The Role of Semantic Web in the Development of Fire Management Geoportals

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Abstract

The proliferation of the World Wide Web has opened new ways for web-based fire management systems. The category of geoportals, web-based systems that provide enhanced automatic capabilities (e.g. visualization of web maps, geographic gazetteers etc.) and tools (e.g. geo-coders, route finding services etc.), is developing rapidly. In the area of fire management, a geoportal is a centralized web-based system that could provide easy access to a large range of geospatial data and services such as fire management data (real-time detection cameras, GPS data, online tracking of firefighting vehicles etc.), one-click away access to weather forecasting maps, daily fire risk maps, real-time fire behavior maps, vehicle and resource positions, satellite images etc. Nevertheless, there is often a difficulty to find the appropriate data because they are build on keyword-based techniques that cannot perceive the meaning of the available information. These querying-based techniques are often too complicated, especially for novice portal users who may not know which keywords to use, have too little help on how to fill in interactive forms, or find it difficult to estimate how many filter criteria have to be used each time. This paper describes the development of a web-based fire management system based on the technology of the Semantic Web. While users are navigating in the graphical interface of the portal, the navigation steps they follow correspond to the semantic organization of the metadata resources. Thus, finding suitable information does not rely on keywords, as in conventional systems. On the contrary, users explore useful information through hyperlinks that correspond to semantic relationships. Users ‘‘mine’’ data of interest by navigating to semantically or spatially related data.

Keywords: fire management, geoportal, semantic web

1. Introduction

The World Wide Web provides the means for easy sharing of different spatial data and services. Spatial databases, spatial models and mapping services--created by several organizations all around the globe--can now be easily exploited through geographic portals (geoportals). Geoportals are web-based entry points that provide the means for the dissemination of a large range of data and services (Tait 2005, Maguire and Longley 2005). In the area of fire management, a fire geoportal is a web-based system that provides easy access to a large range of spatial information such as fire management data (real-time detection cameras, GPS data, online tracking of firefighting vehicles etc.), weather forecasting maps, daily fire risk maps, real-time fire behavior maps, vehicle and resource positions, high-resolution satellite images etc.

Geoportals act as intermediaries between users and providers (Fig. 1). Providers offer their data by publishing corresponding declarative metadata (i.e. information that describes the data characteristics). The geoportal receives the metadata and organizes them in metadata catalogues. Users search for suitable information through the geoportal's graphical user interface. The results are accessible at the providers' side for viewing or downloading (Athanasis 2009).

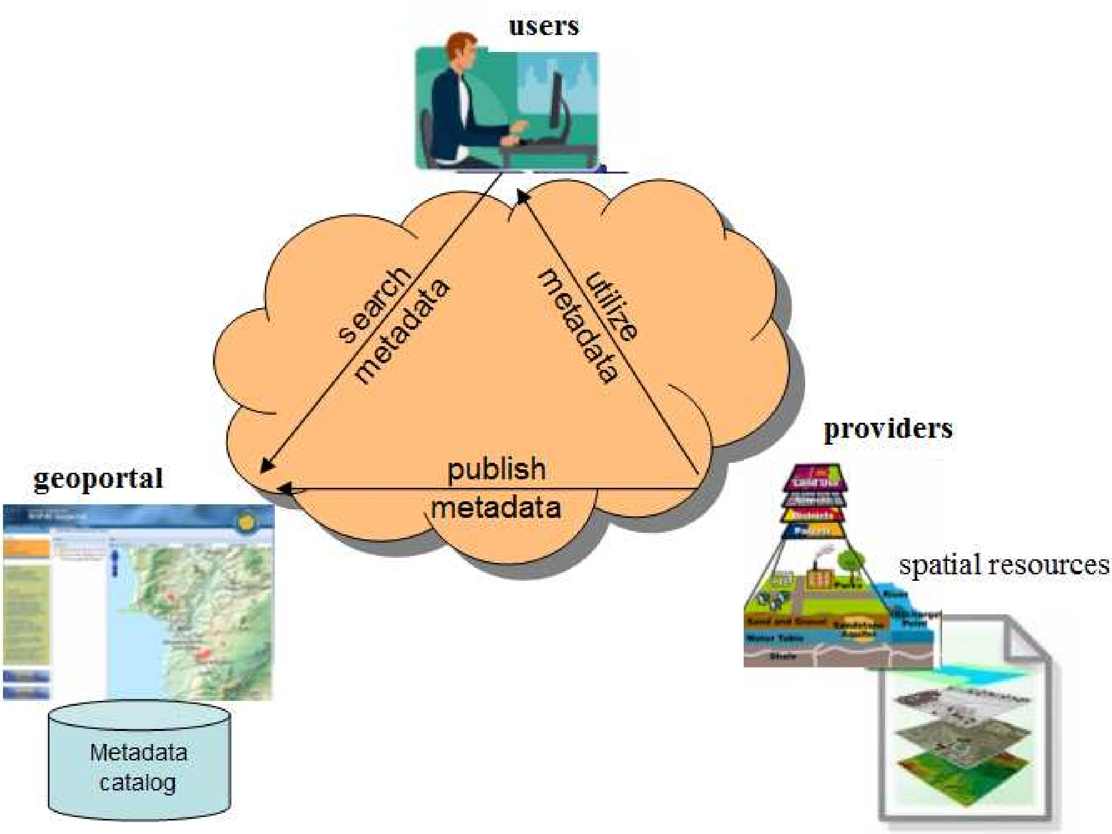

Fig. 1: Geoportals are intermediaries between users and providers

Searching in geoportals is mainly based on keyword-based querying. Filtering criteria about the time reference of the datasets, their data type, their categories or their provider are also used when users search for data of interest. An interactive map helps to specify the geographical area where the resources should be located (Fig. 2).

