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Open data repositories and Geo Small Data for mapping the wildfire risk exposure in wildland urban interface (WUI) in Spain: A case study in the Valencian Region

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ABSTRACT

The risk of forest fires in areas of wildland urban-interface (WUI.) is increasing due to the increase in urbanized areas and the progressive abandonment of traditional farming and forest uses. The global increase in catastrophic episodes in regions with a Mediterranean climate is worrying. Resilient towns and villages have given way to extensive and scattered residential estates that are in contact with forest fuel. These changes in the landscape when added to those of the climate, increase the danger of what some call 'igneous storms'. The risk in many areas has increased greatly in the last few decades. It is necessary to limit the growing exposure to this type of risk – and geographical information resources are essential for determining the territorial magnitude of the problem. Official libraries offering remote sensing data or geographical databases on land use and land cover (LULC) may be the best option (although accessing this data is complex for many end users). This research proposes identifying areas exposed to fire risk in the wildland-urban interface (WUI) through the automated integration of massive data from official geographic information sources. The application of this study to the region of Valencia (Spain) shows that the integration of these official sources of geographical information can achieve the objective at a detailed scale with relatively short processing times and for large geographical areas (approximately 8 h required to process about 70 Gb of LIDAR data). Geo Small Data techniques for the process of large datasets and its application to the objective of the study have been the best way to automate the analysis of lidar point clouds, with more than 5 billion echoes, through the use of free and open tools, containerization technologies, parallel processing and specific python libraries for geospatial data management. The LIDAR data has provided the necessary geometric definition to complement and improve the WUI area map from the reclassification of hundreds of thousands of polygons from the official Spanish land use geodatabase (SIOSE), achieving a map scale of more than 1: 25,000, for its part, the quality of the SIOSE geodatabase has allowed us to reduce the total LIDAR data to process by 97.8%.

1. Justification and assessment of research topic

The Intergovernmental Panel on Climate Change (IPCC) states that forest fires have become significantly more frequent and devastating since the 1970s due to extreme weather events, including global warming, prolonged droughts, and recurrent thunderstorms (Moreno, 2005). During the period from 1984 to 2013, there were a total of 1933 deaths globally as a result of 303 devastating forest fires, affecting a population of 5.9 million people, with a 0.03% probability of death. This figure exceeds other types of natural hazards such as floods with only 0.006% (Doerr et al., 2013).

An area like the European Union burns worldwide on average every year causing social, economic, and environmental damage, with loss of life and the devastation of large natural and urbanized areas (Andela et al., 2019). In the European Union, more than 1.2 million hectares of natural cover burnt in 2017, with 127 victims and losses estimated at €10 billion. About 25% of these burnt areas were part of the Natura 2000 protection network, and this affected efforts to conserve natural habitats and biodiversity (San-Miguel-Ayanz et al., 2018). In 2018, fires in Greece and California killed 176 people, burnt more than 100,000 ha, and destroyed almost 15,000 houses. Such events illustrate the danger of forest fires as extreme disasters (Ribeiro et al., 2020). The occurrence

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and intensity of such events has increased considerably in the last two decades because of climate change and changes in land use (Badia et al., 2011; Moreira et al., 2011; Moreno et al., 2014; Moritz et al., 2014; Westerling et al., 2006). This dynamic requires a comprehensive vision of extreme forest fires in order to design policies that prevent or mitigate their effects (Tedim et al., 2020).

The proximity of human settlements to the forest vegetation introduces us to a simple concept from the spatial point of view, but very complex from the geographical point of view, because of the interactions involved. This issue has been analyzed by many scientific works, highlighting those of Stewart, S.I. et al. (2007) for the United States and Caballero D. (2007) and Galiana, L. (2012) for the Spanish territory. Since the 1970s, the development of low-density edification in the wildland has been considered an influencing factor for forest management (Theobald and Romme, 2007). Wildland urban-interface zones correspond to areas where residential infrastructures are mixed with flammable vegetation (Alcasena et al., 2017). In Spain, the basic guidelines for civil protection in forest fire emergencies define WUI zones as those in which 'buildings come into contact with the forest' (BOE, 2013), adding that fire can spread within inhabited areas in these zones. Moreno et al. (2018) analyzed the development of the concept of WUI zones in Spain and explained how this term is increasingly linked to forest fires with serious consequences. The WUI communities could correspond to three different categories: interface, intermix and occluded communities, being the first two the more studied. Interface is where the buildings meet the wildland fuels showing a clear demarcation between them, meanwhile Intermix is where the buildings are scattered inside a wildland area (USDA and USDI 2001).

The trend of fires in WUI for Spain implies the concurrence of: (A) an increase in the areas of WUI due to the continuous growth of urbanization in wildland; (B) new more frequent and intense fire regimes due to climate change and (C) accumulation of fuel contributing to firepower, due to rural neglect (Galiana et al., 2011; Pastor et al., 2020). Recent land use and land cover changes (LULC) in many of these WUI areas in Spain shows that residential expansion coexist with an abandonment of traditional rural/farming activities and its approaching forest areas, also growing, but without active exploitation and poor management. This is a combination of elements that influences the danger of this type of trend, due to the increase in the vulnerability of pine forests and sclerophyll formations (Badia et al., 2019). If recent evolution of the landscape in many countries of the Mediterranean environment is conditioning the growth of urbanized areas, in Spain, the metropolitan environments (Madrid, Barcelona or Valencia) and the Mediterranean coast stand out, associated with the tourist phenomenon (Galiana, 2012).

The search for natural spaces in which to live has the effect of increasing the exposure of human lives and high-value goods to the risk of fire, and increasing the vulnerability of forest stands, since the proximity of people increases the danger of fire (Galiana-Martín and Karlsson, 2012). This is a system in which changes in land use interacts with and affects each of the three factors of forest fire risk: hazard, vulnerability, and exposure (see Fig. 1). The proximity of buildings to forest fuel is the most obvious geographical sign of this process, a change in the landscape brought by a new economic and territorial model that represents a sharp break with the past (Antrop, 2004).

Fig. 1 shows a diagram with the complex interaction that occurs in the WUI zones between the components of forest fire risk and land uses. As we have said, in Spain the LULCC are causing the increase of the WUI areas and the exposure of human lives and high value goods to risk of wildfire. About the components of risk, the LULCC not only influence the increase in exposure, they are also causing an increase in hazard, since the rural spaces abandonment and the scattered settlements growth lead to an increase in fires and, on the other hand, the abandonment of agricultural and silvopastoral activities are increasing the growth of wild vegetation that is highly vulnerable to these fires. At the base of the graph is the geoinformation on occupation of the territory: LULC databases and the results of Remote Sensing. Combining these two sources of information is essential in the study of wildfire risk (Chuvieco et al., 2010) and in this research, for the delimitation of the risk exposure in WUI zones. For this reason, we are focusing research on applying

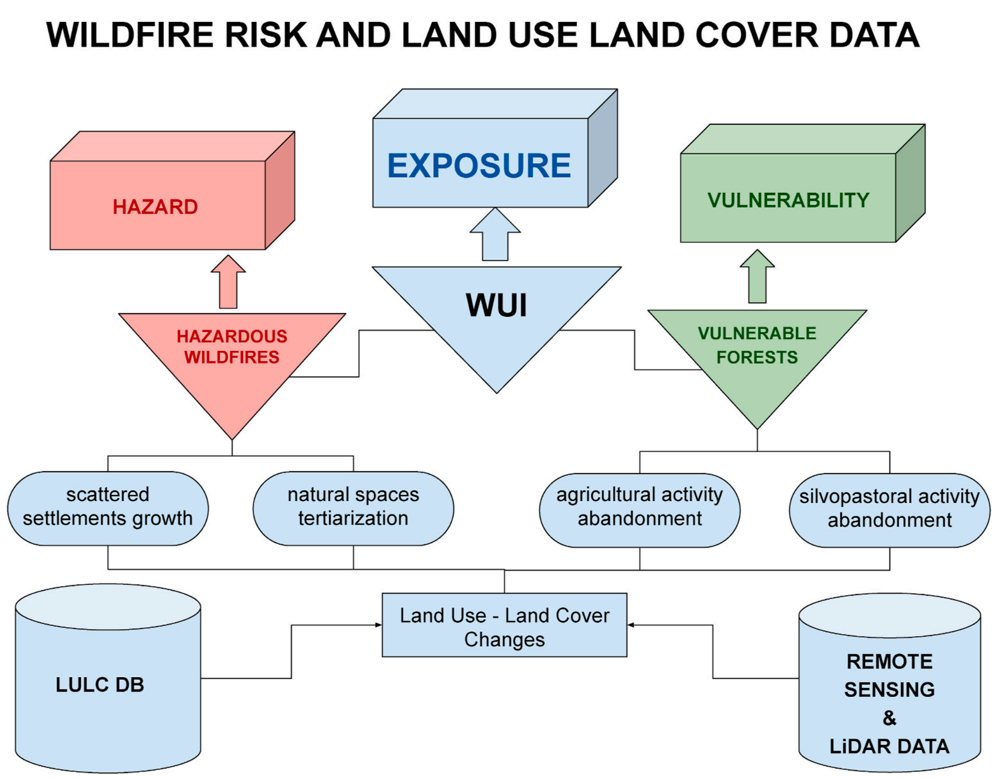


Fig. 1. The figure shows the importance of land use databases for the determination of landscape changes and increased urban exposure to forest fire risk. Land use changes lead to an increase in exposure, but indirectly, they are also increasing the vulnerability of forest areas and increasing the fire hazard.

methods to combine official information sources that allow us to improve the identification of residential areas exposed to fire risk.

