FIRE PLANNING OF URBAN-RURAL INTERFACE IN OPEN SOURCE GIS ENVIRONMENT: CASE STUDY OF THE APULIA REGION (SOUTHERN ITALY)

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ABSTRACT:

Fires represent one of main challenges of the last decades as global changes are causing an increase in economic and environmental damages. Indeed, just in 2017, more than 10,000 km2 of land were burned in Europe, causing significant damage to both the natural heritage (25% of burned areas were part of Natura 2000 protected areas) and the economy with estimated losses around 10 billion euros. In addition, every year there are losses of human life that make even more necessary new strategies of action and monitoring. Therefore, an efficient management of forecasting, prevention, active fight and post fire phases, is essential to make the territories less vulnerable and reduce the impacts on human lives. But these steps require an integrated approach of different tools in order to make faster and more efficient the different operations. In this context, the study illustrates the expeditious and standardized methodologies in open source GIS environment proposed in a research project with the Civil Protection of Apulia Region in order to implement a vulnerability index to improve operations in forecasting, emergency management in real-near time and post-event analysis in urban-rural interface. All the techniques and methodologies proposed were based on the use of QGIS software as it is a highly user friendly software that can be easily used even by non-specialized technicians. Moreover, the methodologies have been validated through a direct comparison with the tools currently in use in Civil Protection Department of Apulia Region.

1. INTRODUCTION

The problem of forest and interface fires is particularly serious, due to that set of environmental and socioeconomic factors, which make Mediterranean areas particularly fragile with respect to this phenomenon (Darques, 2015).

In Italy this issue is strongly attended to, as it represents one of the main problems in fire fighting (Carlucci et al., 2019). Italian legislation reiterates the mandatory nature of both providing for the municipal planning of Civil Protection, so that each municipality can equip itself with a tool streamlined and expeditious that allows to secure the population in the event that a forest or rural fire threatens the settlements or infrastructure in its territory.

The Handbook for the Development of a Civil Protection Plan (Apulia Region, 2007), sets out guidelines for a methodological approach with the aim of suggesting the minimum requirements to be met in order to draw up risk maps over the Italian territory. In particular, the operational manual also refers, in the fire risk part, to the definition of the vulnerability index related to the exposed in the so-called interface areas. This is part of the forecasting phase, which together with the surveillance phase defines the warning system at the regional level implemented by the operational centers. Interface areas, can be defined as those zones, areas or bands in which the contact between anthropogenic structures and natural vegetation areas is very close, more precisely they are the geographic locations where in the case of fire there is first contact between anthropized areas and fire (Stewart et al., 2007; Lampin-Maillet et al., 2010). In order to be able to plan the optimal deployment of Civil Protection forces, it is necessary to know the location of buildings and in general infrastructure and their function of use within the aforementioned area. Punctual knowledge of the area and with it the urban center is essential for calculating the risk affecting the interface (D'Este et al., 2021). In this paper a preliminary expeditious methodology is proposed to improve the current protocol of the Italian Civil Protection in regards to urban-rural interface fires. Specifically, it concerns the realization of some information layers based on the integration of different open data available online. These layers thus created are intended to be considered within a vulnerability index and hazard index in order to combine both so as to assess the risk within urban-rural interface zones. All operations performed are based on QGIS software (QGIS, 2022).

2. MATERIALS AND METHODS

2.1 Study area

Apulia region (Figure 1) extends into the north-eastern Mediterranean in a NW-SE direction and constitutes the easternmost part of the Italian Peninsula. It has a high territorial discontinuity determined by the considerable development of the coastline, from the Gargano promontory to the Cape of Santa Maria di Leuca along the Adriatic Sea and in the Ionian Sea to the Gulf of Taranto, and a highly articulated surface morphology. The regional territory has an area of around 19,350 sq. km. and is mostly flat, with the lowland area accounting for more than half of the entire area (53.2%), the remaining part being occupied by hills with 45.3% and just over 1% by mountains.
In 2020, the last have for which there are official statistics, 398 fires occurred with a total area covered by fire of almost 3,600 ha. Of this just over 40 percent (1,474 ha) was classified as forested, with events locally also affecting protected areas or in any case areas with greater naturalistic and landscape value. In

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2020, the average area per fire was always found to be less than 10 ha in all provinces considered, except in one where an average value of more than 40 ha was found.