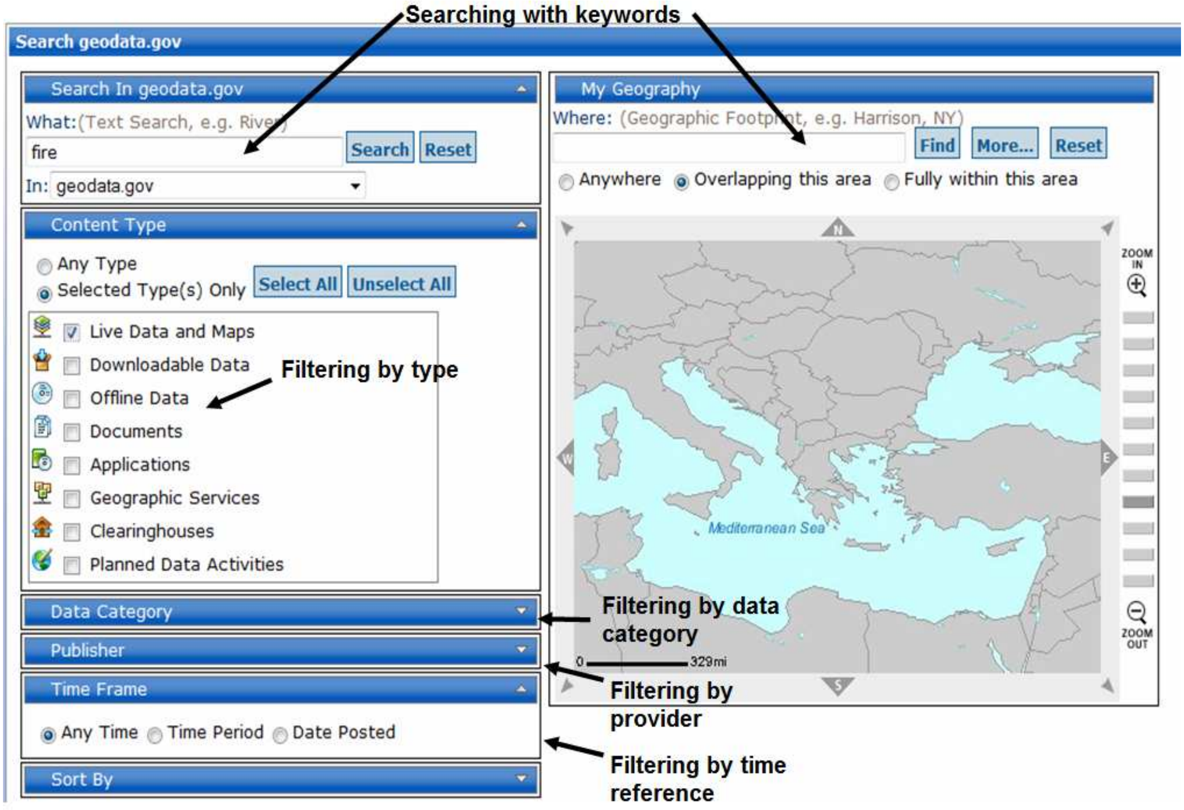

Fig. 2: Searching for data of interest in geoportals

Finding data of interest in spatial portals depends on geospatial metadata standards (e.g. ISO 19115, FGDC and INSPIRE metadata standards). However, spatial metadata standards cannot cope with the different interpretations and discrepancies (Bermudez and Piasecki 2006). Providers that share their metadata descriptions may interpret their meaning in different ways. As a result, semantic heterogeneity issues often lead to poor results, due to the different conceptualizations between providers and users (Bishr 1998, Klien et al. 2004, Kavouras and Kokla 2008). These semantic discrepancies make searching in geoportals to return results with low recall, where not all relevant information sources are discovered, or low precision, where some of the discovered data are not relevant (Klein and Bernstein 2004). Figure 3 shows an example of how discrepancies in the meaning of the available data can frustrate users during their searching; the user searches for resources about fuel mapping. Nevertheless, the available querying mechanisms are not able to understand the difference in the semantics between fire fuel and tank fuel. As a consequence, the returning datasets contain irrelevant information for the user and degrade the searching effort.

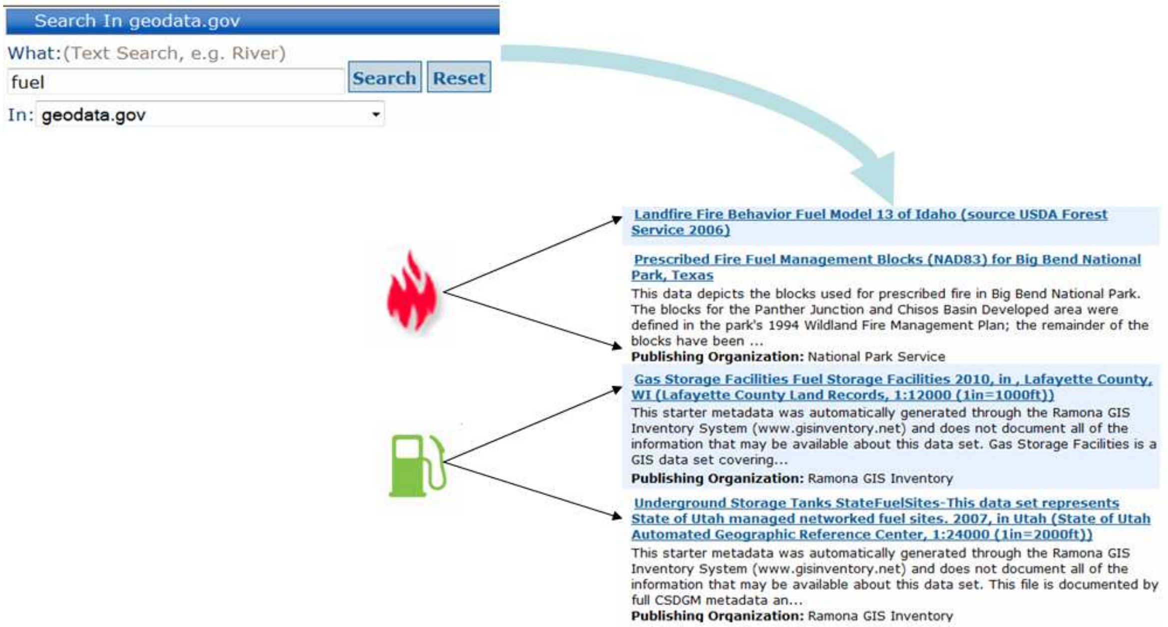

Fig. 3: Searching based on keywords and filtering conditions often lead to irrelevant information

Furthermore, querying-based techniques are often too complicated, especially for novice users who may not know which keywords to use, have too little help on how to fill in interactive forms, or find it difficult to estimate how many filter criteria have to be used each time (Hochmair 2005). Users must not only be experienced about how to fill in different filtering conditions, but also must have a good knowledge about the characteristics of the application domain. Afterwards, a time consuming comparison and evaluation of each resource from the list of the results returned is needed, in order to ensure that each of them is appropriate for further utilization (Marshall and Shipman 1997).

The Semantic Web (Berners-Lee et al. 2001), an extension of the World Wide Web in which information is given well-defined meaning, can provide useful answers to the aforementioned limitations. A key to this approach is the use of ontologies. Ontologies are perfect candidates for communicating a shared and common understanding (between people and computers) of some domain of discourse (Studer et al. 1998), as they constitute formal and explicit specifications of a shared conceptualization of the domain (Gruber 1993).

This paper presents an innovative approach for metadata organization and management in geoportals in the area of fire management. Our approach exploits the meaning of the geoportal’s metadata through an ontology about wildfires. The ontology ensures semantic interoperability, thus resolving semantic heterogeneity issues that obstruct users when looking for data of interest. Furthermore, our approach does not rely on queries based on keywords. Instead, users navigate in the geoportal and find resources even if the have a vague picture of what they are looking for. The navigation mechanisms provided allow users to find data either based on the metadata ontology (i.e. semantic navigation), or based on the topological relationships between resources and the geographical area specified at each navigation step (i.e. spatial navigation).

The contribution of our approach in the development of fire management geoportals is:

1. The development of a methodology about searching for resources in geographic portals based on the user's semantic and spatial navigation.
2. The creation, development and exploitation of a domain ontology for fire management and natural hazards.
3. The development and exploitation of a semantic geoportal on forest fire management. The portal contributes in the dissemination of knowledge and to the preparedness of the operational stakeholders.