This paper proposes how to solve the first step to analyze the risk of wildfire in these WUI areas: the automatic delimitation of buildings exposed by the proximity of fuel forest masses, using official repositories that initially have not been designed for this purpose. Some interesting and high quality research has been published about the mapping of WUI areas exposed to the risk of forest fire in Europe and Spain (Caballero, 2007; Galiana et al., 2011; Modugno et al., 2016; Badia et al., 2017; Vilar et al., 2019). In this work, an automated method is proposed to apply it anywhere in Spain, using official and open information repositories (SIOSE LULC data base with reference scale 1: 25,000, together with active remote sensing LiDAR data, minimum 1 echo for every 2 square meters) very suitable to obtain results with sufficient detail to be applied in local planning.

Planning and prevention in these WUI areas are aspects highlighted in many research works (Vince et al., 2004; Martínez et al., 2009; Montiel and Herrero, 2010; Galiana, 2017) and adequate cartography is necessary for this purpose. A massive data processing method that allows obtaining a detailed mapping of the WUI areas exposed to fire is of vital importance to improve prevention plans at the local (municipality) level. The local emergency prevention plans establish all the actions and procedures related to emergency management (for example, evacuation-confinement protocols, self-protection, resources and roles of the organizations, etc.). The employing of a high definition scale is recommended in order to successfully accomplish this task, but this is not always easy to obtain from public databases directly (Pastor et al., 2020).

Geotechnologies offer valuable information for the development of analysis before, during, and after a natural disaster. Public organizations often have the information that enables finding a solution to territorial planning problems, but these organizations are not always aware that they possess the information, or do not have the appropriate tools or methodologies that enable its use by territory planning agents.

Geotechnologies have made it possible to increase the quantity, quality, and speed of data collection and processing. However, it is necessary to formulate proposals to automate the processing of data from official geographical information sources so that the data can be exploited through reproducible methodologies. Geographic knowledge has progressed for many years using Geo Small Data, characterized by processed data in relational databases (GIS) to answer specific questions. It is a strategy that has been remarkably successful, enabling the geosciences to advance in leaps and bounds, but this data management is nowadays being challenged by the development of Geo Big Data (Goodchild, 2013). Small data studies will however continue to be necessary and valuable in the future, because of their utility in answering specific problems and targeted queries identified in spatial planning works. Methods of Geo Small Data will increasingly be adapted to coexist with Geo Big Data and work with development of new spatial data infrastructures with larger datasets (such as data from Remote Sensing), encouraging sharing, reuse and open geodata. Small Data gain value and utility when made accessible for reuse and are combined with other datasets (Kitchin and Lauriault, 2015).

The methodology of this paper uses the logic and value of Geo Small Data studies, but exploiting massive geodata and abording the problems of scaling Geo Small Data into large volume data infrastructure, with a complex land use geodatabase and billions of LiDAR points. The efficient processing of large, often technically complex datasets requires dedicated algorithms and software dependent on users created tools, methods and approaches. The academic, governmental, and private-sector communities need solutions to address a growing demand for open and accessible data, the scientific community is recognizing the importance of free and open-source software (FOSS) and users-defined workflows (Roussel et al., 2020).

In this work, the challenges of handling large volumes of information are addressed through the use of free and open source tools for containerization, relational databases, geospatial data management libraries and open geodata. This research shows how to use various sources of geographical information to generate a methodology that enables a rapid determination of the buildings exposed to forest fire risk in the wildland urban-interface (WUI) and demonstrates its utility through a case study applied to the Spanish Mediterranean coast.

2. Research hypothesis and targets

The hypothesis of this research establishes that processing Geo Small Data with free tools can reduce the processing times and enhance the degree of detail of spatial analysis for the planning and management of natural risks when using official open data libraries of geographical information.

As an experimental analysis to verify this hypothesis, the study of exposure to fire risk mapping at the wildland urban-interface (WUI) has been proposed, because it is a good example of how to properly combine diverse geographical information from the official databases of the National Territorial Observation Plan (NTOP) produced by the Spanish National Geographic Institute (IGN).

The specific targets to answer the research question in this paper are:

- Review the context of land use and land cover changes (LULCC) at a regional level and the impact on the occurrence of forest fires in the WUI.
- Analyze the suitability of the various official sources of geographical information and select those most suitable for resolving the problem posed.
- Obtain the geographical information data from these databases for integration into a PostGIS database suitable for the objectives of this research.
- Identify those polygons in the Spanish National Information System on Land Occupancy (SIOSE) in WUI with buildings less than 100 m from fuel (and so presenting a potential forest fire risk). The reference scale is 1:25.000.
- Structure the LiDAR information in the PostGIS database for the province of Alicante to analyze, compare, complete, and correct any geometric ambiguity in the data provided by the SIOSE and make it suitable for detailed scale analysis (1:500 or 1:100).
- Extract LiDAR points corresponding to buildings and fuel to redefine the geometric information within the polygons previously obtained with the SIOSE.
- Validate the WUI exposure data obtained with the SIOSE by crossing it with the LiDAR data to perform a basic statistical analysis that enables a verification of coincidence by both sources of information and, in addition, to summarily quantify the general processing times necessary to manage LiDAR data for this purpose (Verify the research hypothesis through a case study applied to the Mediterranean touristic coast of Valencian Region).

3. Land use - land cover changes and WUI in the Valencia Region

Half a million hectares are burnt annually in southern Europe by forest fires (Moreira et al., 2011). The number of identified forest fires has increased significantly in countries such as Portugal and Spain (Rodrigues et al., 2016). The existence of extensive areas with flammable vegetation, together with dry warm winds and long periods without rainfall, increases the probability of these events occurring in Mediterranean countries (Doerr et al., 2013).

The Intergovernmental Panel on Climate Change (IPCC) produced a report in 2012 that warned of an increase in aridity in Central and Southern Europe. In the case of the Mediterranean, this could increase the risk of forest fires due to the presence of coniferous forests, and especially sclerophyll and shrubby scrubs (such as garrigue, marquis, and chaparral) (Murray and Ebi, 2012).

Mediterranean basin landscapes are composed of a mosaic of grasslands, cultivated areas, abandoned farm fields, and forests with a predominance of pines, oaks, and bushes (Moritz et al., 2014). There are also large and abundant areas of urban-forest interface (San-Miguel-Ayanz et al., 2013). A territorial policy in the Valencia Region has encouraged the construction of weekend and holiday homes, and this policy has been favored by the economic importance of tourism and boosted by the prices reached in a property bubble.[1]

Fig. 2 shows the changes in the principal land uses in the Valencia Region over the last 120 years. The bar graph shows the clear increase in urbanized areas and their approach on the spaces that can become forest fuel during a fire. In the first half of the last century, there was an increase in farmland and deforestation, but this trend changed from the 60s and 70s, with a notable fall in farming activity. Furthermore, this decline in farmland coincided with an acceleration in the growth of urban settlement. The growth of expansive urbanism is so significant that it can even be seen on these small-scale maps.

A more detailed analysis shows a growth in artificial surfaces that increase from 2.6% to 4.9% of the Valencian territory. At some points on the coast in the province of Alicante this growth has reached up to 12% (Costa Blanca - Alicante), while in the rest of Spain this value is much lower and varies from just 1.2%–2% (Membrado, Tena, 2013). These figures reveal the extent of the economic and territorial changes to which we referred earlier.

In areas where buildings proliferate, we also find increased danger of forest fires due to the combination of human activity and the increasing presence of fuel produced by the growth of natural vegetation and the abandonment of farming. The construction of buildings sometimes implies a decrease in the presence of fuel; however, this does not diminish the risk, because of the increased probability of a fire occurring due to the increase in population and changes in land use (San-Miguel-Ayanz et al., 2013).

These residential development projects seek the presence of pine forests to enhance the aesthetic and commercial valuation of the landscape and create a false perception of environmental value. As there is no space left near the beaches to satisfy the demand for residential properties, these developments have 'climbed' the foothills and slopes, seeking views of the sea next to wooded areas. These developments are a 'product' of a tourist market made up of new residents. These new arrivals are often foreigners and unaware of the natural environment in which they are buying their properties, and unaware of the danger of forest fires. The new settlers, often seasonal, far from considering this mass of vegetation as a fuel, consider it a natural attraction that adds to the attractiveness of the coast, sun, and beach.

This reduced perception of danger ignores reality, since from 1979 to 2016 there were a total of 821 deaths due to forest fires in Mediterranean Europe (Portugal, Spain, Greece, and Italy), according to (Molina-Terrén et al., 2019). The average number hectares burnt annually was 447,800, much of which was produced by fewer than 15% of the number of fires in that period (San-Miguel-Ayanz et al., 2018). We are facing a situation in which mega-fires associated with heat waves travel for miles and increasingly affect the urban-forestry interface (Cardil et al., 2014; Castellnou i Ribau and Miralles Bover, 2009; San-Miguel-Ayanz et al., 2013) due to climate change (Barrera-Escoda and Cunillera, 2011; Cardil et al., 2014; Kuemmerle et al., 2016; Moreira et al., 2011; Piñol et al., 1998). This seems to be confirmed by the results of the most recent fires in Greece and Portugal (2017 and 2018), with more than 200 deaths in just two years (Bento-Gonçalves and dos Santos, 2019).

