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Mapping the Wildland-Urban Interfaces for Forest Fire Prevention in the Province of Mila (Algeria)

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Areas where the habitat is in contact with the forest represent danger and become a real concern for managers who need location tools to act and limit fire risks in these territories. In this context, our study focuses on determining and mapping the different types of wildland-urban interface (WUI) existing in the Zouagha forest. The methodology integrates four types of a housing structure, limited to a radius of 100 meters around each house and three classes of vegetation aggregation. The GIS tool maps and identifies twelve types of WUI in the study area. Our results show that WUI areas in the Zouagha forest increased rapidly over the last decade. New houses were the main cause for new WUI. In 2019, the number of buildings in the study area was 51% higher than in 2009. These urban areas are more exposed to wildfire risks due to their proximity to flammable fuels. The spatial analysis allows highlighting the WUI type most sensitive to a fire risk that needs the interventions of environment protection institutions to limit the damage of wildfires.

Keywords: wildfires, vegetation aggregation, wildland-urban interface, Zouagha, Mila, GIS.

Introduction

Forest fires are the most serious natural disasters and have heavy environmental, social and economical consequences in many Mediterranean countries including Algeria. Each year, around 1,700 forest fires burn 36,000 hectares of forests, which represent 0.9% of the forest patrimony of the country. For example, the year 2017 had a great fire damage: a lot of injured fire-fighters, numerous burnt dwellings and more than 53,984 ha (28,841 ha of forests, 10,398 ha of maquis and 14,745 ha of scrub) were burnt over the 36 provinces of Algeria. These burnt areas are almost triple that were consumed by the fires in 2016, which represented 18,370 ha, and that was due to adverse weather conditions. The forest species mostly affected by this hazard are Aleppo pine and cork oak, two resilient species because of their regenerative capacity. The origin and causes of these fires are little known and managers are limited in Algeria to the fire extinction phase, rather than moving more towards management that combines extinction and fire prevention techniques.

According to Meddour-Sahar and Bouisset (2013), the pressure exerted by residents on or nearby the forests is at the origin of most large fires (those having an area over 100 ha), representing 3.2% of wildfires in Algeria. The urbanisation in forest area generates new spatial configurations called wildland-urban interfaces (WUI). They are defined as the area that can be significantly affected by the jump of the firebrands, which can cause secondary fires (Lampin-Maillet et al., 2010a). Several studies in Algeria have been carried out on forest fire (Madoui, 2002; Meddour-Sahar et al., 2008; Arfa et al., 2009; Meddour-Sahar and Derridj, 2012; Benderradji et al., 2004). However, it is difficult to find precise data on the spatial location of the WUIs and their temporal dynamics. Studying the WUI is especially important in the context of wildfires because the majority of fires are concentrated in the WUI. On the other hand, vegetation near homes provides fuels that allow forest fires spread and threaten inhabited areas (Conedera et al., 2015; Lampin-Maillet et al., 2010a; Hammer et al., 2007; Radeloff et al., 2005).

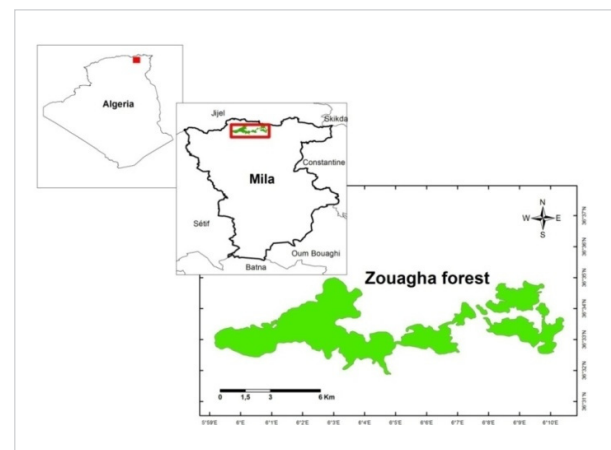
The present study is the first attempt to characterise wildland-urban interfaces (WUIs) in eastern Algeria

(province of Mila) and map their change over time using remote sensing and geographic information system technique. The development of an effective method for accurately mapping wildland-urban interface would be necessary to act as quick as possible in order to limit the risk of wildfires.

Study area

The study area is located in north-eastern Algeria in the province of Mila, between $36^{\circ}31'30''\text{N}$ and $36^{\circ}35'30''\text{N}$ latitude, and between $5^{\circ}59'30''\text{E}$ and $6^{\circ}10'30''\text{E}$ longitude, at altitudes ranging from 483 to 1,344 m above sea level (Fig.1).

Fig.1. Study area



The study area includes the Zouagha forest and extends over three municipalities: TassalaLamtai, Amira Arres and TerraiBainen. The natural vegetation is formed by pure cork oak forests or mixed with Algerian oak or afares oak.

We chose this study area because it frequently experiences severe forest fires each year. In 2019, over 16 fires destroyed 564 hectares in this region. The most burnt area is located in the Zouagha forest (approximately 58% of the total burnt area in the Province of Mila). Thus, the forestry experts have emphasised the need for forest level approaches to wildfire mitigation in this region.

Materials and methods

Data sources

The imagery data source used in this study is the Landsat 8 data acquired in July 2019, with a 30-metre spatial resolution. Landsat images were downloaded from the United States Geological Survey (USGS) (<https://earthexplorer.usgs.gov/>). We selected the images of July period to minimise the possible occurrence of environmental condition.

Other data used in this study include topographic maps at a scale of (1/50.000) produced by the General Directorate of Forestry (GDF) and high resolution imagery of Google Earth. The data were used to digitise the forest limit and the residential houses.

To extract topographic variables (slope and aspect), we used digital elevation model (DEM) data provided by the NASA Shuttle Radar Topography Mission (SRTM) model, which is an open source. The resolution of SRTM is 30 m.

ArcGIS software (10.1 version)

It is a set of geographic information software (GIS) developed by the American company Esri (Environmental Systems Research Institute). This software allowed us to acquire process and analyse geographic information. It was used here to combine different layers and to map results.

ENVI software (4.7 version)

Environment for visualizing images (ENVI) software (developed by Harris Geospatial Solutions, Broomfield, Colorado, United States of America) is useful for the visualisation, analysis, and presentation of all types of digital imagery.

FRAGSTATS software (4.2 version)

FRAGSTATS is a computer software programme produced by the authors at the University of Massachusetts, Amherst (McGarigal et al., 2012). It is designed to compute a wide variety of landscape metrics for categorical map patterns. It allows particularly the calculation of an aggregation index (AI) on vegetation.