2. Methodology

The proposed approach in the development of semantics-based fire management geoportals includes:

1. The development of the ontology in wildfires. This includes
   a) the creation of the fire management ontology. The Resource Description Framework (RDF) (Brickley et al. 2004, Lassila and Swick 2001), a model for describing and processing metadata in the web, is used as the model of the ontology. In RDF, metadata are represented as directed labeled graphs, also called nodes and arc diagrams. The arcs represent the named properties, each of them connecting two nodes, coming from a resource, drawn as an oval. To accommodate the definition of descriptions, the RDF model is enhanced with an ontology language called RDF Schema (RDF/S) (Brickley and Guha 2000) at a higher level of abstraction. At the RDF/S level, classes represent abstract entities referring to sets of similar resources, while properties represent attributes or relationships among classes.
   b) the development of the database where the semantic-based metadata will be stored. The open source application ICS-FORTH RDFSuite (Alexaki 2002) allows the storage of RDF metadata in a PostgreSQL[1] database. ICS-FORTH RDFSuite comes with a corresponding semantic query language, called RQL (RDF Query Language), which provides the means to query the portal's ontology-based metadata (Karvounarakis et al. 2003).

2. The development of the mechanisms for the management and searching of the geoportal's metadata, i.e.
   a) the mechanisms for publishing new metadata. New metadata descriptions can be published by authorized users (i.e. providers) through the geoportal. The metadata are automatically checked for their validity and are incorporated in the already published set of available ontology-based metadata descriptions. Similar mechanisms are provided to update or remove metadata descriptions.
   b) the mechanisms for searching for data of interest. These mechanisms may include
      - searching based on semantic navigation; and
      - searching based on spatial navigation.

[1] http://www.postgresql.org/

3. The ontology of fire management

Risk depends on hazard factors, as well as vulnerability factors (Blaikie et al. 1994). Fire risks arise because of biophysical conditions such as vegetation fuel, topography and weather (Pyne et al. 1996). Vulnerability is about the sensibility and fragility of population and social-economic activities in a natural hazard (Vlachos and Braga 2001, Vlachos and Correira 2000) and includes urban areas, road networks and high danger areas etc. Topography alters the climate of an area and thus affects the availability of fuel and fire behavior.

This analysis of the key elements in the area of fires and natural disasters leads to the ontology of fire management. Even though the ontology refers to forest fires, the analysis includes other types of natural hazards, in order to provide the necessary semantic context of forest fires and their associated risks.

The relationship *hazard* expresses the relationship between data of class *Natural Risk* with data of class *Physical Environment*. In a similar way, the relationship *vulnerability* relates data of class *Natural Risk* with data of class *Infrastructure*. Class *Natural Risk* is the domain of relationship *vulnerability*, while its range is class *Infrastructure*. This semantic relationship expresses the fact that data about natural risks can be are affected by data about a vulnerable community (i.e. data of class *Infrastructure*) (Fig. 4).

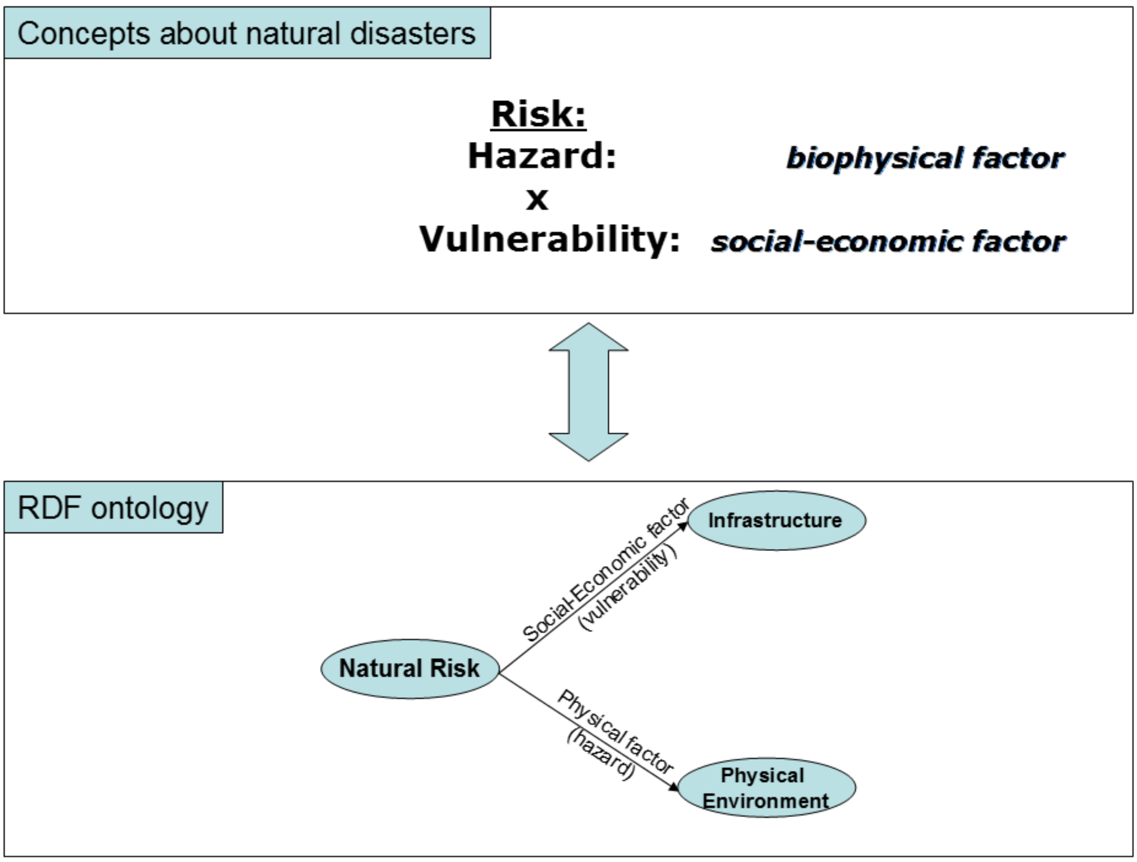

Fig. 4: Conceptualization for the domain of natural disasters

The ontology of the geoportal is presented in Figure 5. Relationship *vulnerability* relates classes *Natural Risk* and *Infrastructure*, while relationship *hazard* relates classes *Natural Risk* and *Physical_Environment*. The dependency of the natural environment with the climate, vegetation and topography is expressed through the corresponding relationships *depends_meteorology*, *depends_vegetation* και *depends_topography*. In the upper level, we use a generic abstract class that its attributes are the fields of the metadata elements of the ISO 19115 standard. This is ensures that every resource in the geoportal is described not only according to the ontology metadata but also according to the ISO 19115 metadata standard.