In Spain, initial efforts to combat forest fires were based on fines and repressive measures, rather than awareness and prevention, and the results were poor. Recently, measures aimed at training, awareness, and prevention have been gaining more attention from authorities in these areas (Fernandez-Alvarez et al., 2019). There is a difficulty in defining the peri-urban belt in these areas. This used to be obvious – but residential developments are now scattered in forest areas and so buildings and forest fuel have begun to share space (Badia et al., 2011).

Spanish regulations guide and supervise the preparation of local action plans, and these regulations require the description, identification, and geographical location of population nuclei and forest masses, as well as a listing of WUI areas and the implied risks (Spain, 2013; Generalitat Valenciana, 2017). Therefore, an automated methodology that enables obtaining this detailed information from official and open geographical data sources would be useful for this planning and prevention task.

4. Geographical open data and WUI (LULC geodatabase and LiDAR)

At present, there are several sources of geographical information available for Spain that cover this subject matter – such as the CORINE Land Cover (CLC), the Cadastral Geographical Information System (SIGCA-2), and the Valencia Regional Forestry Plans. These sources provide valuable information for comparative and planning studies at medium and small scales; however, they present limitations for detailed work in terms of thematic information, geometric definition, production scale, and scope of application.

For this reason, we have used the databases of the National Plan for Territorial Observation (NPTO) as these include information on land use, aerial photography, multispectral remote sensing data, airborne light detection and ranging data (LiDAR), field photographs, and offer standardized open formats and national coverage. The databases are also produced with parameters appropriate for achieving our objectives.

The NPTO is a project of the National Geographic Institute (IGN – Spanish Ministry of Development) and includes territorial information of special interest for our study: The National Aerial Orthophotography Plan (NAOP). This plan incorporates visible, laser, and infrared information, as well as the Information System on Land Occupancy in Spain (SIOSE).

The SIOSE is a database defined for a reference scale of 1:25,000 within the ETRS89 geodetic reference system. It was first launched in 2005 and updates have been made every three or four years. It has been established as a key reference in the management and coordination of geographic information among Spanish public administrations by harmonizing databases and standardizing procedures (IGN, 2018a). The value of this system was recognized by the United Nations in 2013 with the prestigious Public Service Award. When using this database, we are benefiting from an important process of integration of various sources: official maps, forest inventories, farm and crop use maps, regional administration data, remote sensing, fieldwork, etc.

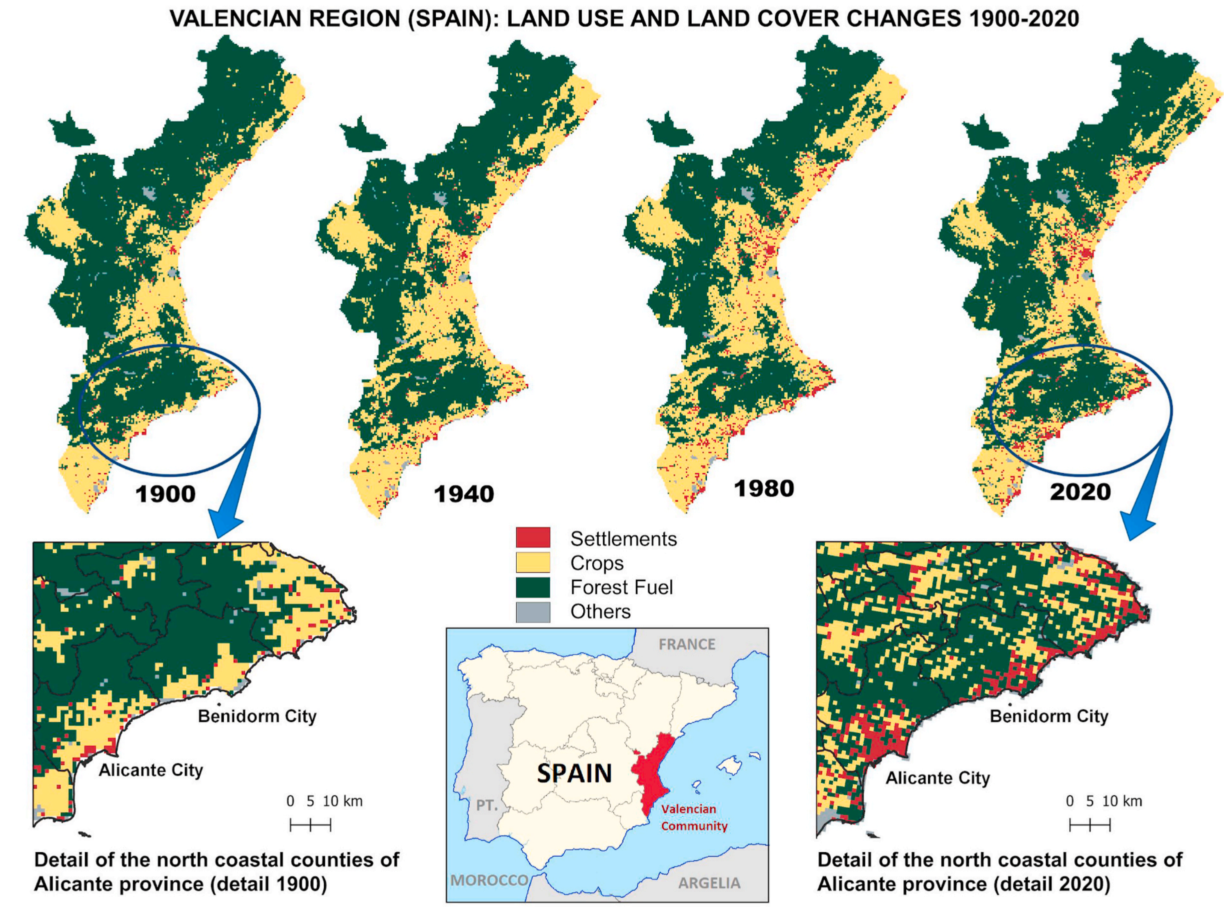
The SIOSE uses vector topology to represent units that can group several land covers within each polygon. The official document that shows the SIOSE data model details the conceptual structure[2] that describes the objects, attributes, relations, consistency rules, and philosophy of the system's digital vector geographical data (IGN, 2018b, 2015).

From the SIOSE data, the main source for our research has been the LiDAR information from the NPTO project. Currently, two coverages have been made, the first was developed between 2008 and 2015, and the second started in 2015 and is still in progress.

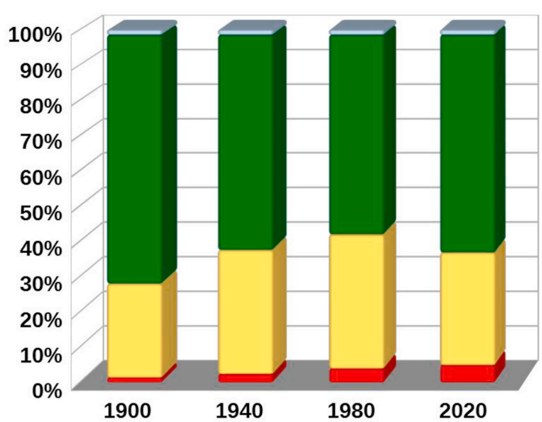
LiDAR technology has been used worldwide for preparing forest inventories or describing the structural attributes of forests (Garcia-Gutierrez et al., 2014). In the field of forest fires, it is very common to make

[1] The concept of a 'bubble' refers to the market behaviour of property prices by making a comparison with a soap bubble (which expands then bursts): an initial phase of growth, which in Spain coincided with the entry into the euro, and a second phase of sudden decrease.

[2] A document entitled 'Estructura y consulta de la Base de Datos SIOSE' is available on the SIOSE project website. It describes the table structure used to store geometries and the associated information.



(annual percentage of 2,325,500 ha)



Years	1990	1940	1980	2020
Settlements	1.4%	2.4%	3.9%	4.9%
Crops	26.6%	35.2%	38.0%	31.9%
Forest Fuel	70.5%	61.0%	56.6%	61.7%
Others	1.4%	1.4%	1.4%	1.4%
Total	100.0%	100.0%	100.0%	100.0%

Fig. 2. Changes in principal land uses (1990–2020) in the Valencian Region. The graph shows urban areas growing towards the forests (spatial resolution of 1 km pixel). In detail, we see the area of the northern coast of the province of Alicante (La Marina County) in which the exposure of the WUI is very notable. Source: Authors from data provided by the Historic Land Dynamics Assessment Database (HILDA), version 2.0 1900–2010 (Fuchs et al., 2013) and Corine LC data (ESA-IGN) reclassified and adapted to combine with HILDA data to complete the interval for the 1980–2020 period.

use of this data to develop fuel models, or to study the consequences of fires (Cottle et al., 2014; Haarig et al., 2018; Pelletier and Orem, 2014; Reddy et al., 2015; Rengers et al., 2016; Sankey et al., 2010). In 2019 (Fernández-Álvarez et al., 2019) worked with very high-resolution LiDAR datasets to describe fuels and their use for forest fire prevention and management (using GIS and decision trees).