Methodology

Production of a land cover map

The land cover map of the study area was created on

Table 1. Characteristics of the spectral bands used

Spectral band	Wavelength (µm)	Resolution (m)
Green	0.525–0.600	30
Red	0.630–0.680	30
Near infrared, NIR	0.845–0.885	30

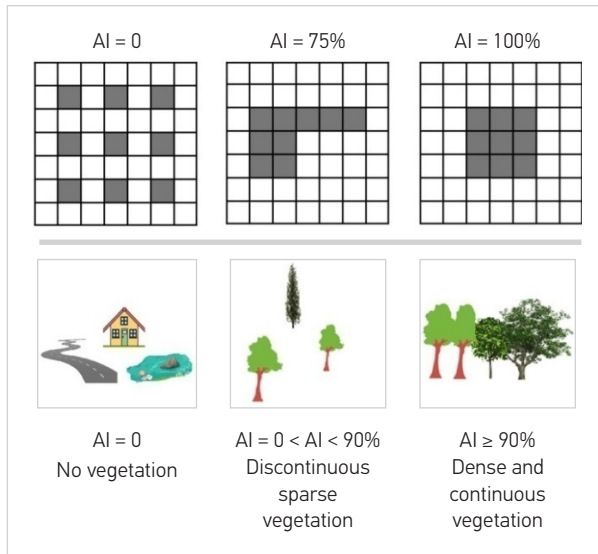
the basis of the Landsat 8 image (path 194, rows 35), which has 9 spectral bands with a spatial resolution of 30 m for bands 1–7 and 9, while band 8 has a spatial resolution of 15 m (panchromatic band). Three spectral bands were used for image classification (Table 1).

The image classification was carried out by using ENVI (version 4.7). A supervised classification technique with a maximum likelihood algorithm was applied. The Landsat image was classified into four types of land covers based on the reflectance properties acquired by satellite sensor data: cork oak forests, Algerian oak forests, afares oak forests and urban land. Training samples using ancillary datasets were taken as signature classes for classification. After supervised classification, post-classification sorting was performed to improve classification results. The classified images were then sieved, clumped, and filtered before yielding the final output. All forest vegetation classes obtained from image classification were merged into a single class of vegetation.

The classification image was exported to FRAGSTATS4.2 software to generate the aggregation index of vegetation (AI) with 30m of spatial resolution. AI measures the degree of aggregation between forest patches (He et al., 2000) (Fig.2). It allows the quantification of the landscape configuration which is related to fire behaviour (Galiana-Martin et al., 2011). AI is defined by the following formula:

$$AI = \frac{g_{ii}}{\text{Max } g_{ii}} \times 100 \quad (1)$$

Fig. 2. Illustration of structural vegetation types according to the values of aggregation index (AI)



Where: g_{ij} is the number of contacts between the pixels of a class i ;

$Maxg_{ij}$ is the maximal number of contacts between the pixels of a class i .

To simplify the results, three classes of aggregation values (Fig.2) were carried out as it is illustrated below:

- AI = 0 corresponds to land covers different from vegetation;
- $0 < AI < 90\%$ corresponds to discontinuous sparse vegetation;
- $AI \geq 90\%$ corresponds to dense and continuous vegetation.

Wildland-urban interfaces mapping

Wildland-urban interfaces are areas where urban settlements and wildland vegetation intermingle, making the interaction between human activities and wildlife especially intense in these areas (Calviño-Cancela et al., 2016). The WUIs were mapped according to the method of Lampin-Maillet et al. (2010a), which defines the WUI as the area within a 100-m radius around buildings at a distance of up to 200 m from wildland vegetation. This method integrates housing configuration and vegetation aggregation for fire prevention. The method involves four steps.

Step 1: the layer of houses was mapped from topographic maps and from high resolution imagery of Google Earth. Houses are located in less than 200 meters from forest boundary.

Step 2: the configuration of houses was quantitatively defined and classified into four types of configuration using buffer analysis of ArcGIS 10.1 software:

- Isolated housing: this class corresponds to one to three houses. The distance between groups of houses is more than 100 meters.
- Scattered housing: the distance between groups of 4 to 50 houses is more than 100 meters.
- Dense clustered housing: this class includes one to ten houses but the distance between groups of houses is more than 30 meters.
- Very dense clustered housing: this class corresponds to more than 10 houses. The distance between groups of houses is less than 30 meters.

Step 3: the vegetation structure was determined by measuring the aggregation index of vegetation (AI). As it was detailed previously, the AI emphasises the horizontal continuity of vegetation. For our analysis, we selected three types of aggregation: high aggregation (forest vegetation), low aggregation (transition forest/agricultural uses) and zero aggregation (without forest vegetation).

Step 4: WUIs are delineated by a radius of 100 m around the types of housing (isolated housing, scattered housing, dense clustered housing and very dense clustered housing) using spatial analysis tools in ArcGIS 10.1 software. This distance takes into account the perimeter wherein fuel reduction operations can be imposed on home owners. The ArcGIS 10.1 software maps the intersections between the four types of housing and three types of aggregation, thus characterising 12 types of WUI (Fig.3).

Method for mapping the wildfire risk index

A geographic information system (GIS) can be used effectively to combine different forest-fires causing factors for demanding the forest fire risk zone map. To produce the fire risk map, we used the method of ERTEN et al. (2004). This risk model for fire spreading is based upon a combination of remote sensing and GIS data such as topographic factors (slope, aspect), vegetation types, distance from roads and settlements (Fig.4).

Fig. 3. Flowchart illustrating the elements involved in classification of WUI types