Natural Risks are distinguished into climatic and geological, while climatic are further distinguished into atmospheric, hydrological and biophysical. This hierarchy of risks is translated into is-a relationships between the corresponding ontology classes. Thus, classes *Climatic* and *Geological* are subclasses of class *Natural Risk*. Subclasses of class *Climatic* are classes *Atmospheric*, *Biophysical* and *Hydrological*. A subclass of class *Biophysical* is class *Fire*, while subclass of *Atmospheric* is class *Storm* and subclasses of class *Hydrological* are *Flood* and *Drought*. Subclasses of class *Geological* are *Earthquake* and *Landslide*.

The subclasses that refer to human factors are *Urban Areas*, *Road Network*, *Land Uses*, *Ownership & Jurisdiction*, *Fuel break*, *High Danger* (i.e. *Gas stations*, *Landfills*, *Power lines)* and *Fire management* such as *Firefighting outposts* and *Firefighting vehicles*.

The physical environment (class *Physical Environment*) is affected, as we have already analyzed, from meteorological and climatic factors (class *Meteorology_and_Climate*), the topography of the area (class *Topography*) and its vegetation (class *Vegetation*). Class *Topology* is further specialized into classes *Contours*, *Coast Lines*, *Elevation Models* and *Hydrographic Network*, while class *Vegetation* is further analyzed into classes *Cover Types* and *Fuel_types_or_models*. Between classes *Physical Environment*, *Topology* and *Meteorology_and_Climate*, there are corresponding relationships that express the dependence of physical environment with these factors.

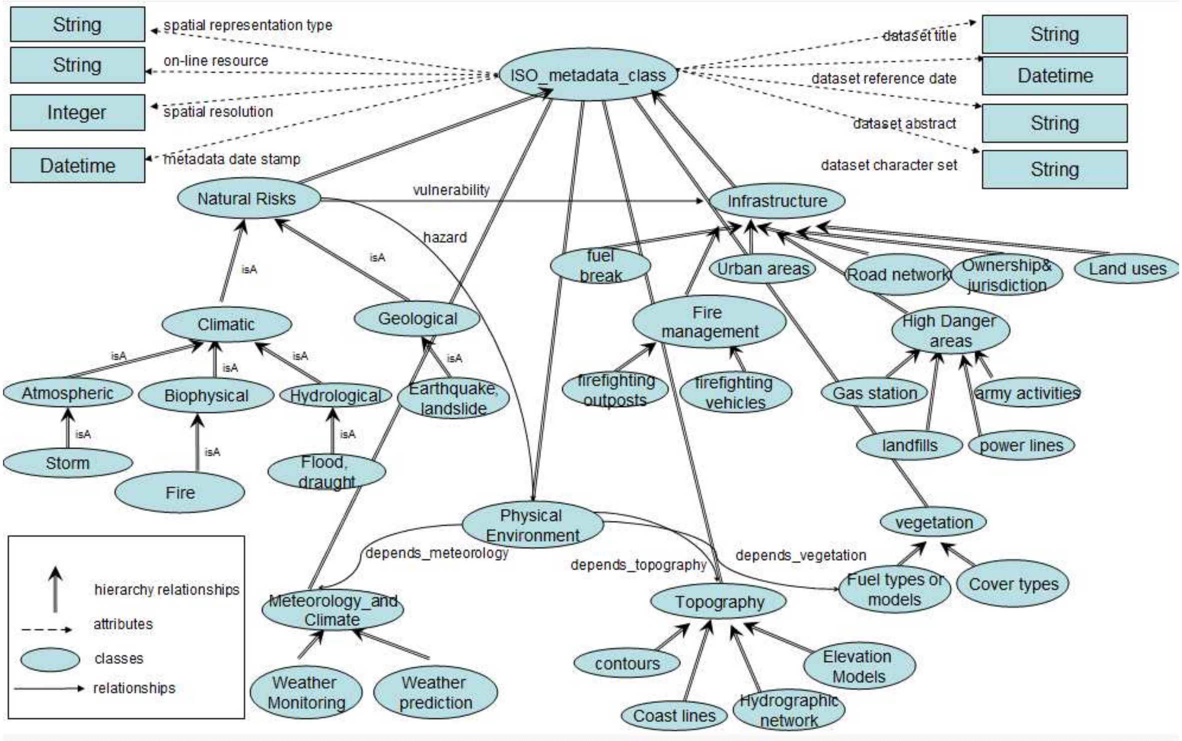

Fig. 5: The ontology of fire management

4. The semantic geoportal of fire management

We have developed a semantic geoportal about natural disasters and fire management data in the area of Lesvos Island, Greece. Providers can access the portal and publish, modify or delete metadata descriptions, while simple users can exploit the semantic and spatial navigation mechanisms to find data of interest. Based on the proposed ontology-based metadata organization, the geoportal offers “intelligent” navigation mechanisms that exploit the data semantics in order to make information discovery more accurate and efficient.

Figure 6 shows the main page of the portal’s interface. In the left side, a tree-view hierarchy presents the data categories that correspond to the classes of the ontology. In the central part, there is an interactive map where users can specify the geographic area of interest. In the right part of the application, users can specify filtering criteria based on the title, the abstract and the reference date of the metadata descriptions that correspond to the ISO 19115 metadata elements dataset title, dataset abstract and dataset reference date.

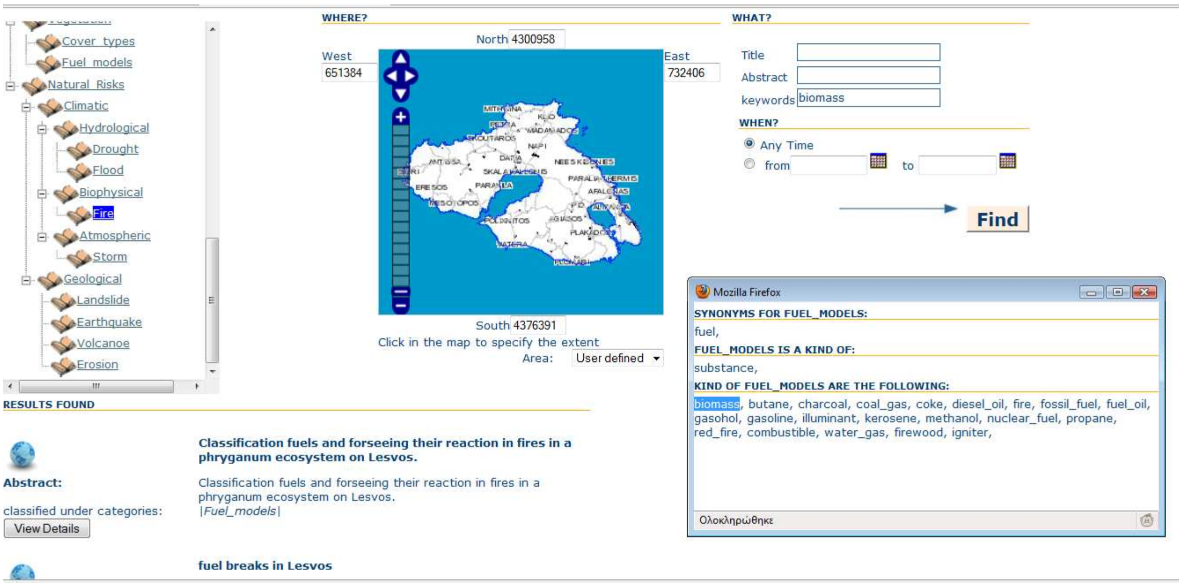

Fig. 6: Searching for data of interest in the portal

In Figure 6, the user has chosen to find fire data in the whole area of Lesvos Island. The returned metadata sets are shown in the lower part of the page. For each of them, its title and its abstract are shown. The user has selected to find data about fuel biomass. Even though there are no metadata descriptions about biomass, the portal is able to return data from its semantically related concept fuel mapping, according to the semantic network of concepts WordNet[2]. Users in the portal can evaluate the meaning of each data category by clicking the corresponding icon ( ) from the tree-view in the left part (Fig. 7).