Platt (2014) combined LiDAR and satellite images to determine the danger of forest fires in a home ignition zone (HIZ). In 2016 (Robles et al., 2016) carried out work in Galicia (Spain) to determine forest masses and evaluate compliance with forestry legislation, and (Barrado Rubio, 2019) has applied LiDAR to forest fire hazards in the WUI.

Most of these works use LiDAR data to obtain fine detail on the characteristics of vegetation in small study areas. If more extensive zones are studied then processes of territorial compartmentalization are employed, given the cost of handling such large volumes of information.

The NPTO LiDAR information uses the specification published by the American Society for Photogrammetry and Remote Sensing (ASPRS) version 1.2, format 3. Point clouds are automatically classified according to ASPRS standards, and additionally, the IGN uses the infrared or RGB values of photogrammetric flights to improve the results. The attributes and classes that are accepted for the classification attribute of the LiDAR 1.2. specification with their respective associated numerical values are shown in the tables in Fig. 3 (in which we have highlighted the values used in this research).

The NPTO LiDAR data is downloaded from an open library in LAZ format (compressed LAS) and RGB true color or near infrared values are incorporated using the NPTO orthophotos (spatial resolution at 25 cm pixel), or with orthophotos obtained simultaneously with the LiDAR data.

The main disadvantage of using LiDAR data is the volume of information to process, for this reason the LAS files that are downloaded from the IGN library usually include a maximum of 3.5–6.5 million echoes and cover surfaces of 2 × 2 km. If we consider the information associated with each echo, the management of a single LAS file using a desktop GIS may be jeopardized because of the impossibility of loading all the data into RAM. For example, in the province of Alicante, the number of LAZ files corresponding to the most recent data survey is 3416 – with a total volume of approximately 6 billion LiDAR echoes stored in more than a 100 GB of data (after superimposed data, duplicates, noise, etc. have been eliminated).

The use of LiDAR data has other inconveniences in addition to the volume of information to process. The temporal resolution of the IGN LiDAR data is much lower than the SIOSE data, and sometimes (depending on the physiographic characteristics of the area) LiDAR pulses provide erroneous thematic classification information – assigning building values to what might be bare rock (Barrado Rubio, 2019). For the determination of the low lying Mediterranean sclerophyllous scrub, the LiDAR also needs to be checked with other sources or very exhaustive fieldwork.

The SIOSE is a database with a great wealth of thematic information, although geometric accuracy is limited to a scale of 1:25,000 and some ambiguity is introduced regarding the location of smaller elements. However, LiDAR technology offers rapid data acquisition and a high spatial resolution, so it can be considered as the best option for obtaining data in areas where the SIOSE does not provide geometrically detailed information on land use and cover, or in its absence, for the evaluation and improvement of existing information.

The best option for our research has been to integrate both information resources in the same PostGIS database, thus starting from a vector topology for all geometries (points-LiDAR and polygons-SIOSE) apply a methodology capable of exploiting the advantages of each source and compensating for their disadvantages.

5. Methodology for massive geographic data use

The methodology proposed in this work can be considered a

POINT DATA RECORD FORMAT 3:

Item	Format	Size	Required
X	long	4 bytes	*
Y	long	4 bytes	*
Z	long	4 bytes	*
Intensity	unsigned short	2 bytes	
Return Number	3 bits (bits 0, 1, 2)	3 bits	*
Number of Returns (given pulse)	3 bits (bits 3, 4, 5)	3 bits	*
Scan Direction Flag	1 bit (bit 6)	1 bit	*
Edge of Flight Line	1 bit (bit 7)	1 bit	*
Classification	unsigned char	1 byte	*
Scan Angle Rank (-90 to +90) – Left side	unsigned char	1 byte	*
User Data	unsigned char	1 byte	
Point Source ID	unsigned short	2 bytes	*
GPS Time	double	8 bytes	*
Red	unsigned short	2 bytes	*
Green	unsigned short	2 bytes	*
Blue	unsigned short	2 bytes	*

ASPRS Standard LIDAR Point Classes

Classification Value (bits 0:4)	***Meaning***
0	Created, never classified
1	Unclassified
2	Ground
3	Low Vegetation
4	Medium Vegetation
5	High Vegetation
6	Building
7	Low Point (noise)
8	Model Key-point (mass point)
9	Water
10	*Reserved for ASPRS Definition*
11	*Reserved for ASPRS Definition*
12	Overlap Points
13-31	*Reserved for ASPRS Definition*

Fig. 3. The figure shows Format 3 for the storage of LiDAR points data in version 1.2 – and the classes for LiDAR points according to the ASPRS standard that have been used in this study. Authors from (ASPRS, 2008).

revaluation of Geo Small Data in the "Big Data Era" given the use of large amounts of massive data (volume) with heterogeneous characteristics (variety), and with accuracy assured by its official character (accurate). When exploiting this data with integration techniques, we can obtain a level of knowledge or information that would not have been reached in an isolated approach. Unlike Big Data, there is no immediacy in the capture of information (speed), but since it is an official and open database, the update depends on an administrative and management process that entails update periods of 3–5 years, but that ensures a very high quality of information.

This methodology is based on Geo Small Data with the target of the usability of the data and the reproducibility of the research. Small Data tries to facilitate or enable complex or voluminous information processes, focusing interest on the data that is most suitable for the investigation and the resolution of the analyzed problem. Small Data usually differs from Big Data in order to reject all unnecessary information and so collect and deal with data that clarifies the situation we want to measure, in order to reduce, simplify, or decompose a massive volume of information with a very clear objective.

Our methodology is inspired by the democratization of data and the dissemination of knowledge as proposed by the Open Knowledge Foundation. In the words of Pollock (2013) "Big data smacks of the centralization fads we've seen in each computing era … For many problems and questions, small data in itself is enough." (para. 2). On this matter professor Banafa (2016) reflects that "The real revolution will be the democratization of the means of data access, storage, and processing". Furthermore, Kitchin (2013) warns on two risks to the integrity of geographic scholarship: (i) the increase of empiricism and pseudo-positivism and (ii) the marginalization of Small Data studies, because Small Data Studies can be better adapted to answer specific inquiries.

The methodologic objective is to use data that would otherwise be very complex or impossible to handle, so that it can be operated using modest computer equipment typical of a technical office in a local public or private organization that works on prevention and management of natural risks.

The procedure is based on the combination of the information provided by the polygons of the Information System on Land Occupancy in Spain (SIOSE) and the LiDAR data of the NPTO-LiDAR project – with the use of free tools for containerization; databases; and libraries for geospatial data management. This has enabled us to make a fast and precise determination of the buildings exposed to the risk of forest fire in the province of Alicante, according to the typologies of the wildland urban-interface (WUI) as defined by (Stewart et al., 2007).

The data was processed using, among other tools, the relational database manager PostgreSQL (with the extensions PostGIS and PointCloud) in a Docker container environment and the GNU/Linux operating system command line interface. The main advantage of working with this set of tools for the execution of geo-processes lies in its capacity to handle layers with a large number of geometric entities without causing the system to collapse. This means that spatial continuity can be maintained in the analysis of large areas with massive volumes of geometric and alphanumeric data.

Once the SIOSE polygon and LiDAR point data is loaded in the PostGIS database, the land cover information from the SIOSE database is used to select thematic exposure areas – with the aim of filtering the LiDAR point cloud domains that will be processed in a second step.

The LiDAR data that coincides with the SIOSE polygons was then selected to indicate where there is a risk and presence of forest fuel (buildings and forests). The LiDAR pulses for these areas, thanks to the high level of spatial detail, enable an accurate localization and spatial distribution of the elements present within the SIOSE polygons.

In a third step, the results were verified using NPTO aerial photography (spatial resolution of 25 cm RGB pixels) and field photographs used by the IGN to produce the SIOSE, as well as photographs taken during fieldwork campaigns.

Finally, once the quality of the results obtained from the automation of both sources for the whole province of Alicante is verified, the results for WUI exposure obtained using only the SIOSE system and those obtained by combining this source with the LiDAR pulses, are compared to measure the suitability of the SIOSE as a source of information and to analyze the results of combining both sources.

The types of exposure to wildfire risk in WUI that we want to accurately define are based on the coexistence of forest fuel and buildings in the same SIOSE polygon (INTERMIX), or by the determination of polygons with fuel that are very close to other polygons with buildings (INTERFACE). The problem is that the SIOSE only reaches a geometric definition for a scale of 1:25,000 and a minimum mappable area of between 0.5 and 2 ha (depending on the type of land use). However, the thematic richness of the SIOSE is greater than its geometric definition and provides percentages of occupation for different land covers within the same polygon in great detail (provided that a given cover occupies at least 5% of the surface of the polygon).

Based on the thematic information of the SIOSE, the type of INTERMIX was defined for those polygons in which at least 50% of the extension is occupied by forest fuel together with scattered residential buildings or populated areas.

The second type or INTERFACE consists of two types of zones: forest fuel and exposed buildings. The SIOSE polygons with at least 75% of their surface area with forest fuel can be catalogued as fuel INTERFACE zones and we have also identified exposed buildings INTERFACE zones, or SIOSE polygons that have a built-up area inside them and are within a radius of 100 m of the fuel polygons identified above. In other words, an INTERFACE consultation produces areas with fuel and nearby inhabited areas that are exposed to the risk of a forest fire.