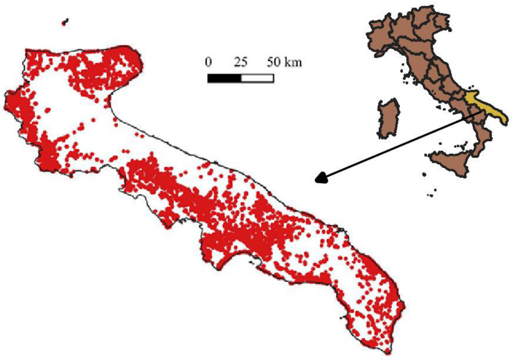

Figure 1. Location of Apulia Region. In red, historical fire recorded in 2000-2018 period.

2.2 Search for up-to-date open data

The operative manual of the Italian Civil Protection, defines the interface in the narrow sense (or interface strip) as the strip of contiguity between anthropogenic structures and the vegetation adjacent to it, exposed to contact with the probable fire front. The width of this strip can vary from 25 to 50 meters depending on the physical characteristics of the area and the type of settlements. In this study, the value was imposed at 50 meters.

The first step is to search for up-to-date map data to identify the perimeter line that divides the urban aggregate consisting of buildings and infrastructure from the vegetation zone, a possible source of fire. To properly establish the presence of artifacts, reference is made to technical cartography. To date, however, the Regional Topographic Map (RTP) of reference for the Apulia Region, is stopped at 2011, the date of the last update of the relevant RTP of 2006. Even the ISTAT (Italian National Institute of Statistics) data, useful for defining the urban aggregate, has 2011 as its last update. To make up for the lack of information from the official dataset, also taking into account that the civil protection manual was drafted in 2007, with references to the use of datasets that are no longer valid, today it is possible to use, consult and download for free, numerous open-source platforms, which are complete and exhaustive both in terms of the amount of data present and the continuous updating by the user community. Currently, OpenStreetMap is the largest map database available online that can be consulted and downloaded for free. However, there are other portals, DatiOpen.it, Opendata Puglia, and DBPrior, which contribute to the free sharing of available datasets. As the input datasets are updated, it is possible to draw up thematic maps that better correspond to reality. All data were processed and reprojected in the reference system: WGS84/UTM zone 33N - Datum: WGS84 - Projection: UTM - Zone: 33N - EPSG: 32633 (Figure 2).

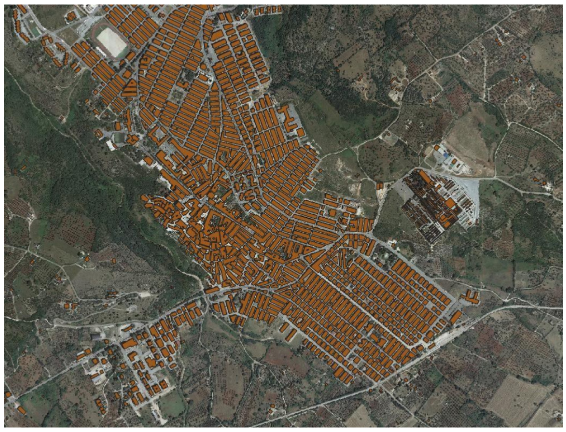

Figure 2. Example of digitization of urban building.

2.3 Definition of the new urban aggregate area

In order to obtain an up-to-date map of buildings and infrastructure, the official data from the technical cartography was cross-referenced by examining the built-up typology and the *osm_buildings_* information layer of OpenStreetMap, because the latter is more up-to-date particularly in the areas of urban expansion close to the perimeter areas of the built-up area. Once the new built-up area was defined, the aggregate was processed as prescribed by the operations manual, reducing discontinuities between the elements present.

The new aggregate was merged with the localities provided by ISTAT in order to update the data to the most recent period (Figure 3). The main steps of the processing have been reported below.

1 - Definition by selection of features resulting in the Technical Cartography reference as of 2011 and OpenStreetMap to detail the urban center area;

2 - Update of the new urban aggregate polygon compared to ISTAT 2011.

3 - The final layer also has very small area aggregates. Since a perimeter 50 meters buffer must be defined on all of them, for a very small polygon the buffer could cover the entire area. To overcome this problem, the aggregate was selected based on the largest area 80000 m^2 in order to eliminate very small areas where it would not make sense to define the buffer later.