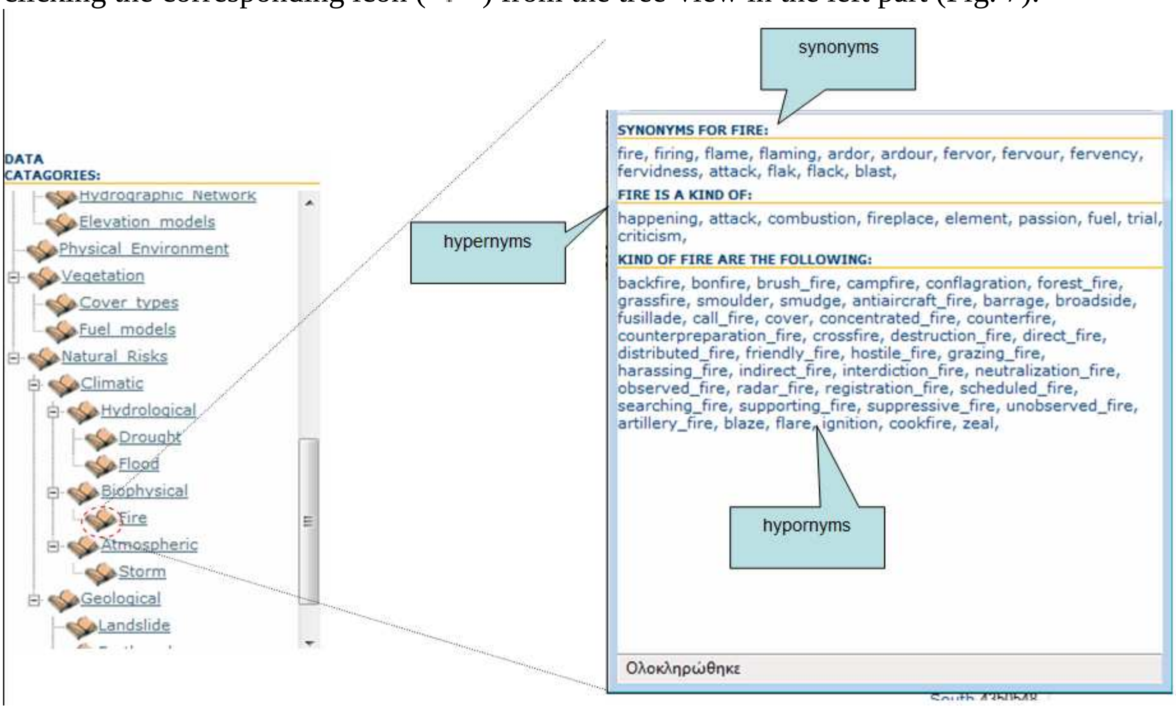

Fig. 7: Using the Wordnet lexical database

[2] http://wordnet.princeton.edu

5. Semantic navigation

By clicking the button “View Details” (Fig. 6), users get a full description of the resource selected (Fig. 8). The system suggests users to explore semantically related information according to the corresponding ontology. The conceptual relationships at the ontology level are translated into hyperlinks that connect the semantically associated information through the graphical interface of the geoportal. Thus, while users navigate in the system, this navigation progresses with the semantic organization provided helps finding the desired information in a more effective way. Users explore more data of interest by further navigating to semantically related information.