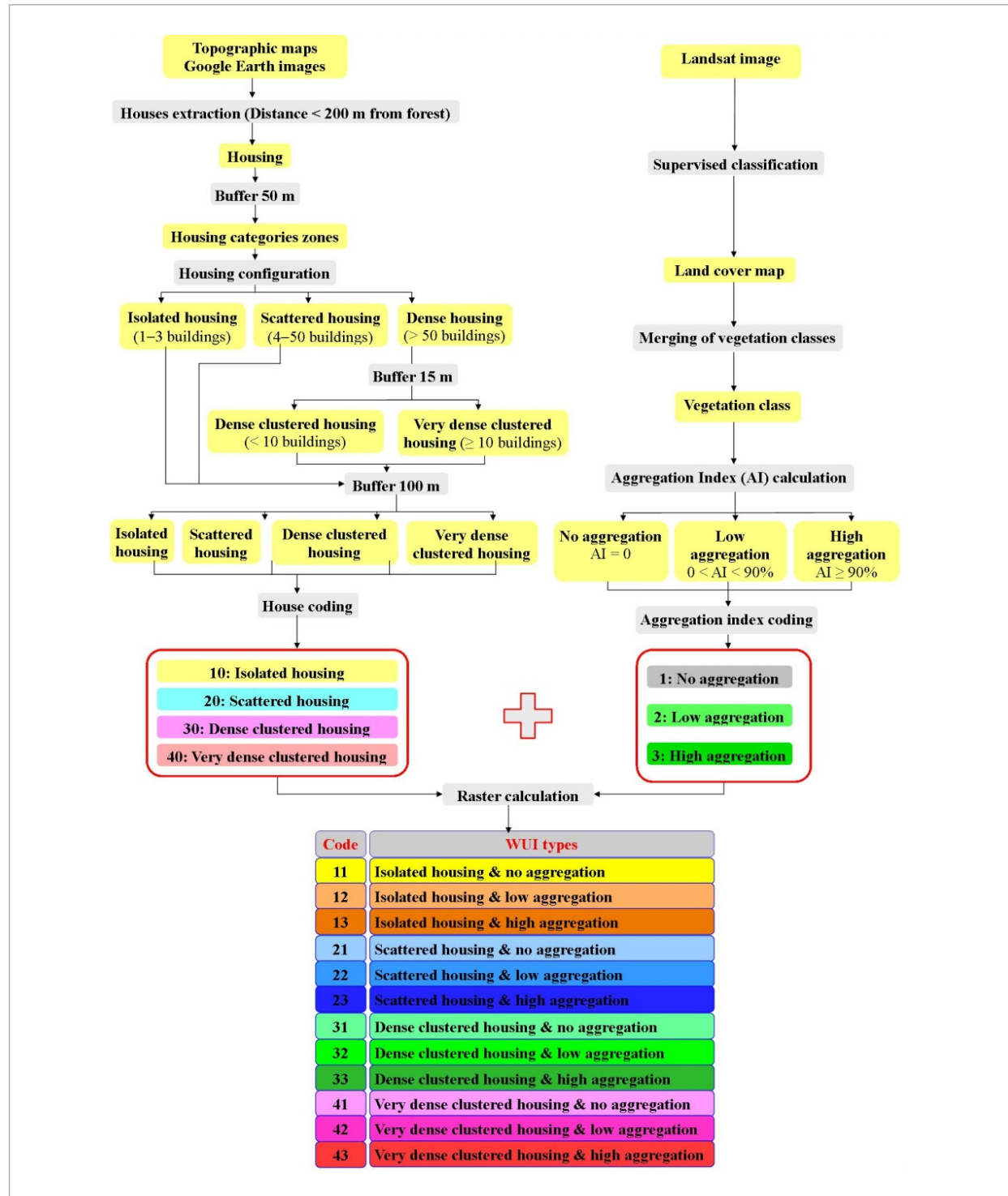
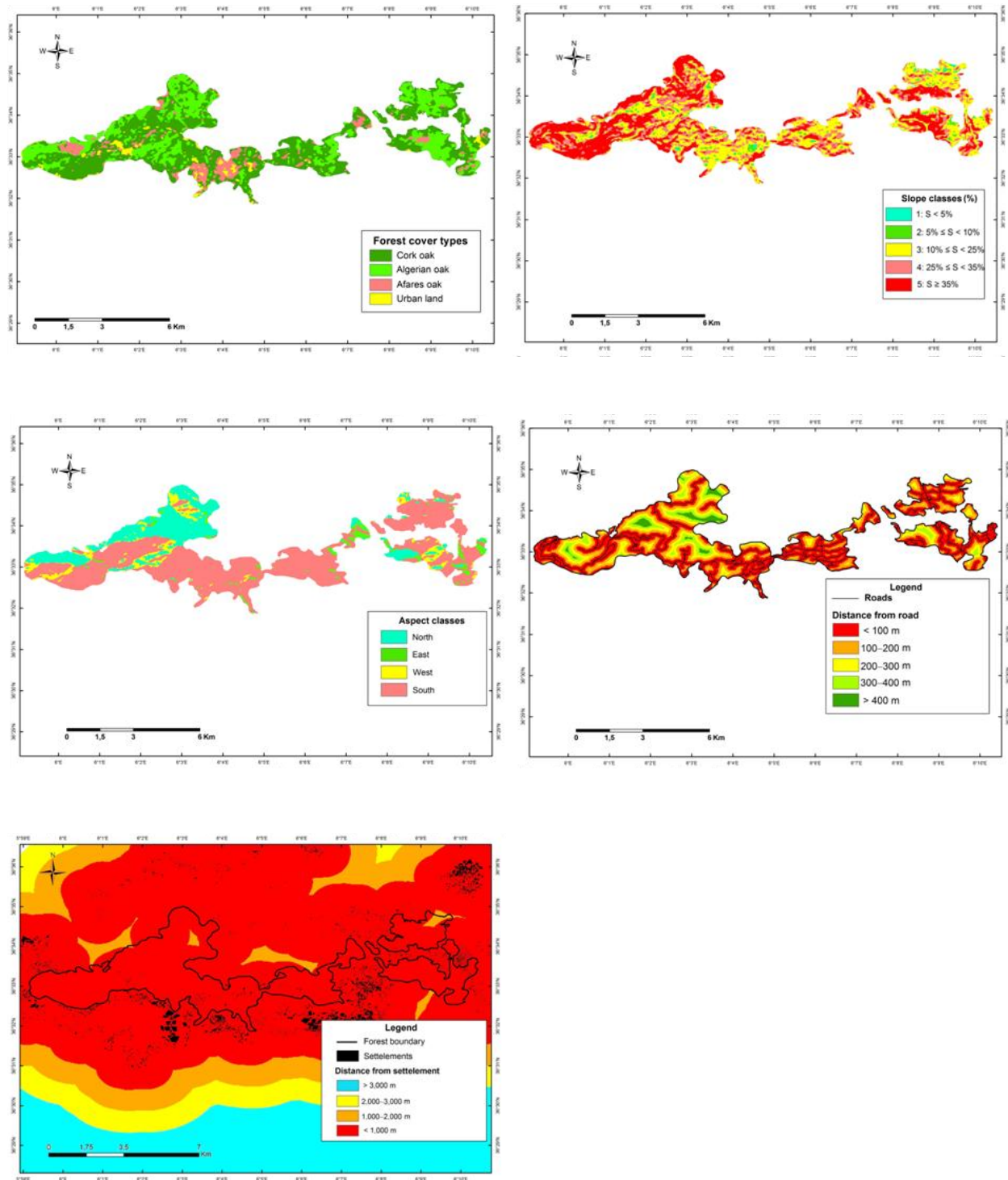


Fig. 4. Land cover, slope, aspect, distance from road and distance from settlement of the study area



Land cover is the main factor that has been widely used for fire occurrence analysis because some types of vegetation are more flammable than others. The land cover map was obtained from the supervised classification of the Landsat 8 image developed in the previous step.

The slope and aspect were extracted from the digital elevation model (DEM). They were selected because fires may travel fast in upward-slopes but slower in areas with downward slopes, whereas aspects may influence on wind speeds spreading fires. In terms of human-made factors, the distances from roads and distances from settlements were created by using the buffer function of ArcGIS software. The various distance measures were defined by basing on their

importance regarding forest fires, the radius of human activities and expert experiences. All the thematic maps were then reclassified into value intervals using ArcGIS reclassifying tool (Fig.5).

The equation used in the GIS to determine forest fire risk places is shown in equation (2):

$$RI = (7VT) + 5(S + A) + 3(DR + DS) \tag{2}$$

Where: *VT* – indicates the vegetation type;