The intermix and interface concepts are not considered as attributes on the SIOSE database, and were technically established based on the work of Stewart et al. (2007). In order to adapt the methodology to the Spanish territory we have started from the adaptation of these concepts carried out by Moreno et al. (2018) where instead of using CENSUS data, it uses the SIOSE database, applying an approach based on the percentage distribution of surface within a SIOSE polygon and considering its neighbors in the case of the interface analysis, as described in the diagram in Fig. 4.

The determination of a distance of 100 m includes different forms of exposure to forest fire risk, ranging from: direct contact of the dwellings with powerful flames in the nearest areas, heat radiation and convection, sparks generated nearby, and wind-blown sparks with a longer trajectory for the more distant areas. This way, the three levels of exposure of the distance criteria used by Moreno et al. (2018) and described in the Technical Guide developed by Tecnoma (2005) about WUI in Spain was integrated in this study.

The SIOSE made it possible to select polygons exposed to fire risk in the WUI (INTERMIX or INTERFACE) thanks to its wealth of thematic information. However, photo interpretation revealed that inside these polygons the reality may vary and be complex, to the point that sometimes the distances between coverages does not create exposure to risk.

The points clouds from Airborne Lidar Scanner (ALS) were used to correct the geometric ambiguity of the SIOSE. The method consisted in automatically verifying the spatial distribution of the buildings, and the forest areas inside each of the SIOSE polygons selected as INTERMIX or INTERFACE. From the point clouds obtained it was possible to quantify the overestimation of exposure to forest fires previously detected by photo interpretation.

LiDAR echoes were selected with classification values 3 to 6 (bush, medium vegetation, tall vegetation, and buildings respectively). Clusters with a minimum size of 25 points and a maximum distance between points of 5 m were then calculated, and each cluster was characterized either as a source of fuel or a set of buildings. Finally, by computing the distance ratio between pairs of fuel and building clusters, the exposure within each of the SIOSE polygons previously assigned to INTERMIX or INTERFACE was determined (see Fig. 5).

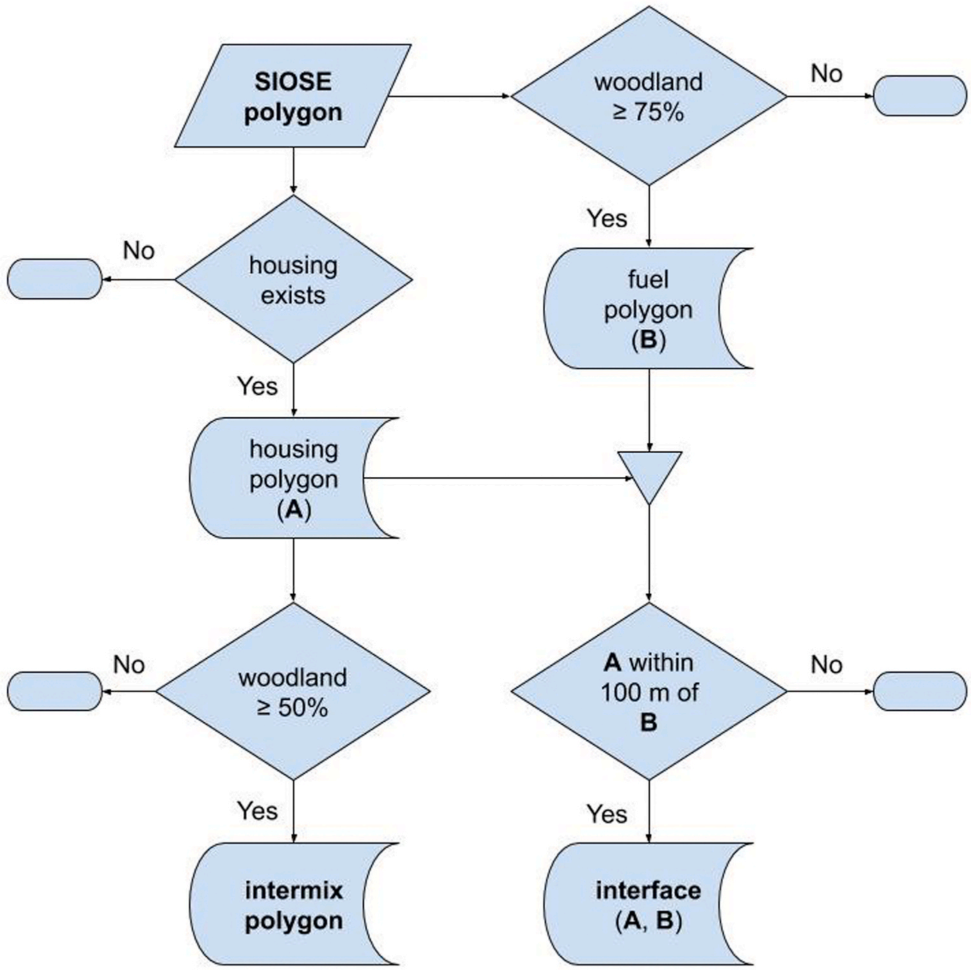


Fig. 4. Flow chart with the process to obtain polygons from the SIOSE database exposed to fire risk in WUI by INTERMIX or INTERFACE. Source: Authors from (Moreno et al., 2018).

6. Empirical implementation

The province of Alicante, in the southern third of the Region of Valencia (see Fig. 2), has been selected because it is a clear example of expansive urban development linked to coastal areas and with many second homes (a phenomenon typical of Mediterranean tourist areas). This urban growth usually occurs in areas of danger from forest fire and comes into direct contact with the fuel on the foothills of the mountains of the north-eastern extension of the Prebetic range – with abandoned farming terraces, Mediterranean sclerophyll scrub, and abundant pine forests (Generalitat Valenciana, 2012).

Alicante enjoys a Mediterranean climate with very mild winters, but very dry and hot summers, and with little rainfall that is very unevenly distributed throughout the year. Storms often occur in spring and, above all, autumn. This climate generates dangerous conditions for forest fires and floods, and these may be aggravated by climate change.

In addition, this southern part of the Valencian Region is one of the most populated in Spain, with a total of approximately 1.8 million inhabitants, according to the municipal census (INE, 2019). Horizontal urban growth has consumed considerable space and urban development on the coast of Alicante has grown faster than almost anywhere else in Spain (500 ha of average growth per year) and was only exceeded during the period of the ‘housing bubble’ in Madrid. Alicante has become the province in Spain where this phenomenon is most notably associated with the presence of immigrants from ‘rich Europe’ (Membrado Tena, 2013).

The province bases its economy mainly on the service sector and tourism, although there is also small-scale industry and farming. The consumption of space has been adapted to improve the performance of these economic activities, although several of these adaptations have had unfavorable consequences in the medium and long term (Fig. 6). Tourism and holiday homes have experienced exponential growth in the coastal areas of the province since the second half of the 20th century (Fig. 2), generating a rapid and aggressive reduction in natural cover and traditional farming. The concentration of forest fuel areas (especially in the northeast of the province in the La Marina area), together with large housing developments, make the province of Alicante the ideal test bed for evaluating the methodological approach outlined above (Montiel, 1990). The calculation of WUI areas that are exposed to forest fire risk has a level of detail suitable for the design of local emergency plans, and so the empirical implementation will enable us to confirm the effectiveness of the automation of the processing of large volumes of information.

6.1. Data load

The sequence of analytical processes described in the methodology was executed from a software virtualization environment based on Docker container technology. Choosing this type of virtualized environment in projects oriented towards computationally intensive processes has a series of advantages that enable a high degree of reproducibility in research (Boettiger, 2014). Fig. 7 shows the sources of

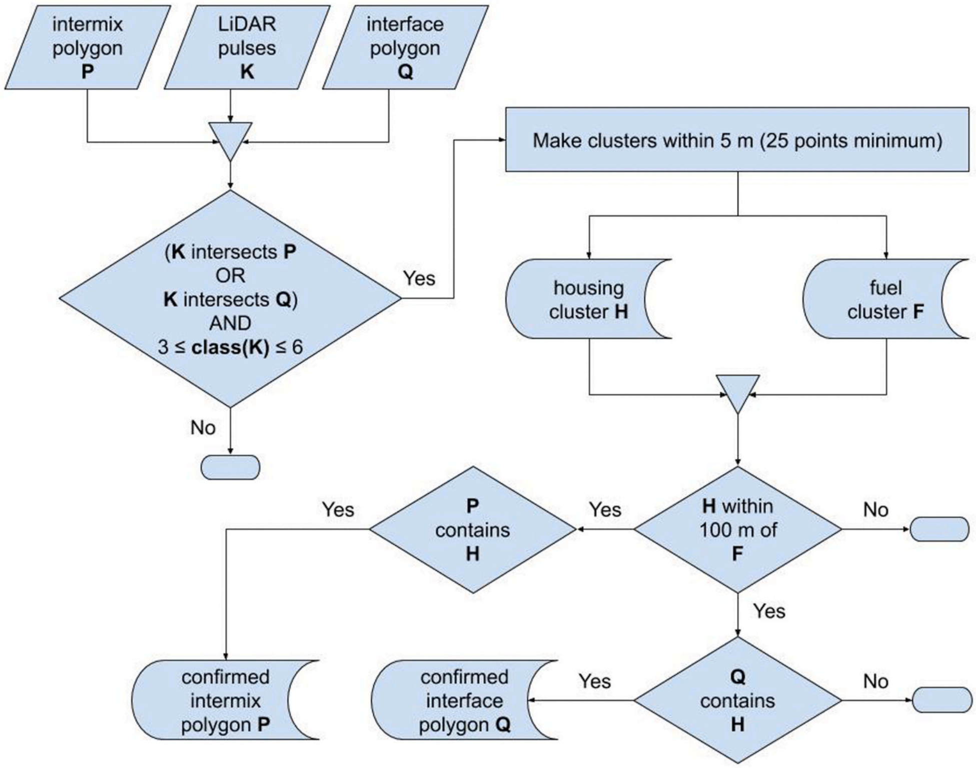


Fig. 5. Flow chart for determination and verification of buildings exposed to fire risk in the WUI (100 m), from LiDAR data that coincides with INTERMIX or INTERFACE polygons obtained with the SIOSE thematic data geoprocessing.