The perimeter of the aggregates can be done manually, with the help of multiple cartographic data (RTP, Orthophotos, Istat Locations, Zoning of Municipal Plans, etc.) or by using spatial functions of aggregation such as, for example, *Concave hull* present in QGIS (it is possible to evaluate the use of the function by plugins or by means of tools in the processing menu). In the case of perimeter using the above function, however, it is advisable to check the result obtained and, if necessary, manually modify the perimeter so that it is as realistic as possible (Figure 4).

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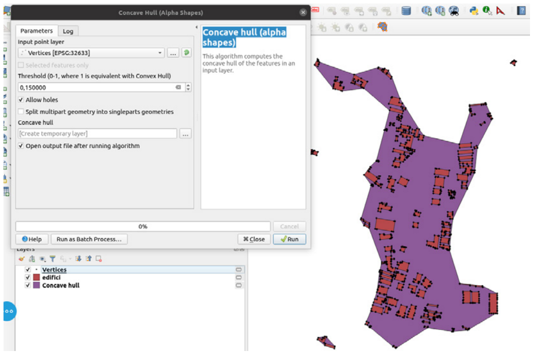

Figure 3. Example application of the Concave Hull tool (alpha shapes). The point data obtained earlier with 'extract vertices' should be selected as input.

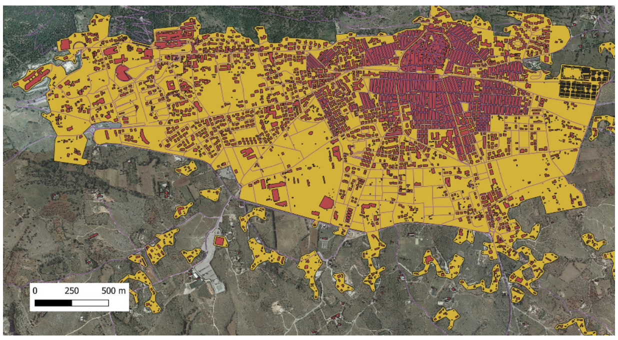

Figure 4. Example of identification and perimeter of urban aggregations (ochre color) with built-up area overlay (red color).

2.4 Classification of interface area perimeters.

From the polygonal theme of the aggregate made above, it is possible to define an inner buffer of 50 meters (can vary from 25 to 50 meters, as indicated in the guidelines) and an outer buffer of 200 meters. The former defines an interface strip to the urban center while the latter defines a perimeter interface strip of 200 meters from the urban aggregate boundary to the outside. Examples where both the 50-meter and 200-meter bands are present are given in this study as examples. However, from a planning and firefighting point of view, the value takes on a different meaning. For the definition of the interface zone we first have to make an inner buffer (*Inner buffer* from QGIS processing menu) of 50/200 meters on the polygon of the aggregate and on the obtained result you have to apply a *Buffer* (processing menu of QGIS) of 50/200 meters (Figure 5).

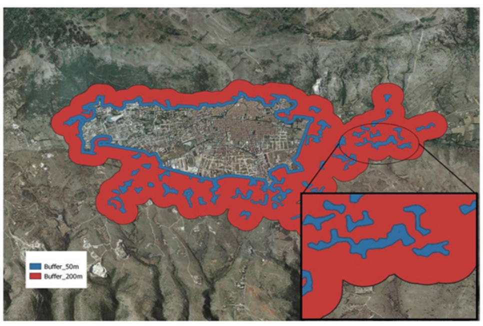

Figure 5. Final result of defining the perimeter strip (Buffer 200m in red) and the interface strip (Buffer 50m in blue).

2.5 Hazard estimation for interface zones

Hazard calculations within interface zones are based on several factors. The Table 1 summarized the factors and their respective values. The factors are described in detail later. The final hazard map will be the sum of the rasters of the individual factors. To make the sum of the different factors, the maps were rasterized, choosing a pixel width of 10x10 meters in order to make them uniform with the layers produced.

Factor	Range value
Vegetation hazard factor	1-6
Morphological hazard factor	1-6
Type of Contact factor	0-1-2-4
Past Fires factor	0-8
Phytoclimatic Hazard	1-4
Municipal Hazard Classification	0-2-4

Table 1. Summary table for defining the calculation of Hazard with range values.