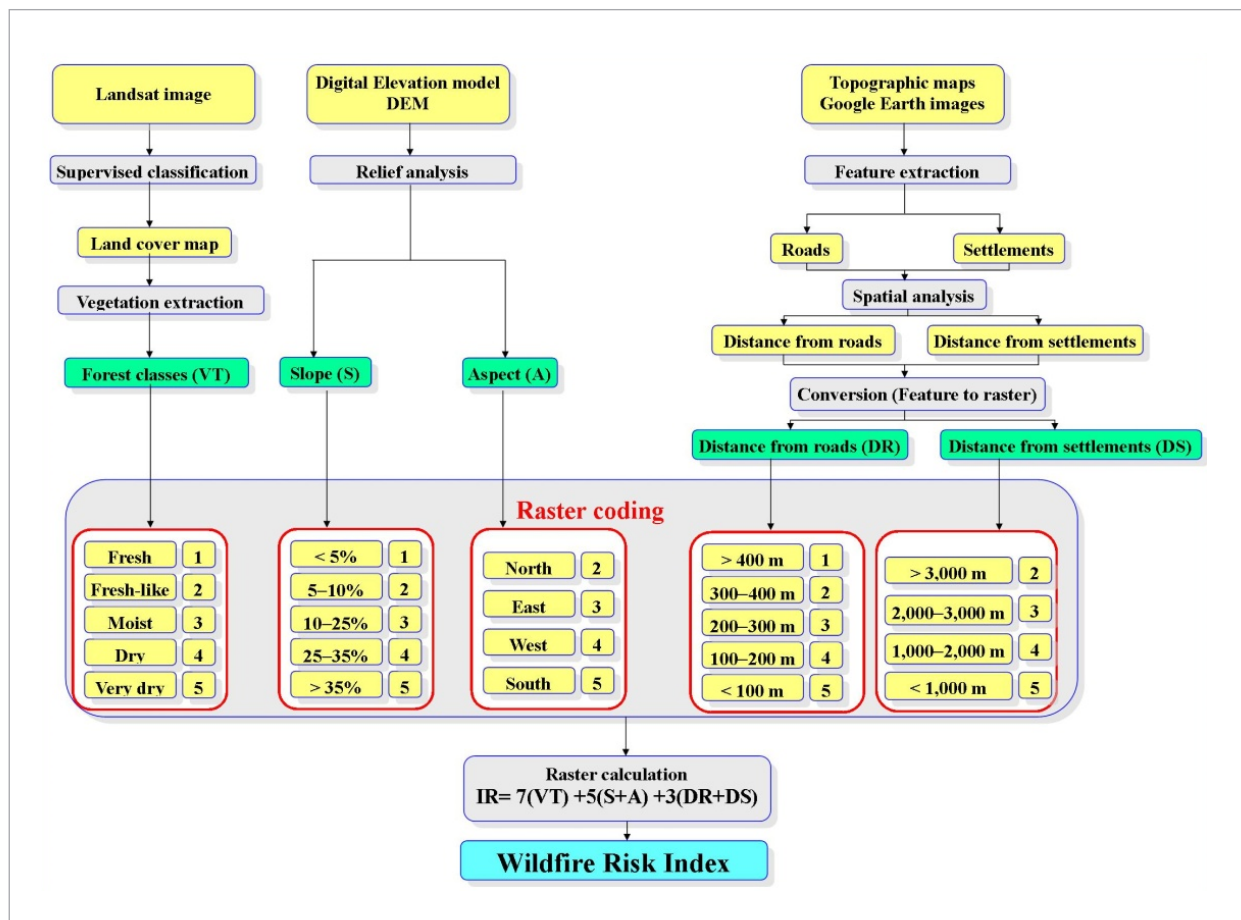
S – the slope factor;

A – the aspect variable;

DR – the distance factor from road;

DS – the the distance factor from settlement

Fig. 5. Workflow of methodology characterising WUIs



Results and Discussion

Mapping of forest cover

The classified forest cover maps of the Zouagha forest, obtained after pre-processing and the supervised maximum likelihood classifier, are given in Figure 6. Moreover, the surface area of each land cover class was estimated (Fig.7).

The map highlights the dominance of cork oak forest with an area of over 1,681ha (rate of 55%). Algerian oak forests and afares oak forests occupied 31% and 10%, respectively, while built-up, urban land occupied only 4% of the study area (Fig.7). This map highlights

Fig. 6. Forest cover type distribution in the Zouagha forest

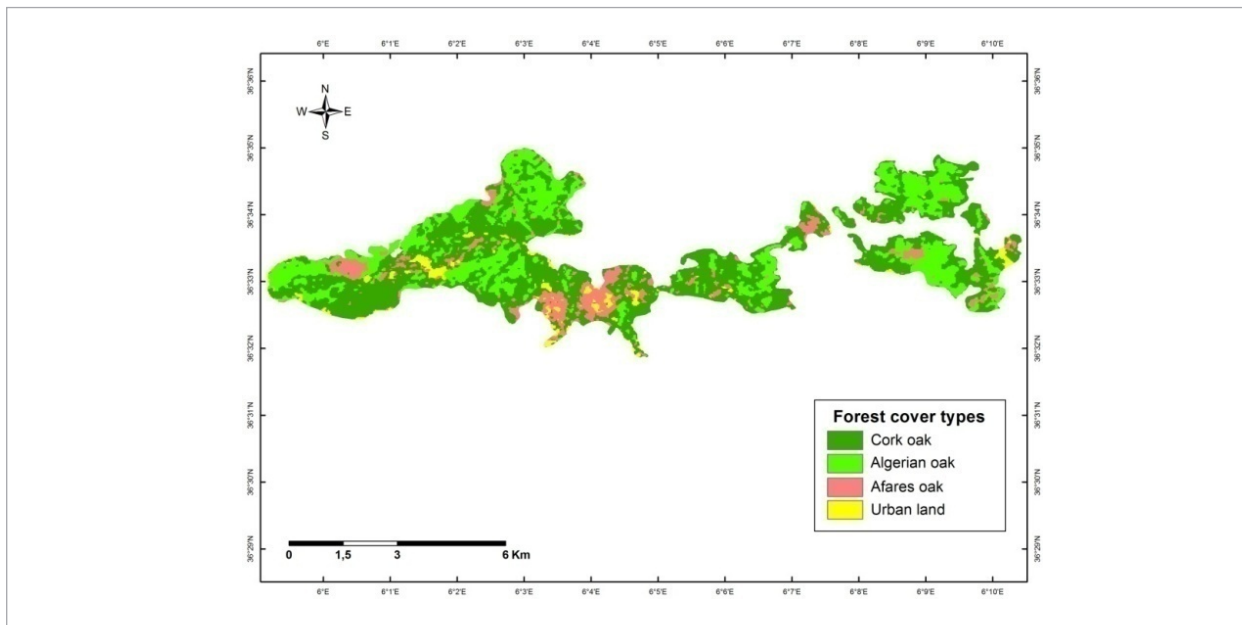
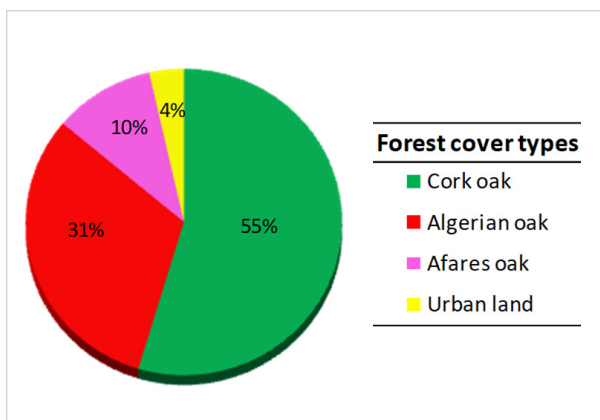