Fig. 6. Benitatxell, Alicante (Valencia Region), September 05, 2016. General view of a fire near the Cumbres del Sol estate, next to the natural park area of La Granadella. EFE/Morell.

the initial data, as well as the various containers used in this study, the latter are characterized according to their role as ETL tools, data warehouses, or SQL interfaces. All data sources are publicly available for download from the server of the National Centre for Geographical Information, with the exception of the SIOSE 2014 database dump file for PostgreSQL (which has been compiled by the IGN for use in the SIOSE-INNOVA research project). As shown in the statistical summary in Fig. 7, the large volume of LiDAR data poses a challenge when accessing subsets of the point cloud in a non-distributed data store. It was decided to perform a geographic partitioning of the point cloud. To do this, the grid of the National Topographic Map 1/25,000 (MTN25) was combined with the PostgreSQL declarative partitioning system (PostgreSQL Global Development Group, 2020) and the sheet number 1/25,000 was used as the partition key.

6.2. Data processing

In a first phase of the process, the SIOSE candidate polygons that met

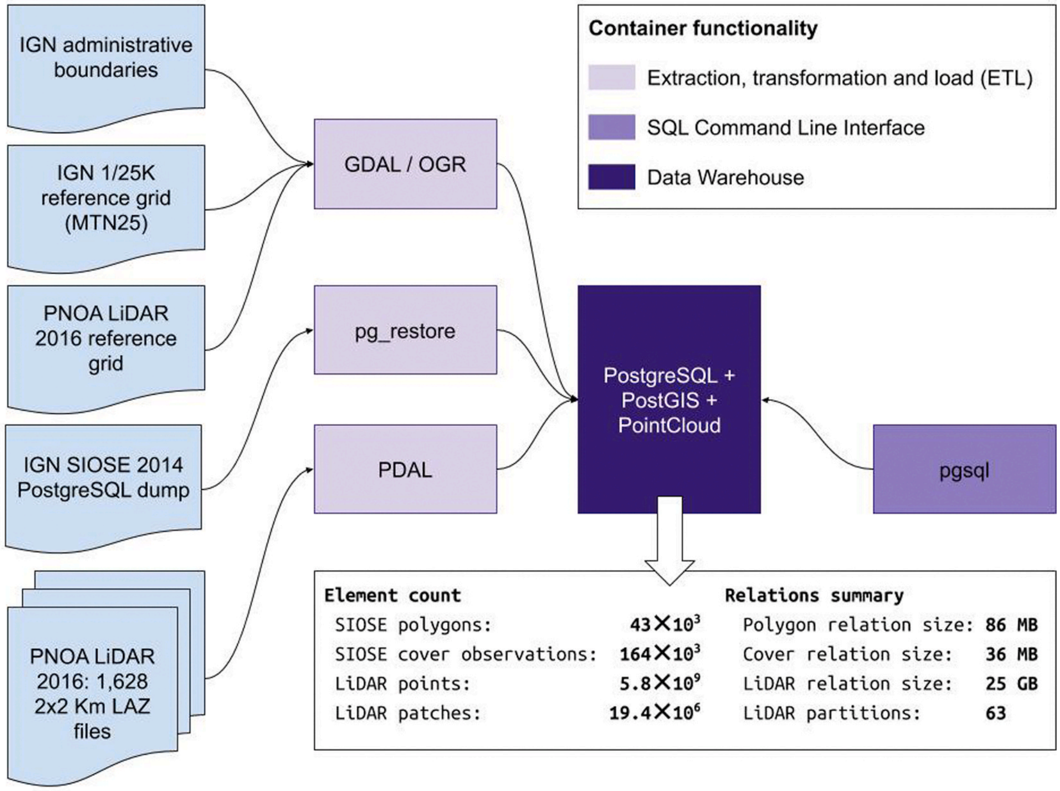


Fig. 7. Information sources and container environment used for the loading process in the data warehouse. Below are some significant figures of the resulting data volume after loading was completed.

the criteria for exposure to fire risk in the WUI were obtained. In accordance with the methodology established in this study, it was necessary to differentiate between exposure categories (INTERMIX and INTERFACE). In the first case, each polygon where buildings and fuel areas coincide was identified provided that the surface of the fuel areas is at least half the surface of the polygon. For each INTERMIX polygon, the accumulated building and fuel areas are recorded, both in absolute and relative terms. In addition, a breakdown of each pair of coverage observations that indicate INTERMIX is computed. Therefore, within an INTERMIX polygon, all the possible associations between each built area and each forest area are established, as well as their respective extensions. The calculation of pairs of polygons in an interface situation is made in two steps. Firstly, set A of polygons with buildings and set B of polygons occupied by at least 75% by forest mass are obtained. From the Cartesian product of both, all the possible pairs are selected in which polygon a_i in A is at most 100 m from polygon b_j in B. Therefore, each selected pair indicates an urban-forestry interface relationship between polygon a_i with the presence of buildings and polygon b_j (which is a source of fuel). For each a_i polygon selected, complementary metrics are recorded such as the isoperimetric quotient, built area, total fuel sources to which it is exposed, as well as the accumulated area of these sources.

In a second phase, the INTERMIX or INTERFACE situation is confirmed by analyzing the spatial distribution of coverage within the candidate SIOSE polygons. To achieve this, the subsets of the LiDAR point cloud inside each candidate are extracted and after filtering by classification value, each selected pulse is converted into a POINT-type vector geometry. The resulting points are reduced to MULTIPOINT-type clusters according to the parameters specified in the methodology. Finally, the minimum distances between building and fuel clusters are computed, and this enables an evaluation of the compliance of the hypothetical intermix or interface phenomenon within each SIOSE candidate polygon.

7. Results and discussion

The table in Fig. 8 provides a summary of the results of both phases of the data process and the map in Fig. 9 shows the territory. If we consider the indicative processing times, we can see that the calculation of clusters represented around 90% of the computational cost. This computational effort was generally acceptable thanks to the design of the declarative partitions of the LiDAR point cloud. However, it is possible to introduce heuristic capabilities in the cluster calculation model that would probably enable a reduction in the computational effort needed.

7.1. Comparison between WUI-SIOSE and WUI- LiDAR risk exposure

The final step is to verify the results from the SIOSE with those obtained from LiDAR data and so confirm that the WUI typology calculated in INTERMIX from the SIOSE database for the study area is mostly correct. The LiDAR building clusters detected using the INTERMIX methodology confirm most of the SIOSE polygons that were thematically revealed as WUI exposed to risk. The greater geometric accuracy of the LiDAR data confirmed 183 of the 187 initial SIOSE polygons, that is, 98% agreement. This enables us to qualify as suitable the use of SIOSE as a source of information for the analysis of this type of WUI.

Map 1 in Fig. 10 shows examples of the INTERMIX polygons according to their situation of exposure in an area of La Marina County and we can see that a comparison with the LiDAR clusters confirms most of the SIOSE polygons that were identified as exposed to risk (red identifies the INTERMIX polygons confirmed by LiDAR data and green shows the unconfirmed polygons). In map 2 in Fig. 10 it is also possible to verify the accuracy of the identification of the buildings exposed to fire risk with the clusters of LiDAR points in INTERMIX when compared with the detailed aerial photograph.

The result is more complex for the INTERFACE mode at a distance of

Data source	Outcome	Item count	Processing time (minutes)
SIOSE	Candidate intermix polygons	187	< 1
	Intermix cover observation pairs	232	< 1
	Housing polygons	9,519	< 1
	Housing cover observations	9,752	< 1
	Forest fuel polygons	9,548	4
	Forest fuel cover observations	11,700	< 1
	Candidate housing polygons exposed to forest fuel polygons	2,270	< 1
	Interface polygon pairs	3,496	< 1
SIOSE + LiDAR	Intermix points / *clusters*	2,874,017 / *3,417*	11
	Interface housing points / *clusters*	10,253,308 / *6,881*	52
	Interface fuel forest points / *clusters*	111,007,814 / *54,332*	254
	Intermix assessment	1378	2
	Interface assessment	6881	18

Fig. 8. Results of the (i) SIOSE polygon candidate selection process in the INTERMIX and INTERFACE categories; and (ii) LiDAR point cluster calculation. For the results on coverage observations, it is clear that the number of elements is always greater than the number of their polygon-related counterparts. This is a direct consequence of the concept of composite coverage on which the SIOSE data model is based.