2.5.1 Vegetation hazard factor: vegetation influences the evolution of the fire due to the different behavior of the species. For the realization of the vegetation hazard datum (Fig. 6) the Fuel Danger Map is useful, made on the basis of the fuel model map elaborated from the Nature Map elaborated and made available in open data by ISPRA (Italian Institute for Environmental Protection) which contains the habitats detected in Apulia in the European classification system CORINE Biotopes (ISPRA, 2022).
Each vegetation type contained in the Nature Map, divided by type and degree of tree cover, is assigned a hazard index (from 1 to 6) that takes into account the pyrological characteristics that determine fire behavior during a fire. This factor takes into account both vegetation type and vegetation density (Figure 6).

The vegetation factor is one of the key elements for risk assessment but also for all operations involving fire planning. Having up-to-date open data with metadata facilitates the work for municipal administrations as it is complicated to have technical expertise for land cover classification methodology with remote sensing techniques.

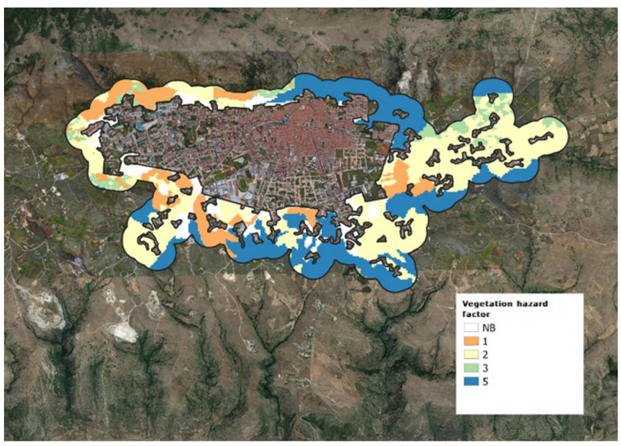

Figure 6. Vegetational Hazard Map

2.5.2 Morphological hazard factor: The characteristics of the terrain have an important influence on the development of flames especially considering the slope (which determines an increase in the speed of propagation and thus the danger of a fire) and exposure (southwestern slopes are the most exposed to the action of the sun therefore the least humid and preferential for the spread of flames). From the digital terrain model information, the slope and aspect information layers were processed with QGIS modules. Both parameters are recoded by assigning hazard values (1 to 6) and then summed by assigning weights to each. The morphological hazard factor (Figure 7) thus obtained is recoded with the assignment of hazard values (1 to 6).

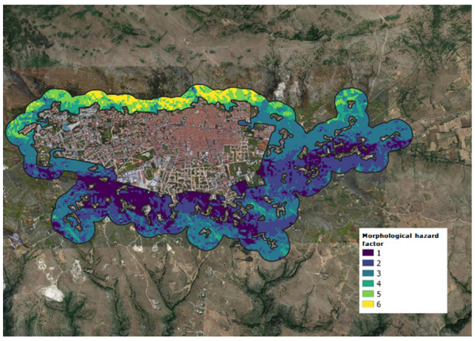

Figure 7. Morphological Hazard Map

2.5.3 Type of Contact (Interface Contact) factor: The Type of Contact (Interface Contact) factor is used to determine the value of the factor over the entire area divided according to the type of contact (described in the guidelines) detected. Operationally, one must proceed to subdivide the perimeter strip according to the type of contact present between its inner line and the aggregate. In QGIS, it is possible to accomplish this by first creating, on the vector file of the perimeter strip, a column of integer type (e.g., named RAST, in which to enter the identifying value of the contact type) and then 'cutting' the strip at that contact (Figure 8).

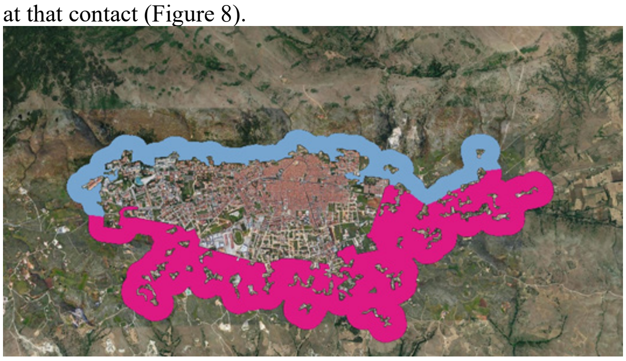

Figure 8. Two types of contact defined by the value 2 (blue) and 4 (indigo). For labelling, please refer to the guidelines (Apulia Region, 2022).