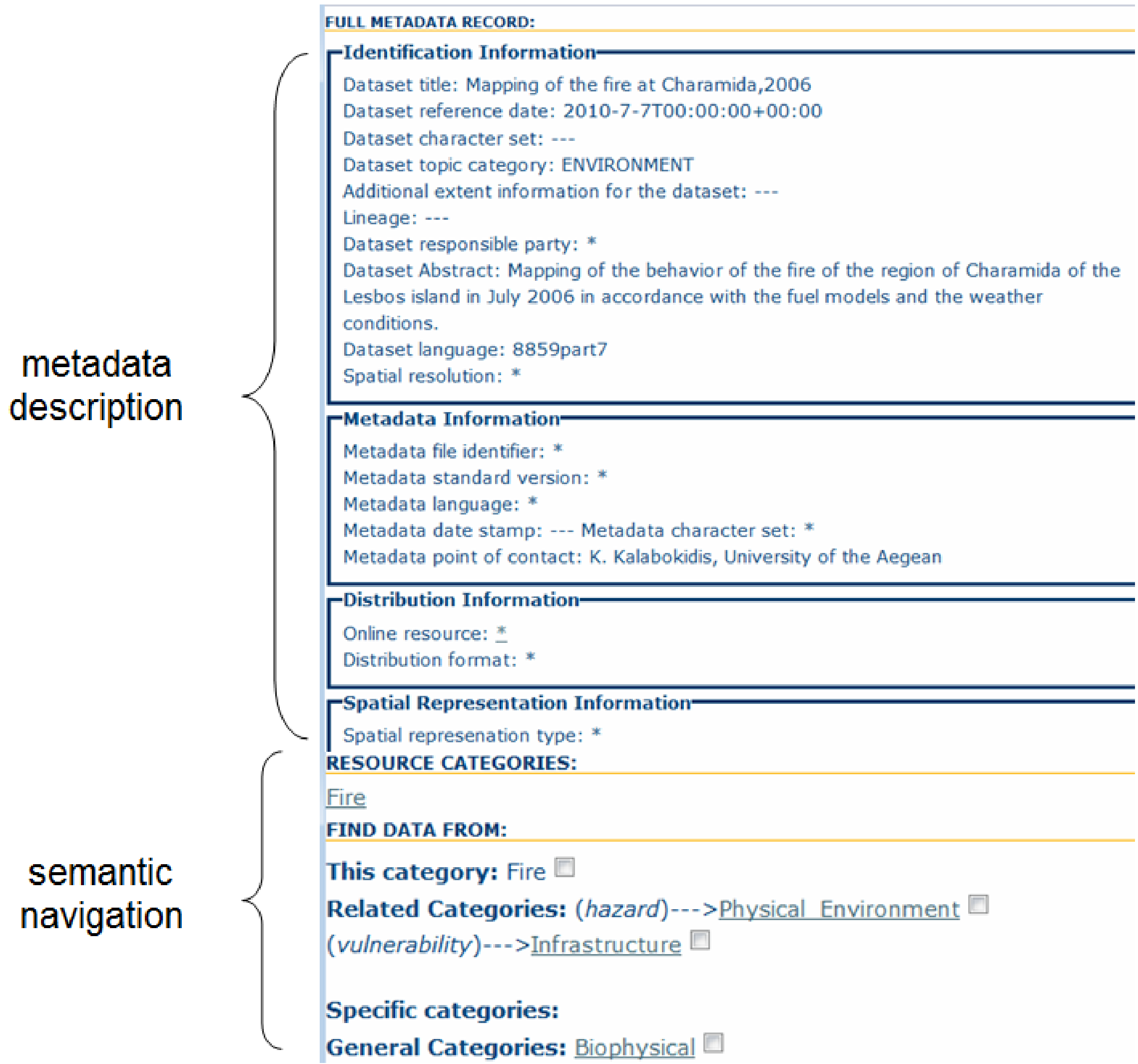

Fig. 8: Metadata descriptions and further semantic navigation

An example of the proposed semantic navigation mechanisms is presented in Figure 9, where a user has chosen a specific resource that belongs to class Fire. According to the fire management ontology, class Fire is a sub-class of Natural Risk which is related with class

Infrastructure and Physical Environment. As a consequence, when the user views the metadata about the fire resource, the geoportal proposes to continue its navigation to the related categories, as well as to the more general class Biophysical. In generally, in browsing action, the users navigate in the graphical interface of the portal while their navigation steps follow the corresponding semantic organization provided by the ontology.

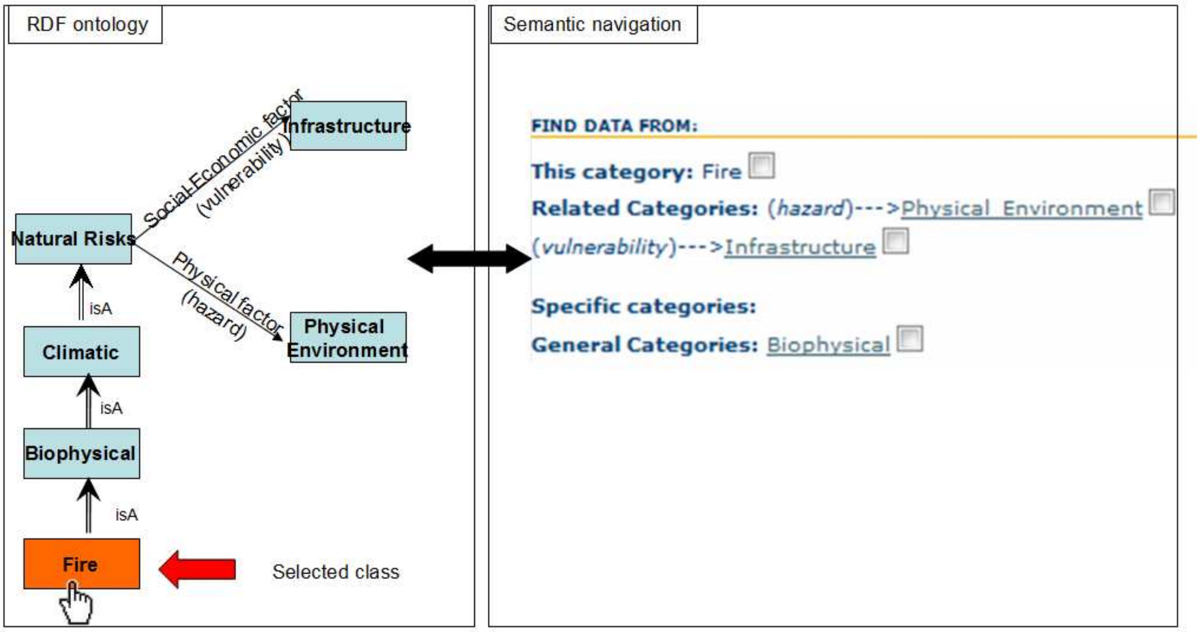

Fig. 9: Navigating to semantic related data

The transition from class Fire (Fig. 9) to the semantically related class Infrastructure, automatically changes the proposed categories for further navigation. We can see (Fig. 10) that the correlated categories have changed and the portal now suggests further navigation to data of natural risks, through the relationship vulnerability. In the “specific categories” field, the direct subclasses of class *Infrastructure* are shown. By activating these hyperlinks, the set of the categories proposed for exploring further the data of the portal changes simultaneously. The navigation mechanisms provided allow users to find data in the portal even if the have an unclear representation of the available datasets.

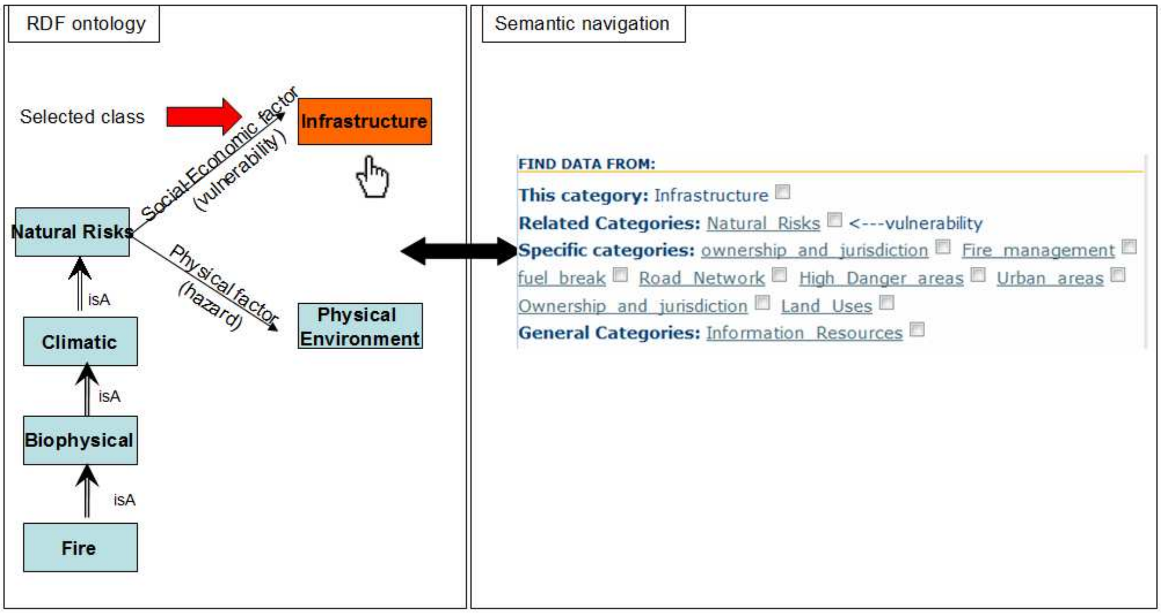

Fig. 10: Further semantic navigation

6. Spatial navigation

Semantic navigation in the portal is combined with spatial navigation based on the topological relationships between resources and the geographical area specified by the interactive map. For each ontology class suggested for further navigation, users can include data classified under the corresponding class by choosing the corresponding check box (Fig. 11). In every navigation step, users can find resources that:

- Their geometry is fully within the interior of the geometry specified by the interactive map.
- Their geometry overlaps with the geometry specified by the interactive map.
- Their geometry builds a buffer with the geometry specified by the interactive map.