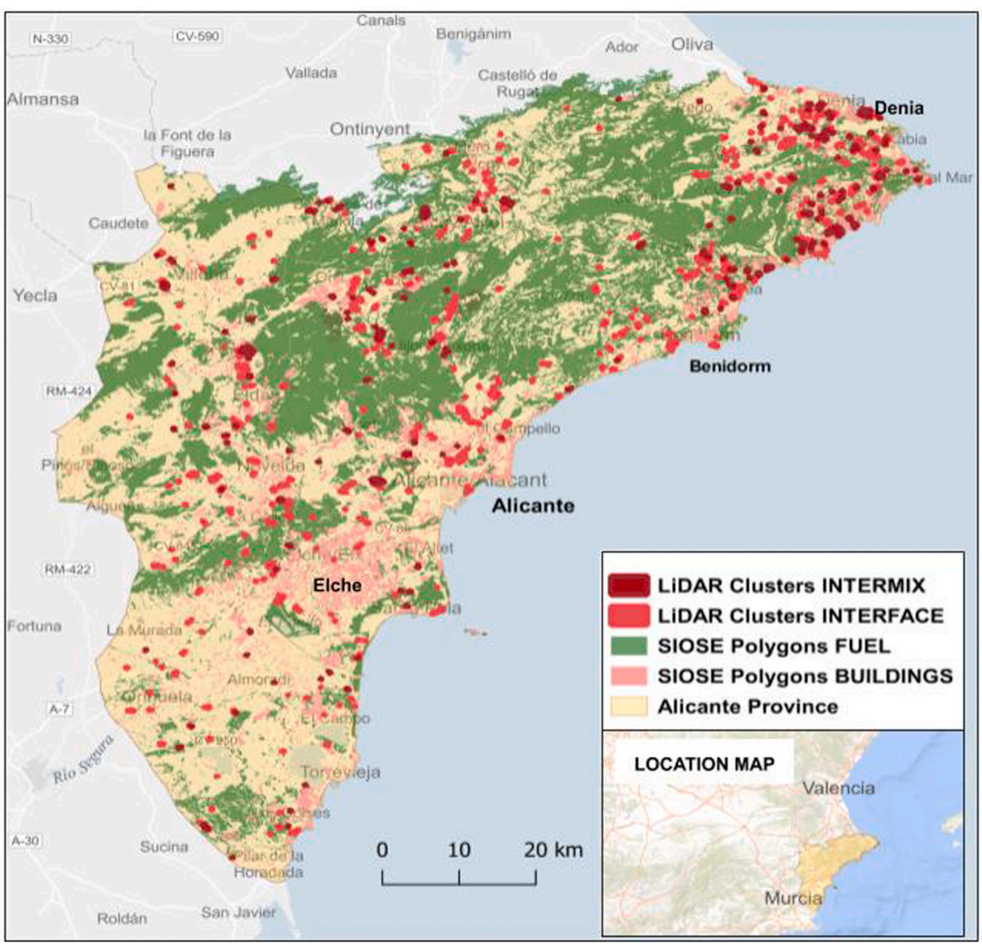


Fig. 9. Map of the distribution of the clusters formed by the sets of LiDAR points of WUI exposure in INTERMIX and INTERFACE. The table shows summarized data about the queries made to obtain the results from the thematically filtered LiDAR data.

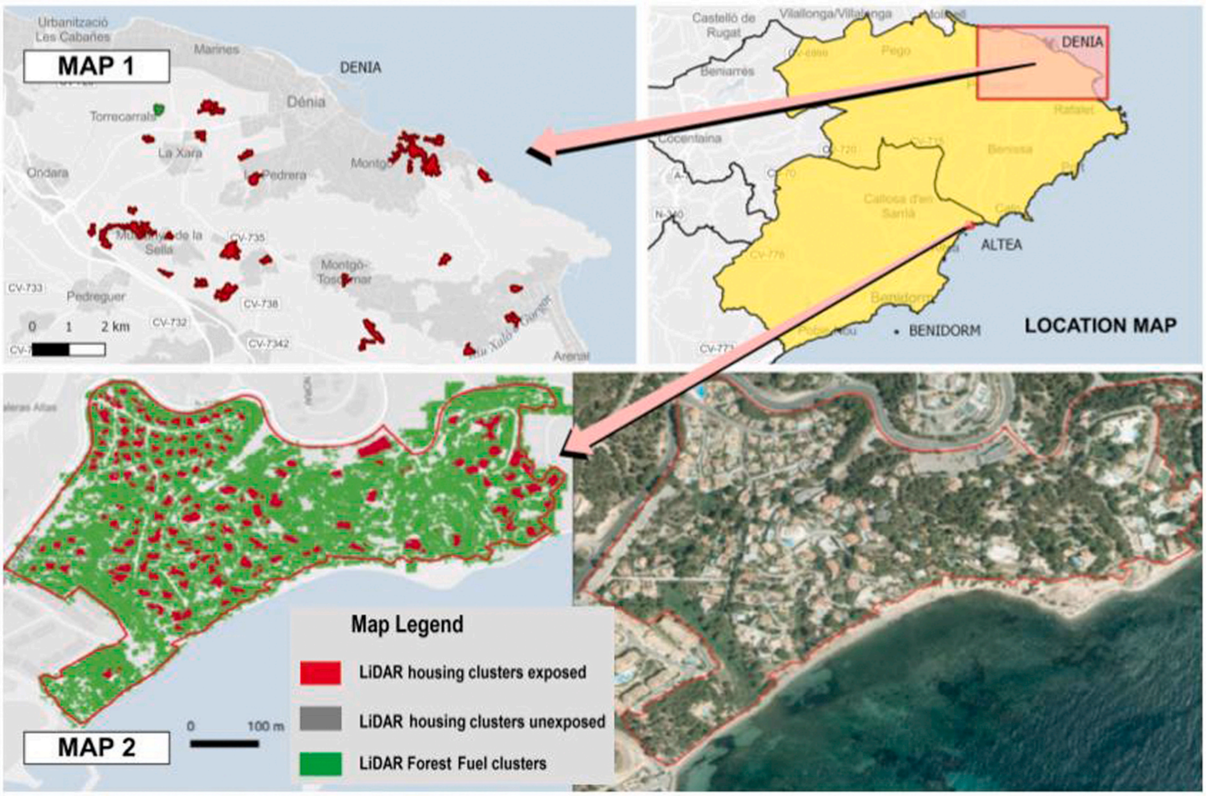


Fig. 10. In Map 1 we see a good example of verification with the LiDAR data of the WUI in INTERMIX obtained with the thematic SIOSE data near Denia. In map 2 we can see the level of detail of the WUI exposure obtained by the LiDAR clusters and its verification with the most recent orthophoto of the National Aerial Orthophotography Plan of an area in the municipality of Altea (La Marina County).

100 m between buildings and fuel. By means of the evaluation process based on the calculation of minimum distances between clusters, it was possible to determine that this WUI mode produces results that distinguish between four situations:

A. **False WUI-SIOSE risk exposure:** INTERFACE polygons according to SIOSE, in which significant building clusters were detected, but none of which were shown in the 100 m INTERFACE (negative INTERFACE checks due to geometric ambiguity within each SIOSE polygon).
B. **Partial WUI-SIOSE risk exposure:** polygons with clusters of exposed buildings together with others not exposed but within the same SIOSE polygon (these are partial verifications, and the result of the geometric precision of the LiDAR data, which enables us to define the location of both situations within each SIOSE polygon).
C. **Total WUI-SIOSE risk exposure**: polygons in which all the building clusters were exposed (positive checks of all clusters within the same SIOSE polygon).
D. **Error detection:** confirmed by aerial photo-interpretation or fieldwork, in which the most frequent cases are interface polygons according to SIOSE, but in which no clusters of buildings were detected with LiDAR (possible false INTERFACE zones, or with buildings so isolated that the cluster generation process did not detect them).

Cases A and D correspond to SIOSE INTERFACE polygons that are not really exposed to risk and represent 52% of false positives, a very high value that suggests it would not be appropriate to use SIOSE as the only data source to indicate risk exposure in the WUI. Cases B and C are polygons exposed to risk in the WUI in INTERFACE at 100 m that are verified by LiDAR data and represent 48% of the cases; however, most are type B (45%), that is, situations in which the exposure to risk identified with the SIOSE thematic information has a partial value, but in reality not all the built surfaces within the SIOSE polygons are exposed to risk. Therefore, for this type of situation, the use of LiDAR data is indispensable to indicate with high definition precision the buildings that are truly exposed.

Fig. 11 shows a map in a municipality (Pedreguer) in La Marina County with good examples of types A and B in the first image, and type C in the second image. These images reveal the level of detail achieved with the LiDAR data when specifying risk exposure in the WUI and considering the elements that determine risk (buildings, fuel, and distance).

The results obtained in the province of Alicante confirm that the joint use of SIOSE and LiDAR data does justify the research effort and demonstrate the synergy of the joint use of these two sources of information by achieving a geographical precision that exceeds the scale of the SIOSE application (1:25,000) and discards almost half of the SIOSE polygons that are candidates for false exposure to risk in INTERFACE (due to the 'geographical ambiguity' of the various land uses or coverage within each SIOSE polygon).