2.5.4 Past Fires factor: represents the distance from the settlements of past fires and involves assigning scores in the range from 100 to 200 meters and in the range less than 100 meters. In the case of no event, the value assigned is 0. In the case of at least one event, the value is 4 in the first band and 8 in the second band (Figure 9). In cases where the number of events is less than the number of years in the time series (and not equal to 0), a linear rescale should be applied, ranging from $0 < X <= 4$ for the first range and $4 < X <= 8$ the second range. In this way, the values will be graded and related to the number of events that occurred during the period analyzed.

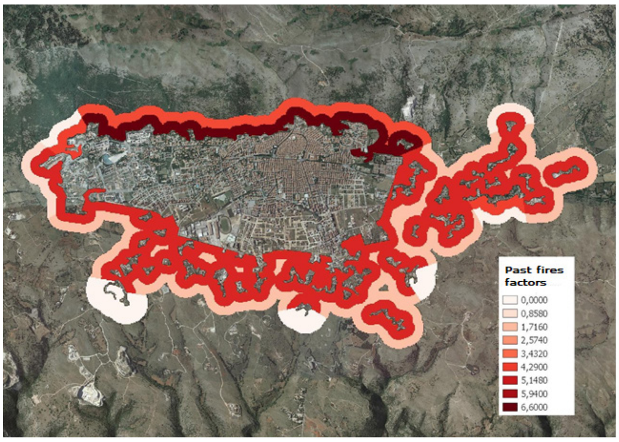

Figure 9. Map of Past Fires factor.

2.5.5 Phytoclimatic Hazard and Municipal Hazard Classification: these two factors, which are being updated, range from 1 to 4 and 0 to 4, respectively.

2.6 Identification of classes of vulnerable buildings

The third step is to identify for each class listed in the operations manual the vulnerable buildings that fall within the buffer and use of each, which should be subsequently assigned a sensitivity value based on the suggestions in the civil protection manual (Table 2). The difficulty in discriminating each category, e.g., knowing whether a building is used as a hospital or school instead of housing, can only be overcome by timely knowledge of the area (municipality). Knowledge of each structure that crosses or is contained within the perimeter buffer, e.g., whether highway, suburban road, residential road, is important in order to be able to assign a sensitivity value to the exposed, depending on its criticality in the event of an event.

Downstream of the intersection for selecting only the buildings falling within the perimeter zone, a buffer of 50 m is created around each of them. It is reasonable to consider that in the case of fire affecting several buildings simultaneously, the overall vulnerability will be given by the superposition of individual exposures falling in the same class, otherwise considered in isolation.

In the sum of all layers, the overlapping portions of the area delineate a higher vulnerability contribution determined by the fact that at that point the eventual fire would affect more buildings.

Finding up-to-date datasets in general can be complex for certain classes of exposures. One solution might be, for example, to conduct a master search of a list of addresses: e.g., state schools etc., by consulting available open data, national archives, and other sources.

Through a *geocoding* tools within QGIS, geographic coordinates can be traced from the address. The result obtained can be cross-referenced with the previously processed mapping of the built-up area, from which it is possible to derive the buildings referred to the relevant class, with respect to the reference perimeter strip (buffer defined earlier).

Vulnerable buildings	Vulnerability value
Continuous building, discontinuous building	10
Hospitals, schools, military station, strategic buildings (regional headquarters, prefecture, municipality ....)	10
Power plants, main road system	10
Secondary roads, telecommunications infrastructure, weather monitoring infrastructure	8
Industrial, commercial, craft buildings, buildings of cultural interest, storage areas	8
Airports, railway stations	8
Sports facilities, recreational places	8
Depuration plants, landfills, green spaces	5
Cemeteries, areas for livestock facilities, areas under transformation/construction, bare areas, quarries and processing plants	2

Table 2. Assignment of scores to be adopted for the vulnerability of buildings based on the Italian Civil Protection Operations Manual

2.7 Vulnerability index

Vulnerability indicates the degree of loss produced on people, property, civil works and vegetation in general. In particular, the vulnerability index represents a value that identifies those areas of the interface buffer that are most exposed to the flame front in the event of a fire. It can be computed and modeled in several ways, but the simplest one is based on assigning weights to each element that makes up the vulnerability (Andersen et al., 2019; Oliveira et al., 2021).

In this word, it analytically represents the sum of the sensitivity value of each exposed area. To identify which vulnerable buildings fall within the interface strip, one can use the *Select by Location tool*, between the residential building layer, for example, and the 50-meter buffer that identifies the interface strip.