Fig. 7. Distribution of the forest cover types in the study area

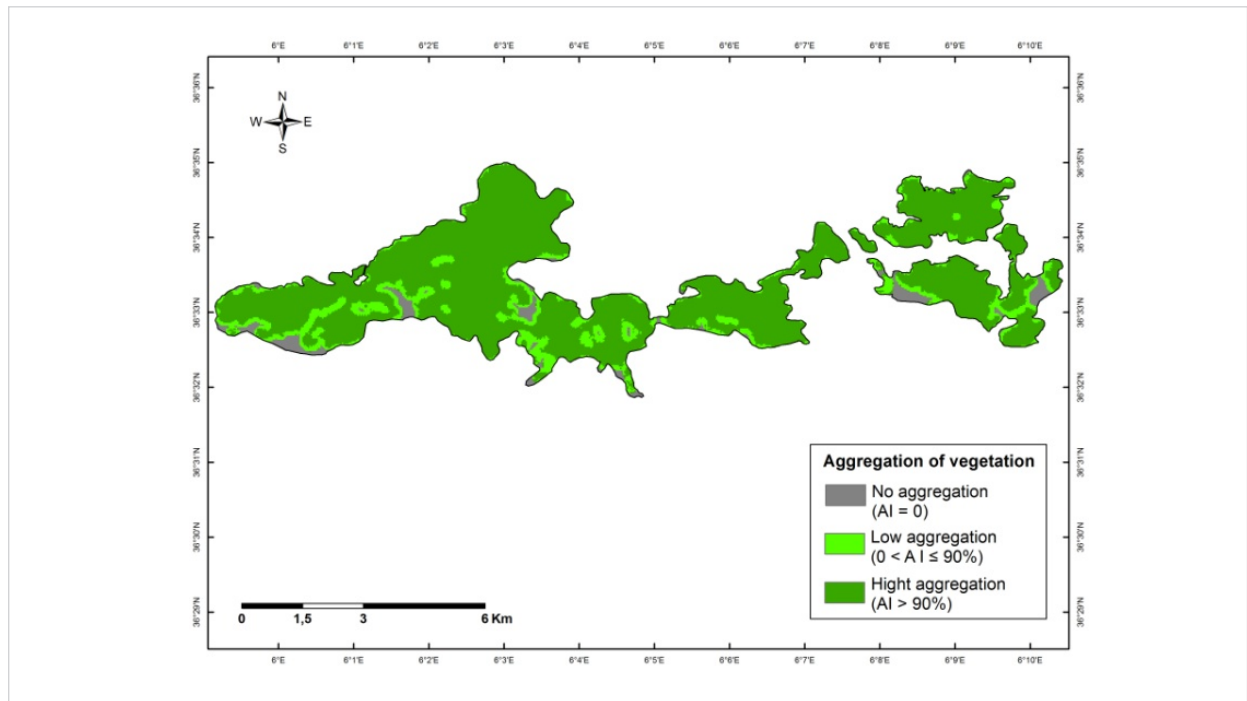


the clear dominance of forest formations, which were close to 96% of the area of the forest and increased the risk of triggering the fires.

The aggregation index was calculated on the vegetation class from the supervised classification image. It informs about frequency of connections between pixels of the same class of landscape such as vegetation class. Figure 8 shows the spatial results obtained from the calculation of aggregation indexes (AI), which are recoded into three classes of vegetation structure (no aggregation, low aggregation and high aggregation).

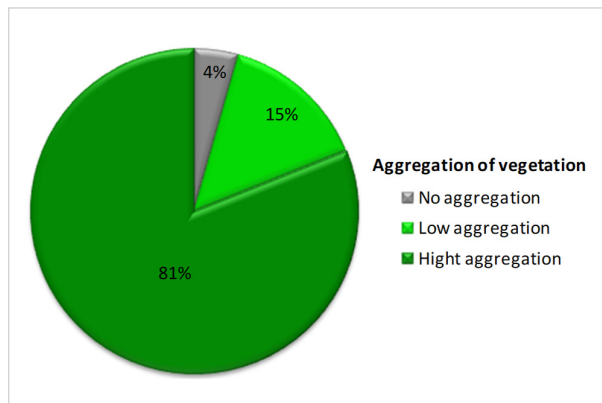
The high aggregation represented 81% of the study area, showing that the vegetation is always present in these regions with a great level of continuity. The

Fig. 8. Aggregation index (AI) of vegetation



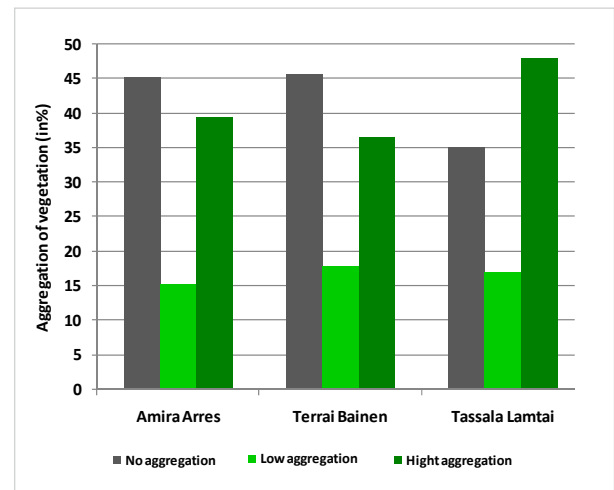
low aggregation and no aggregation of vegetation occupied only 15% and 8%, respectively (Fig.9). The low aggregations indicate more open areas.

Fig. 9. Proportion of the different classes of aggregation index (AI)



The proportion of forest for both Amira Arres and Ter-
rai Bainen municipality was 54%, but in the Tassala

Fig. 10. Aggregation index proportion on the municipality case study area



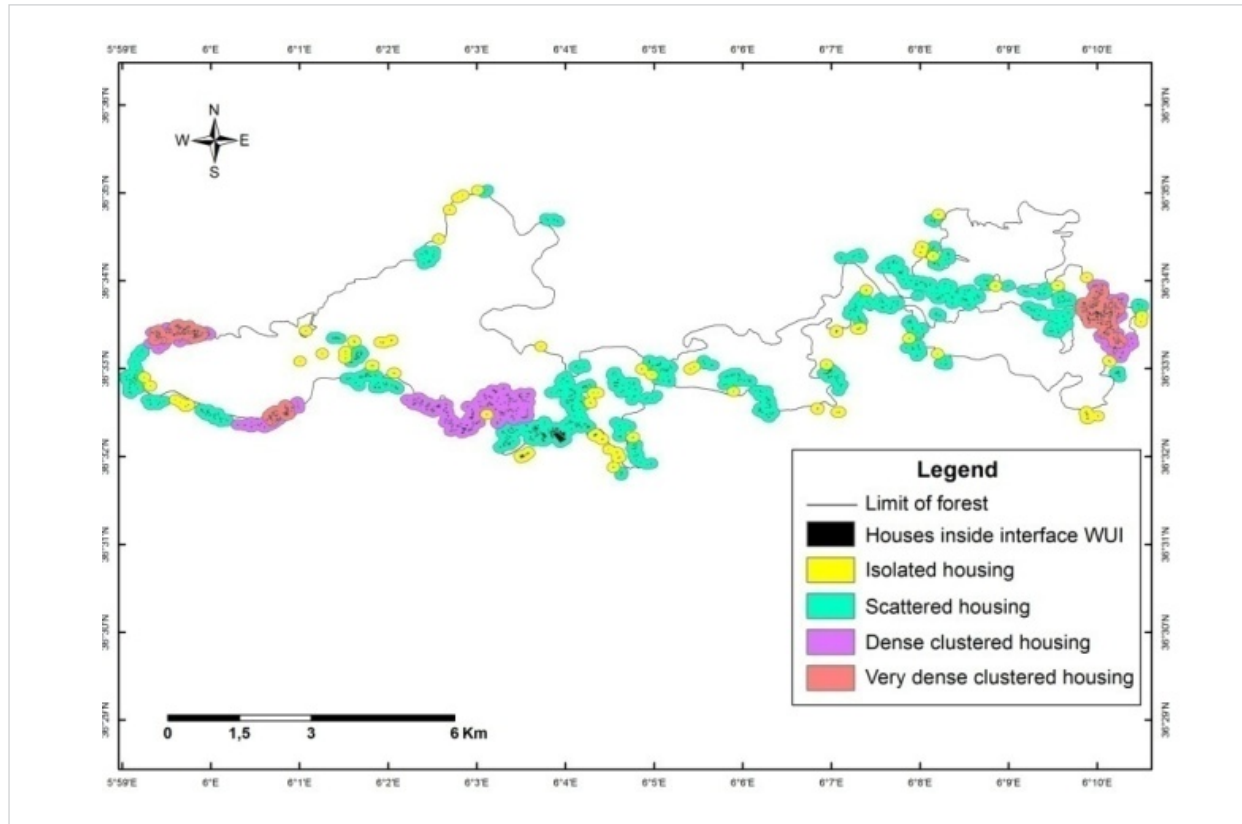
Lamtai municipality, it was 65%. Furthermore, no ag-
gregation index covers an area varying between 35% and 46% of the study area, indicating that these re-
gions are devoid of vegetation (Fig.10).

