. Publications Office of the European Union: Luxembourg.

Seidl R., Schelhaas M.-J., Lexer M.J. 2011. Unraveling the drivers of intensifying forest disturbance regimes in Europe. Global Change Biol., 17, 2842–2852.

Seidl R., Thom D., Kautz M. et al. 2017. Forest disturbances under climate change. Nature Clim. Change, 7, 395–402. https://doi.org/10.1038/nclimate3303

Sirin A., Medvedeva M. 2022. Remote Sensing Mapping of Peat-Fire-Burnt Areas: Identification among Other Wildfires. Remote Sensing, 14.

Sol B. 1991. Comparaison de diverses méthodes d'estimation du danger météorologique d'incendie sur le Sud-Est de la France: feux d'été de la zone côtière et feux d'hiver des Alpes de Haute-Provence. Météo France, Direction interrégionale Sud-Est, Note DIR/SE no.13.

Thom D., Seidl R. 2016. Natural disturbance impacts on ecosystem services and biodiversity in temperate and boreal forests. Biol. Rev., 91, 760–781.

United Nations Environmental Programme (UNEP). 2002. Global Environment Outlook, 3, 92-807-2087-2, 1–424.

Uusivuori J., Lehto E., Palo M. 2002. Population, income and ecological conditions as determinants of forest area variation in the tropics. Global Environ. Chang., 12(4), 313–323.

Van Wagner C.E. 1987. Elaboration et structure de la méthode canadienne de l'Indice Forêt Météo. Service Canadien des forêts, Institut forestier national de Petawawa, 34.

Vladimir Ć., Uroš D., Nemanja R., Ivan N., Nina Č. 2022. GIS application in analysis of threat of forest fires and landslides in the svrljiški timok basin (Serbia), 102-1. https://doi.org/10.2298/GSGD2201107C