With the raster calculator, it is possible to do the pixel-by-pixel summation of all exposed.

2.8 Fire risk assessment

The risk assessment, and thus the calculation of the value within the interface area, was done through the product between the rester of the hazard index and the vulnerability index. The final raster is reclassified from classes ranging from 1 to 9 to classes ranging from 1 to 4. These correspond to risk classes R1- R2 - R3 - R4 through the reclassification rule given in the guidelines. Classes 6 and 9 will take on risk class 4, classes 3 and 4 will take on risk class 3, and classes 2 and 1 will not change classes.

3. RESULTS AND DISCUSSION

The algebraic sum of the different factors contributing to the hazard provides a map (Figure 9) that makes it possible to assess within the interface area, where the spread of a fire may become more dangerous to the population.

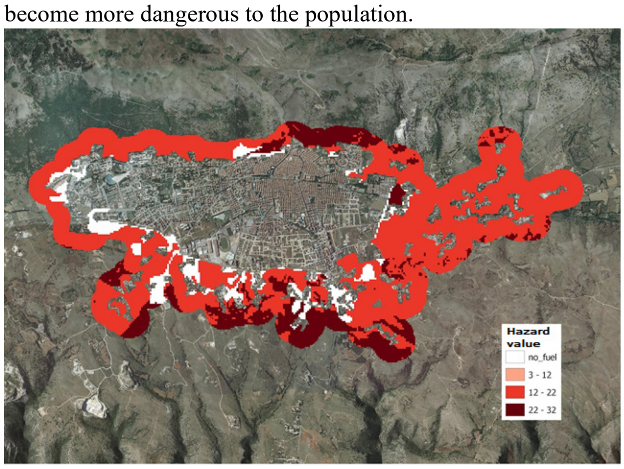

Figure 9. Example of hazard calculation.

In the example in Figure 10, the result of processing the vulnerability value along the perimeter of the main population center and there, where it was not possible to define an interface perimeter, of the small areas whose exposed fall all or in part to the calculation of the same and risk is shown.

For the purpose of the final risk calculation, the vulnerability layer having discrete values between 1 and 29

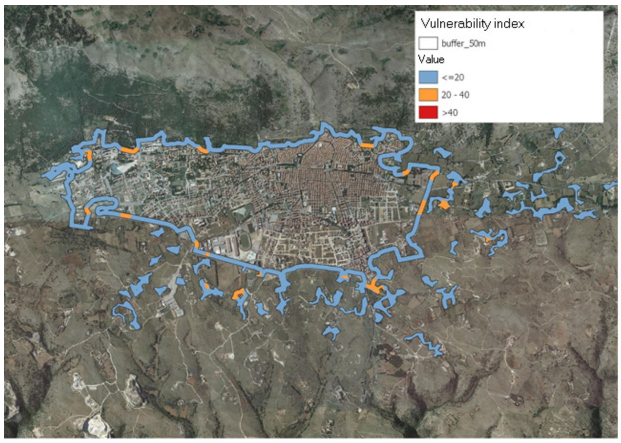

Figure 10. Example of Vulnerability calculation.

And finally, the final raster at 10 meters of resolution, derived from the product of hazard and vulnerability, is a risk map according to the official nomenclature of the Italian Civil Protection.

In this specific case, there are no pixels falling within risk belt 1.

The risk map thus defined also considers the built-up areas falling within the perimeter strip for which the definition of interface strip is not applicable.

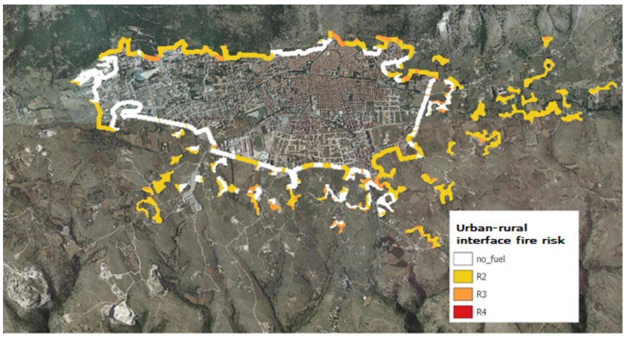

Figure 11. Example of urban-rural interface fire risk calculation for a municipality of Apulia region

The proposal outlined here, allows for the planning of activities related to urban-rural interface fire risk and has been drafted following the guidelines (Guidelines for the Drafting of Municipal Civil Protection Plans Apulia Region 27/08/2019) and the Operational Manual for the Preparation of a Municipal or Intermunicipal Civil Protection Plan (National Civil Protection Department - October 2007) for the updating of municipal civil protection plans in the Puglia region.