Housing type map

Figure 11 presents a map of a housing type in 2009. The number of buildings was 1,255 (75 isolated

housings, 664 scattered housings, 261 dense clustered housings, and 255 very dense clustered housings corresponding to the most urban areas).

Fig. 11. Map of housing types in 2009



Wildland-urban interface location

In 2009, WUIs covered an area of 1,171 ha, corresponding to 38% of the total study area. Based on the housing types, 15.4% of WUI were isolated housings, 58.4% were scattered housings, 21.8% were dense clustered housings, and 4.4% were very dense clustered housings. Based on the vegetation structure, 44% had an aggregation null, 29 had a low aggregation index and 27% had a high aggregation index (Fig.12).

Dynamics of wildland-urban interfaces

The dynamics of the wildland-urban interfaces in the Zouagha forest between 2009 and 2019 were studied

at the interface surface to identify the territories that have undergone the most significant changes and at the configuration of residential housing to identify the territories with the highest subject to the pressure of urbanisation.

Figure 13 shows gains and losses in WUI from 2009 to 2019. Negative symbols in the statistics indicate a loss of surface. The major changes include gains of WUI (293.04 ha, or a percentage of 89.08%). The dense clustered housing and the high aggregation index had the highest amount of gains in 10 years (+61.2 hectares). Furthermore, 20.7 hectares of the isolated housing and aggregation null and 15.21 hectares of

Fig. 12. Wildland-urban interface in 2009

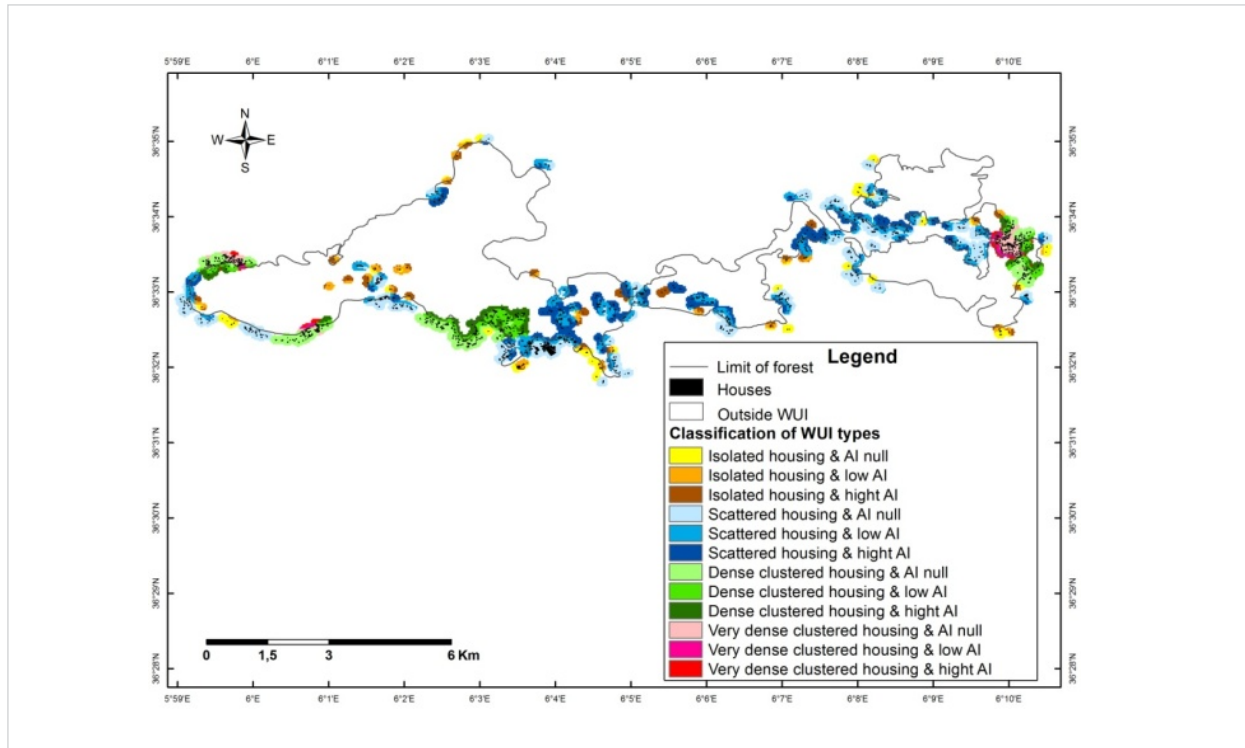
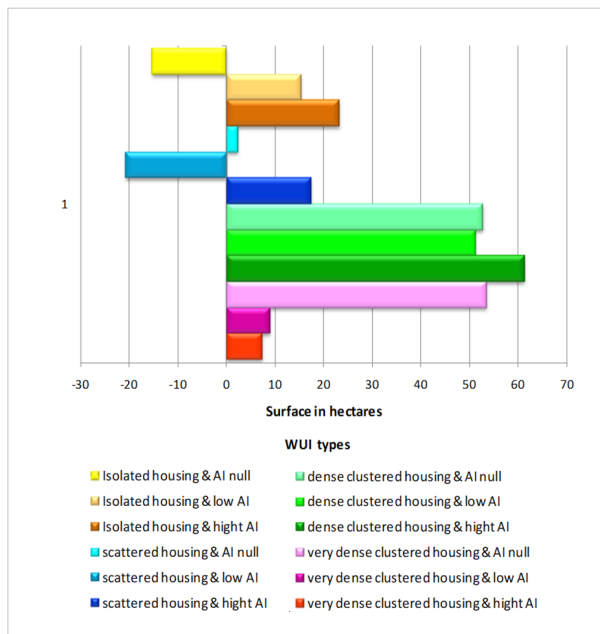