In Figure 10, the user has already found some data about the physical environment in a specific area. From the proposed categories for further navigation, she/he selects to find data about the topography and the climate in a buffer area of 10 km.

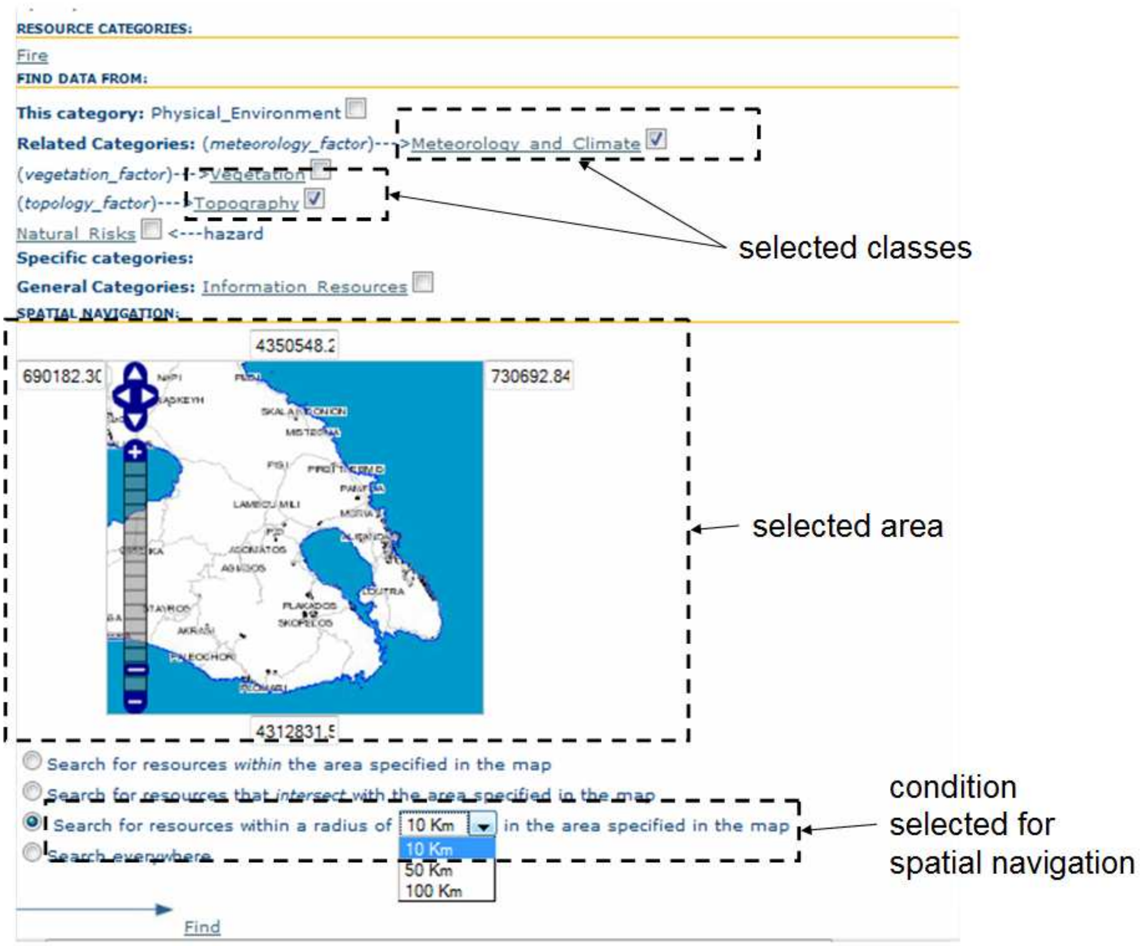

Fig. 11: Find available data based on semantic and spatial navigation

7. Metadata management

New metadata descriptions are published from information providers in the geoportal according to the RDF ontology. Information providers fill in the characteristics of new resources and classify them under specific categories that correspond to the RDF classes of the portal's ontology.

The graphical user interface for publishing metadata (Fig. 12) shows in its left the categories of the portal's ontology, just like in the navigation interface. Next to each class, a checkbox is provided. Its selection indicates that the new resource will be classified under this class. In the middle part of the interface, providers can specify the spatial extent for the new resource, while in the right part the providers fill in the values for the metadata descriptions that correspond to the metadata field of the core metadata set of ISO 19115 metadata standard. The geoportal receives the metadata submitted, automatically translates them into RDF metadata descriptions, and adds them to the existing semantic metadata infrastructure. After their submission, the metadata can be discovered from every user by using the provided semantic and spatial navigation techniques.