The methods presented here are proposed in some cases as in-depth and in others, instead, they are proposed as novelties or variations of elaborations already contained in regional and national guidelines.

One of the new aspects concerns the elaboration of the final summary maps in raster format. The raster data, being structured in cells, allows a more "localized" spatial information of the territory to be determined, and spatial analyses are carried out cell by cell. The spatial resolution of the pixel is 10 meters and, where there is a need, could be reduced to 5 meters. In the tutorial defined on the basis of this paper, the GIS operations to be performed will be shown.

All proposed processing has been simplified as much as possible and carried out through the use of the open source software QGIS which is widely used in topics involving fire (Lanorte et al., 2019).

QGIS software is now widespread even in public administration, has no licensing costs, is highly interoperable, and can handle many spatial data formats. It has a very large number of tools and is also advanced in the management of thematized map printing.

4. CONCLUSION

The methodology exhibited is a valuable support for the design of municipal or inter-municipal fire risk plans. It allows the development of expeditious maps of vulnerability that could be supplemented, if available, with values of the ignitability of the exposed and the availability of escape routes. A detailed map per municipality or even better per urban area requires minute knowledge of the entire territory. The whole process could be automated in the form of a model so that the map could be reworked should the need arise simply by updating the input information layers.

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REFERENCES

Andersen, L.M., Sugg, M.M., 2019. Geographic multi-criteria evaluation and validation: A case study of wildfire vulnerability in Western North Carolina, USA following the 2016 wildfires. *Int. J. Disaster Risk Reduct*. 39, 101123. doi.org/10.1016/j.ijdrr.2019.101123

Apulia Region. Manuale Operativo per la predisposizione di un piano comunale ointercomunale di protezione civile 2007 - Presidenza del Consiglio dei Ministri, Dipartimento Protezione Civile.

Carlucci, M., Zambon, I., Colantoni, A., Salvati, L., 2019. Socioeconomic Development, Demographic Dynamics and Forest Fires in Italy, 1961–2017: A Time-Series Analysis. *Sustainability*, 11, 1305. https://doi.org/10.3390/su11051305

D'Este, M., Giannico, V., Lafortezza, R., Sanesi, G., Elia, M., 2021. The wildland-urban interface map of Italy: A nationwide dataset for wildfire risk management. *Data in brief*, 38, 107427. doi.org/10.1016/j.dib.2021.107427

Darques, R., 2015. Mediterranean cities under fire. A critical approach to the wildland–urban interface, *Appl. Geogr.,* 59, 10–21, doi.org/10.1016/j.apgeog.2015.02.008, 2015.

ISPRA, 2022. Carta della Natura. https://www.isprambiente.gov.it/it/servizi/sistema-carta-della-natura (8 May 2022).

Lampin-Maillet, C., Mantzavelas, A., Galiana, L., Jappiot, M., Long, M., Herrero, G., Karlsson, O., Apostolopoulou, I., Lazaridou, T., Partozis, T., 2010. Wildland urban interfaces, fire behaviour and vulnerability: characterization, mapping and assessment. In: “Towards Integrated Fire Management - Outcomes of the European Project Fire Paradox” (Silva JS, Rego FC, Fernandes P, Rigolot E eds). European Forest Institute, Research Report 23: 71-92.

Lanorte, A., Cillis, G., Calamita, G., Nolè, G., Pilogallo, A., Tucci, B., De Santis, F., 2019. Integrated approach of RUSLE, GIS and ESA Sentinel-2 satellite data for post-fire soil erosion assessment in Basilicata region (Southern Italy). *Geomatics Nat Hazards Risk,* 10(1):1563–1595.

Oliveira, S., Rocha, J., Sá, A., 2021. Wildfire risk modeling Curr. Opin. *Environ. Sci. Health*, 23, 100274.

QGIS Development Team, 2022. QGIS 3.22. Geographic Information System Developers Manual. QGIS Association. https://docs.qgis.org/3.22/en/docs/developers_guide/index.html (15 May 2022).

Stewart, S.I., Radeloff, V.C., Hammer, R.B., Hawbaker, T.J., 2007. Defining the wildland–urban interface. *J. For.* 105:201–207.