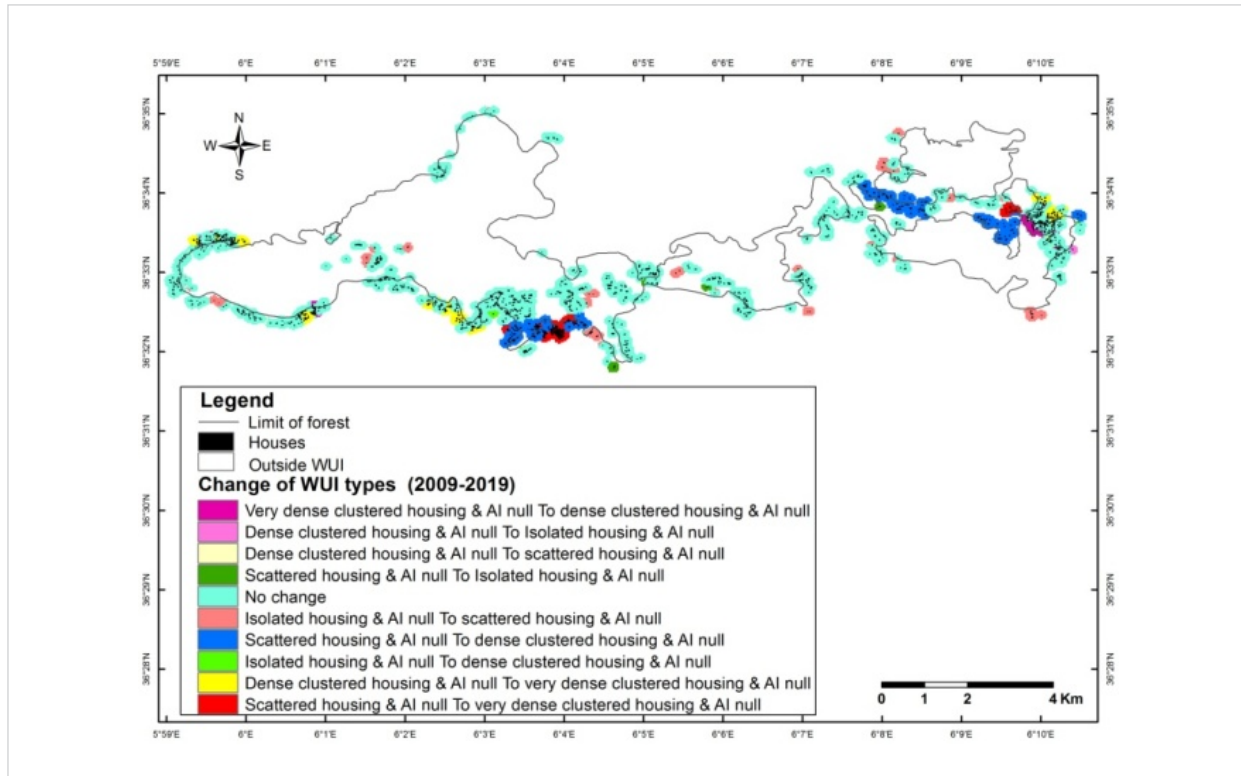
Fig. 13. Gain and losses (in ha) in WUI from 2009 to 2019



scattered housing and the low aggregation index were lost during the same period (Fig.13). These gains and losses translated into an increase in the amount of building and the WUI type transition.

Figure 14 shows the WUI transition between 2009 and 2019. The first remark is that all transitions are only made for WUIs with a zero aggregation index. Based on the analysis, 72.69% of WUI areas were remarkably unchanged over time. In absolute terms, isolated housing suffered from an estimate loss of 5.91% of area between 2009 and 2019. It is converted into scattered and dense clustering housing. Besides, 16.18% of the total area was converted from scattered housing to isolated, dense and very dense clustering housing. Meanwhile, 4.14% were reduced in 2019 and replaced by isolated housing and the same happened with very dense clustered housing where 1.01% was transformed into dense clustered housing.

Fig. 14. WUI transition between 2009 and 2019



The number of houses in the area increased substantially from 1,255 in 2009 to 1,895 in 2019 with an estimated building gain of 640 houses per 10 years. The building gains of the different types of housing are the following: 22 isolated housings, 125 scattered housings, 182 dense clustered housings, and 311 very dense clustered housings corresponding to the most urban areas.

Figure 15 presents the dynamics of the wildland-urban interface over 10 years related to the evolution of the houses located at an altitude of less than 200 m of the Zouagha forest. In 10 years, there was a change in the type of housing, with the appearance of new classes of isolated housing (+9.89%), scattered housing (+21.03%), dense clustered housing (+10.44%), very dense clustered housing (+3.77%), while 54.5% of the total buffer area around the houses remain stable. In addition, the habitats that disappeared in 2019 are negligible (0.5%).

This dynamic is reflected on the one hand by a densification of the houses, but on the other, by continuing to expand houses areas in forest areas.

The superposition of a wildfire risk index map with the sites of WUI allowed us to demonstrate the fire risk distribution in the forest (Fig.16).

The map highlights the dominance of from high to very high fire risk index class with an area of over 1501 ha, (rate of 99.62%). The moderate fire risk index class has only 0.38% of the total surface area of WUI.

Certain types of WUIs represent a high level of fire risk; this is the case for scattered housing with high aggregation indices of vegetation (88.58%). Therefore, the mapping model allows highlighting the WUI types that are most sensitive and to better identify and clarify priority protection areas. This map can be used for equipment installation, firewall trenching and trails establishment.