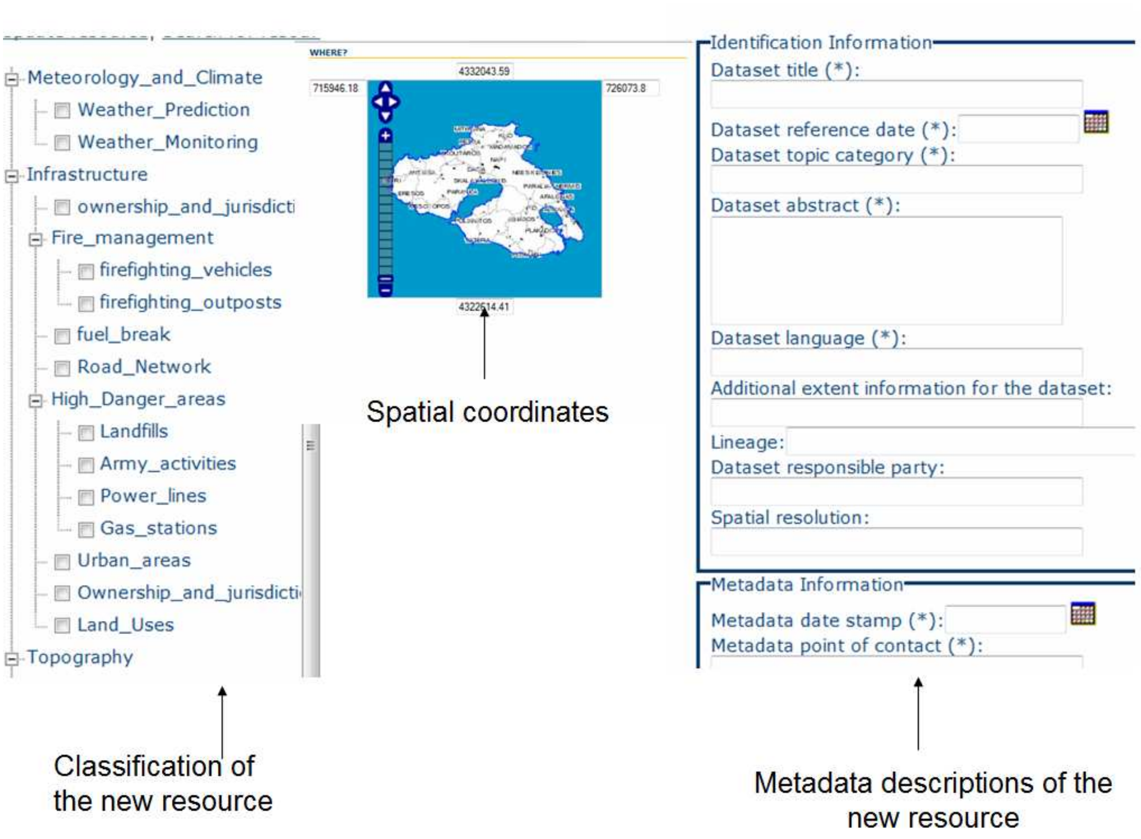

Fig. 12: Publishing new resources

8. Results

To evaluate the functionality of the proposed system, some case scenarios were created and offered to users that had to find specific data according to the scenarios provided. Simple users either belonged to graduate students in the Department of Geography, University of the Aegean, or worked for the local Fire Service of Lesvos Island, Greece. These scenarios were on how to find information about fires already occurred in the island of Lesvos, or on finding information about a specific wildfire that emerged some years ago in the southeast part of the Lesvos Island. Users used the interactive web map to navigate and zoom in this area, and found easily the resource with title "Mapping of the fire at Charamida 2006 on Lesvos". From there, they gathered information such as the date of the fire and visit its online resource that is a fire mapping web service. Through the hyperlinks that relate semantically the data of the geoportal, they were able to (Fig. 13):

- Explore further other information about other fires in the same area or more generic information about biophysical hazards.
- Explore data in the same area about the physical environment (biophysical factors) and infrastructure (hazard factors).
- Ask for resources that are located complementally within the area specified, or have a common area (i.e. overlap), or are located in a buffer zone of 5, 10 or 20 km.

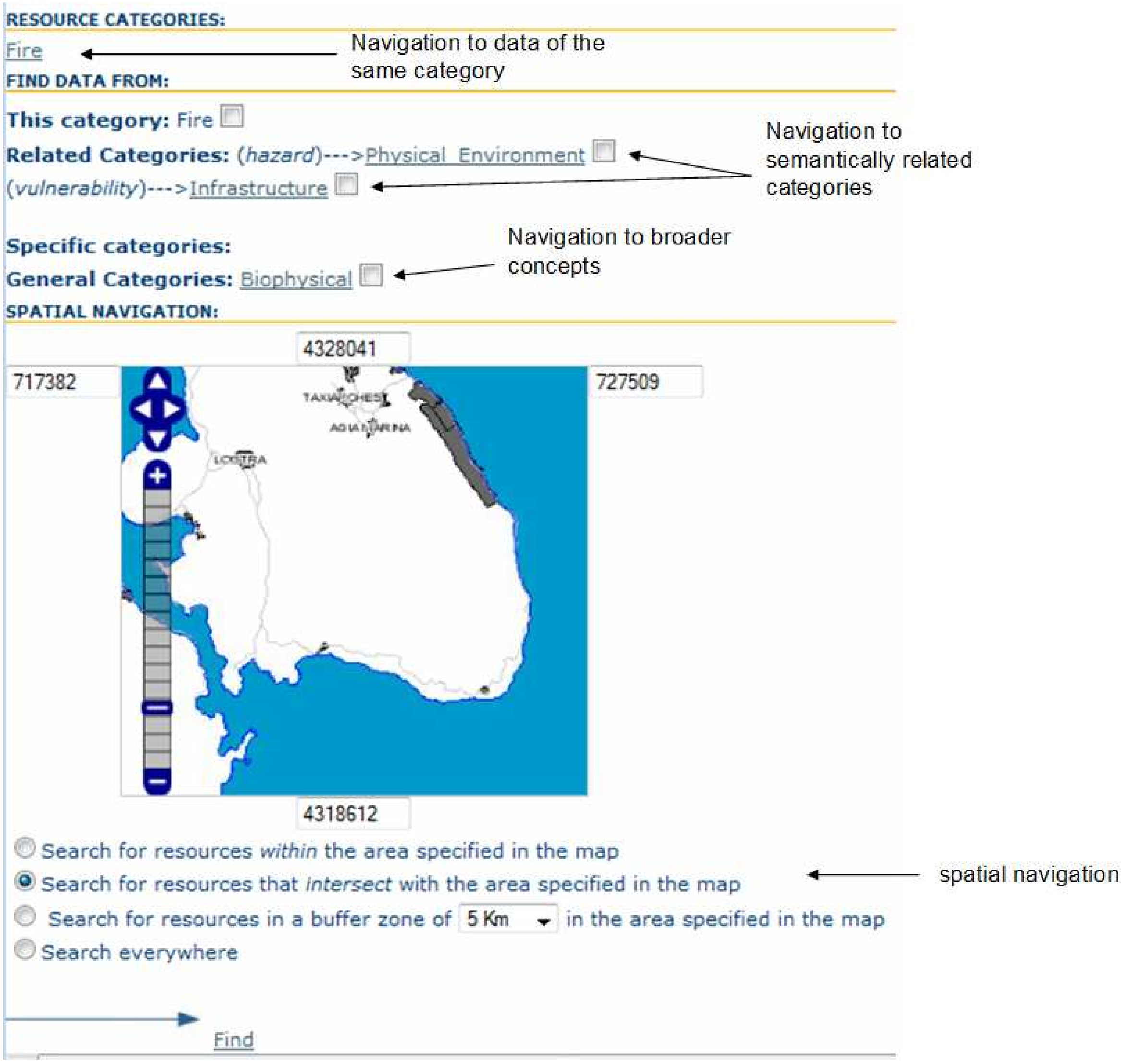

Fig. 13: Find relevant data based on the case scenario

After the completion of the aforementioned case scenarios, users draw a list with their conclusions concerning the system's functionality. Table 1 shows the overall impact of the geoportal, based on the users' comments.

POSITIVE REMARKS	NEGATIVE REMARKS
1. Easy acquaintance with the geoportal's environment 2. Efficient searching for data of interest 3. Navigation into semantically and spatially related information that provided the means for accurate and integrated knowledge acquisition	Greek language is not supported

Table 1: Users' remarks about the system's functionality

9. Concluding remarks

We have described a novel approach in the development of geoportals in the area of fire management. The novelty of this approach is the fact that it exploits the semantic organization of the available metadata in order to provide high level semantic and querying navigation mechanisms when users search for data of interest. While users navigate in the semantic geoportal, this navigation progresses with the semantic organization provided and helps finding the desired information in a more effective way.

The system is currently used by the local Fire Service as an assistance tool for fire preparedness and information dissemination. It is a focal point with a large amount of information organized, contributing in this way to the dissemination of knowledge and to better awareness of the operational stakeholders. The gathered information is vital for the best preparedness on fire emergency situations in the future. Our main goal is to broaden the usability of the geoportal by incorporating data from a wider geographical area.

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