To review the type D cases with errors detected in the LiDAR data, we made selective fieldwork checks and more extensive verification through photo interpretation. Two main causes for false identification of buildings were identified during this review process. The first was the small number of points that formed some building clusters (below the minimum established in our filtering process) which could be solved by refining the criterion and better adapting it to urban typology. The second was the presence of errors or noise in the classification of LiDAR pulses and which is beyond our control.

The verification of the forest coverage offered good results, but the differences between the level of disaggregation in the types of cover handled by the SIOSE and the LiDAR data means that LiDAR can omit or add information (especially in the polygons that represent composite cover). As these two data sources come from the same national project,

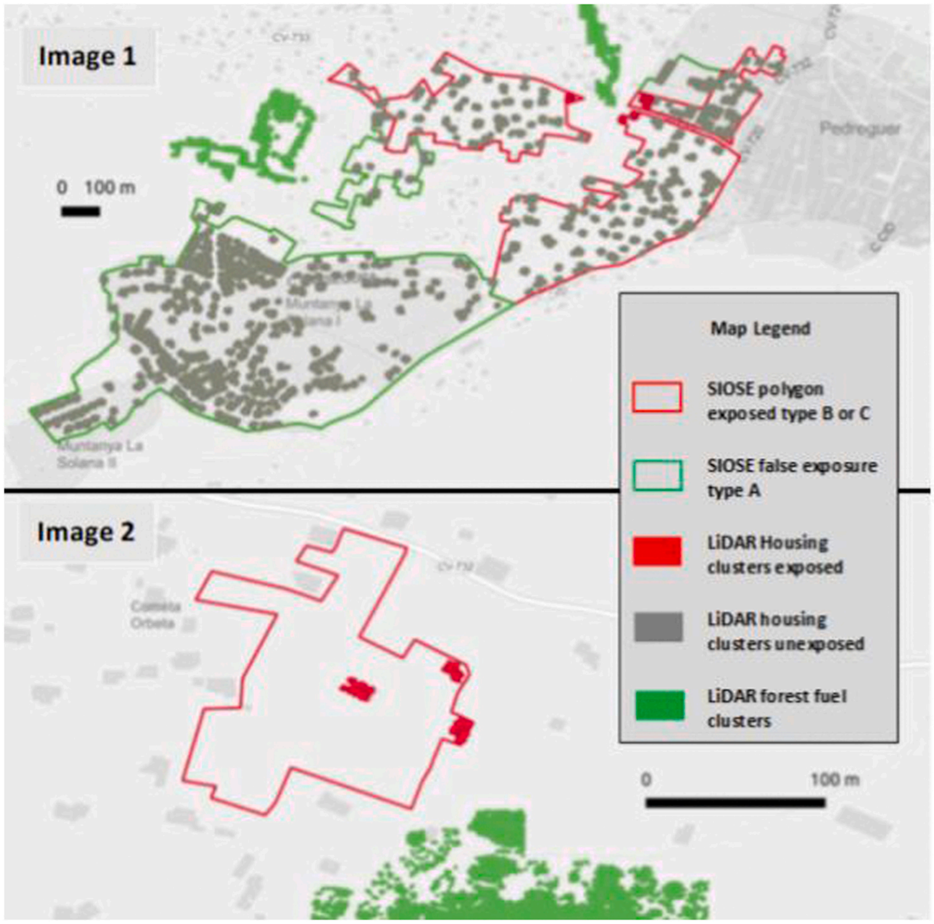


Fig. 11. Image 1 shows examples of INTERFACE polygons with type A (without risk exposed buildings), and B (partial risk exposure of the buildings). Image 2 shows an example of type C (all buildings at risk).

this problem could be overcome by harmonizing or standardizing for better data interoperability.

In addition, the results review process revealed that the workflow with LiDAR data could also be applied to other questions, such as the review and improvement of the results of the LiDAR data classification processes used during the generation of the LAS data files.

To optimize the use of the results in emergency planning at a local level, for a specific municipality, it would be useful to cross the data obtained with the cadastral information at a sub-parcel level. This would make it possible to obtain the cadastral identification of threatened properties and determine such key aspects as their economic valuation – which would ultimately provide information on vulnerability for insurance companies or consortiums. Strategies could even be designed to increase resilience or improve self-protection plans. But these proposals go beyond the objectives of this research, as they would be very local tasks in which the problem is no longer the automation of large volumes of geoinformation.

8. Conclusions

The conclusions have been drawn from an analysis of the sources of information, a review of the dynamics of forest fire risk in the European Mediterranean, and the results obtained from the processing of the information presented in this article.

The review of the changes in land use and cover allowed us to highlight the historical incidence of this dynamic in the increase of the risk of forest fires and to corroborate the importance of the problem in the selected study area.

It is possible to structure and manage a database with land cover and use information from LiDAR files and SIOSE information (from National Territorial Observation Plan of the National Geographic Institute) for large territories (provincial level or even larger), and this method is compatible with various scales of analysis – as well as small scales. The keys to achieving this are: (i) the use of logical partitions for storing LiDAR point clouds; and (ii) the reduction of LiDAR pulses to clusters of vector geometries integrated by thematically and spatially differentiated subsets. This enables the subsequent analyzes to be developed using relational algebra.

This approach can be applied at various scales, and even in another European Union nation, based on Corine LC and thematic cluster data from the multispectral remote sensing Sentinel 2 satellite (NDVI, NDBI, etc.). This is facilitated as the data used in this research follows the harmonization and integration criteria of the EAGLE Group[3] of the European Environment Information and Observation Network (EIONET), as is also the case with other European land use databases.

Comparison of the results obtained with the different data sources determined that the SIOSE data model makes this database a good

[3] The EAGLE group has defined techniques to integrate land cover information from the official libraries of each European country (Arnold et al., 2013), through an object-oriented model (OODM) that considers reference code lists, such as Corine LC and the technical specifications driven by INSPIRE (2007/2/EC) and the ISO standard 19,144–2 (LCML-Land Cover Meta Language). The SIOSE is a standardized and interoperable database that meets this EAGLE standard and complies with ISO 19101 (Geographic Information - Reference Model) as well as ISO 19109 (Geographic Information - rules for application schema).

source of information for the determination of risk exposure in the INTERMIX WUI, due to the relationship described for the coverages within the same polygon and the surface dimensioning of each polygon with respect to distances handled in the spatial analysis. However, its usefulness for determining risk exposure in INTERMIX WUI is mitigated by ambiguity in the geometric distribution of the coverages; and so complementary sources of information (aerial photo interpretation, remote sensing, fieldwork, cadastral mapping) that complicate the process are needed, unless the work is very local, or can be automated, i.e. using LiDAR or object based image analysis - OBIA.

Fieldwork campaigns, photo interpretation, and unautomated office work to solve the problem of the geographical ambiguity of the SIOSE implies considerable effort, time, and cost. The automated use of databases such as SIOSE in combination with remote sensing is highly effective for obtaining accurate topological determinations. In this case, official information is linked with the SIOSE information sources – as is the case of the National Aerial Orthophotography Plan flight information with LiDAR data.

The disadvantage of LiDAR data is its volume (as already noted in the methodological chapter) because a file with some 3.5 million pulses corresponding to an area of 2 × 2 km will begin to saturate the processing capacity of any desktop computer or desktop GIS application, and so effectively making this data unavailable to most territorial users. Working with the SIOSE database has enabled initially limiting the zones for applying LiDAR data processing (reducing the area of analysis to half of the initial total area and so eliminating billions of point geometries). The appropriately adjusted PostGIS geodatabase has simplified the management of large volumes of data and enables us to take advantage of Geo Small Data and use the memory capacity and processing cores of desktop computers.

The LiDAR information could have been processed from raster operations and map algebra, but this would have made it difficult to integrate this information in the same PostGIS database with the SIOSE data – and this is a fundamental aspect for resolving the study problem. Integrating the LiDAR information in the same database as the SIOSE enabled identifying with great detail and precision the residential buildings and forest masses within the areas of interest. However, the need for classification methods and more specific standardized indexes to improve the fidelity of the results with the reality of the land is not discarded; nor the application to other areas of study by defining the sizes of variable clusters according to types of uses, modalities of habitats, or landscapes.

The synergy of combining these two data sources for the topic of fire risk in the urban-forestry interface is therefore confirmed and it is demonstrated how this approach takes full advantage of the thematic richness of the SIOSE and the geographical accuracy of LiDAR. We must highlight the use of a non-graphic environment for the management of large volumes of data with very specific purposes (Geo Small Data and large geo data repositories) to optimize the processing capacity as this is crucial for successfully generating products from LiDAR data in reasonable times. This confirms that the proposed methodology can be applied throughout Spain at detailed scales with conventional computer resources and using official, standardized, and open information using free software – with all the advantages that this implies.

Ethical statement

The authors declare that all ethical practices have been followed in relation to the development, writing, and publication of this paper.

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Navarro Carrión, J.T.: Methodology, Software, Investigation, Validation, Data curation, Writing – original draft. León-Cadena, P.: Software, Investigation, Validation, Writing – original draft. Ramon-Morte, A: Conceptualization, Methodology, Investigation, Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.rsase.2021.100500.

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