Fig. 15. Evolution of spatial organisation of housing between 2009 and 2019

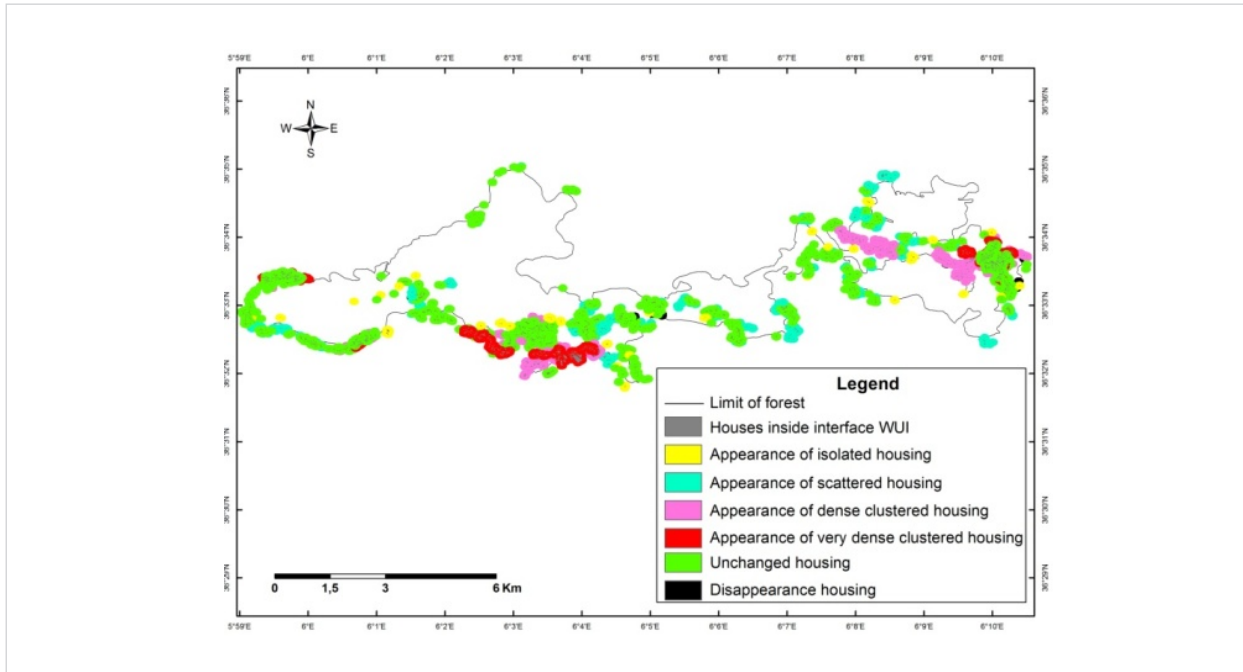
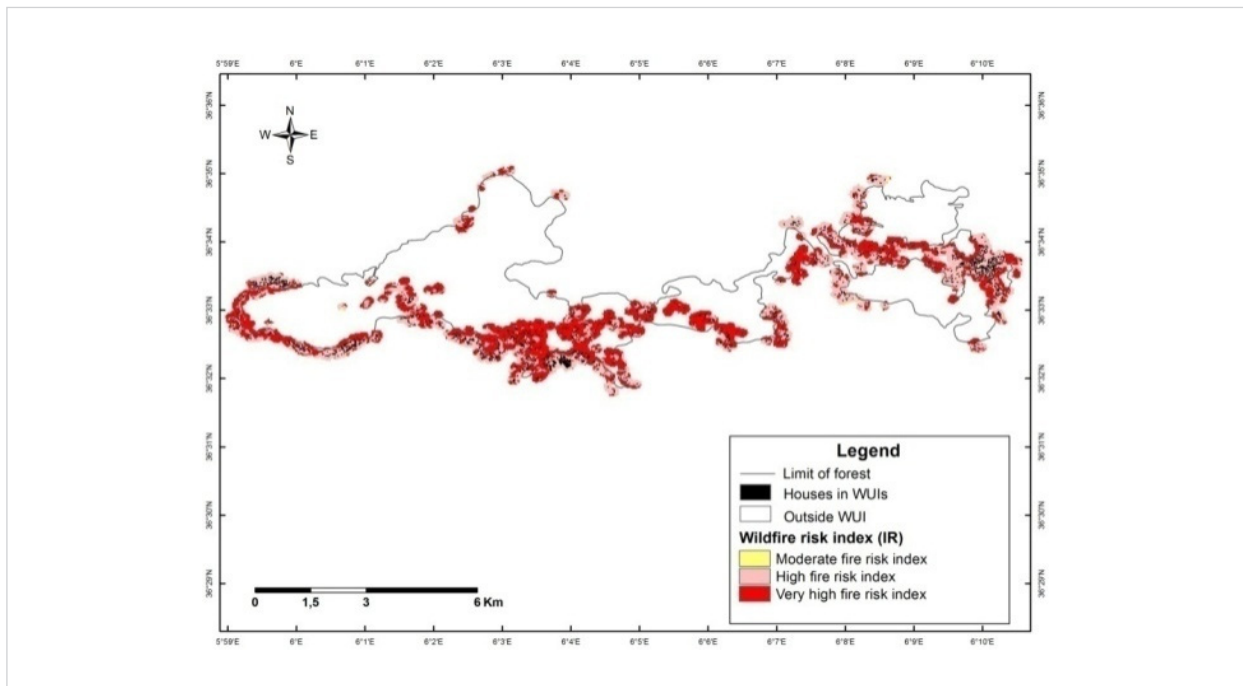


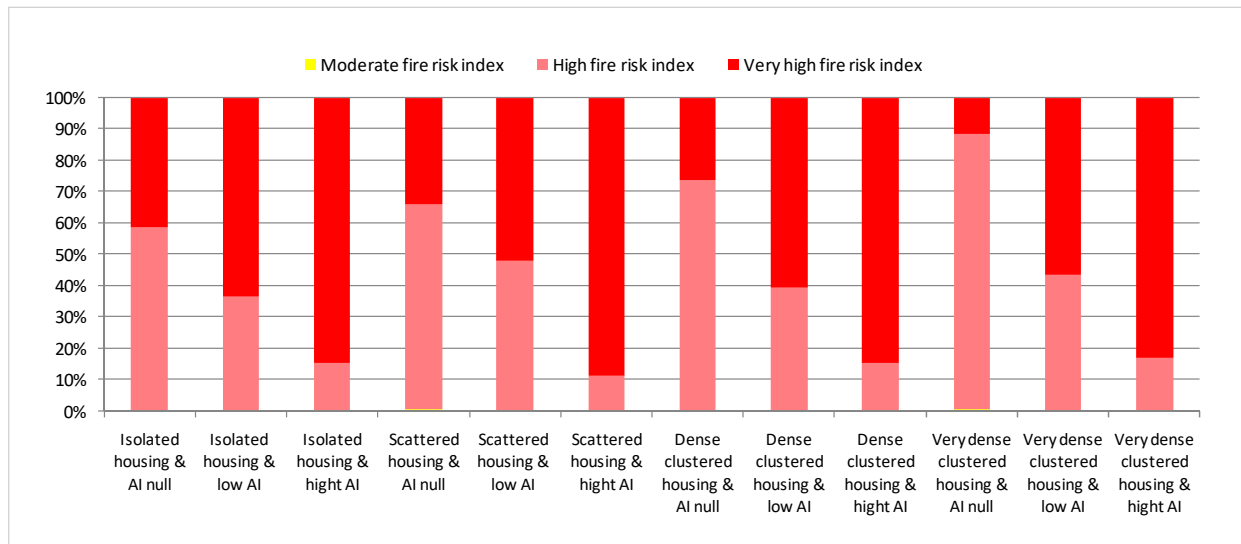
Fig. 16. Map of wildfire risk index in WUIs in the Zouagha forest



Based on the housing types, 49.01% of the high fire risk index class were scattered housing, 28.92% were dense clustered housing, 17.41% were isolated housing and 4.64% were very dense clustered housing.

Based on the vegetation structure, 48.09% of the high fire risk index class had a high aggregation index, 29% had a low aggregation index and 22.89% had an aggregation null of vegetation (Fig.17).

Fig. 17. Wildfire risk index in WUIs



Conclusions

Spatial data processing under the GIS, houses and vegetation made it possible to characterise the wildland-urban interfaces. Their mapping on the Zouagha forest allows a new compartmentalization of this territory. The intersections between urban and vegetation types characterised 12 WUI types in the study area. The map of the WUI produced constitutes an important tool for defining a strategy for monitoring and for effective forest fire prevention in the Mila province.

WUIs have increased significantly over the past decade and this trend will certainly continue in the coming years. It was housing growth that triggered WUI growth in this area. Our results allowed us to observe an increase of 5% per year in the number of buildings located in the wildland-urban interface. The increase in the number of WUIs has exacerbated the problem of wildfire in a region with a high fire frequency and a

burnt area. Our results showed that the type of WUI mostly related to a fire risk was scattered housing with high vegetation aggregation. The results indicate that the regions with a very high fire risk are those characterised by a high proportion of anthropogenic spaces in contact with natural vegetation. They can be the sources of ignition at the seat of the fire caused by human imprudence.

The Algerian government needs to develop a law taking into consideration the thinking of the forest cover within a radius of 100 m around buildings and housings located within 200 m of forests, scrublands or maquis to reduce the risk of house fire and to ensure the safety of the population. Furthermore, housing development on forest land is often not well planned or uncontrolled. That is why urban planning departments must take forest the fire risk into consideration in their technical studies.

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