PRESENTATION OF A WEB-BASED GIS SYSTEM FOR THE MANAGEMENT OF NATURAL DISASTERS

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Abstract

Natural disasters have an effect on many important economic and social parameters, which are related to a wide spectrum of geosciences. The complexity of natural disasters concerning each of the five phases in their lifecycle (prevention, mitigation, preparedness, emergency management, recovery) leads to the selection of strong and capable tools, which contribute towards their management. Nowadays the most appropriate tools for this purpose are the Web-based Geographic Information Systems (GIS). Such a system, named SyNaRMa (Information System for Natural Risk Management in the Mediterranean) is being presented in this paper. SyNaRMa features include collection and analysis of many categories of data related to earthquake, landslide and forest fire, simulation of natural disaster effects resulting from realistic scenarios and prediction of their impact on the urban and/or natural environment on given pilot areas. Furthermore, it contains an effective database tool for recording and evaluating the actual damage of buildings due to a disaster. Overall, the system targets to the management of natural disasters, with an emphasis on the preparedness, response and recovery phase. The system structure is described through the following entities: 1. *Event*, defined as an independent natural disaster occurrence; 2. *Damage*, defined as the effect of an event on the built and natural environment; 3. *Hazard sites*, defined as sites with high probability of causing a dangerous event at a certain time and area; 4. *Vulnerable sites*, which may be either sensitive natural areas or human constructions that could possibly be affected in the case of an event; 5. *Preparedness*, where the user may access the scenario layers (maps) in combination with active events and damage using the GIS tools and 6. *Recovery*, where the stored damage data may be accessed and managed.

Keywords: Natural disasters, Web-based GIS, SyNaRMa, Natural Disaster Management Systems

1. Introduction

The increasing human activities both in urban and forest areas have made more severe the effects of natural disasters. These effects not only have a socioeconomic and environmental impact, but may also result into human casualties (see, e.g., Theodulidis et al., 2004; Savvaidis et al., 2005). In this frame and taking into account the complexity and variety of natural disasters it is imperative to effectively manage natural disasters throughout all the five stages of their lifecycle (prevention, mitigation, preparedness, emergency management and recovery). In order to achieve this goal, capable tools are required to secure the successful completion of the objectives related to the management of natural disasters both at local and regional level. These collections of tools are called Natural Disaster Management Systems (NDMS).

A NDMS named SyNaRMa (Information System for Natural Risk Management in the Mediterranean, http://gserver.civil.auth.gr/Synarma_app/), which was designed and developed under an INTERREG III – B ArchiMed project, is presented in this paper (see, e.g., Doukas et al., 2007). The main goal set for SyNaRMa was to be a flexible and innovative Web-based GIS for the management at local and regional level of earthquakes, landslides and forest fires, expandable for other natural hazards as well. The main components incorporated within the SyNaRMa system, on which it relies in order to be an effective tool for disaster management, are a) the damage assessment and vulnerability inspection of buildings, b) scenarios that predict the impact of a possible disaster event, c) assessment of the existing Civil Protection plans, definitions of failures and weaknesses, d) real time and on-line input and e) a Web-based GIS interface for the integration and analysis of all available information.

2. Natural disaster management systems

NDMS include collection, analysis and management of all the information related to natural disasters and fulfill planning and decision making needs. They are based on large and powerful relational geo-databases where all the spatial and descriptive data are stored (see, Savvaidis et al., 2006). The structure, interoperability, expandability, ease of disseminating information among interesting parties and the overall ability to assist in planning and decision making are key points for defining the usefulness and effectiveness of a NDMS.

The design of geo-databases for storing information related to natural disasters is a crucial part in the design phase of a NDMS (see, Zeiler, 1999; Peters, 2006). Difficulties arise from the fact that most of the information handled is related to time, while a one-to-many relationship is often needed in order to connect various types of data. Hence, bad or erroneous design may lead to a very complicated database structure. The time dependence requires that all the information is time-stamped, which means that each table in the geo-database must include a field of type date/time, in order for the systems to allow the time-based management, filtering and querying of the stored information. Another consideration that has to be taken into account is that some of the data that will be inserted into the geo-database follow specific standards, which have been defined by different authorities at different time periods. An example of this consideration is the various types of damage inspection forms used for recording damage information of different disaster events by different competent authorities at different time periods, i.e., the 1978 Thessaloniki and the 1995 Grevena strong earthquakes. Consequently, the geodatabase design must secure that additional information may be added in the future without affecting the existing relationships.

Reliable spatial and descriptive data are also needed in a NDMS (see, e.g., Oosteron et al., 2005). Data related to previous disasters is a valuable source of information, like for example information about the type of damage that buildings suffered, as given by in-situ inspection of the buildings, or the forest area burnt due to a fire. This historical information is exploited when calibrating models and scenarios for possible future natural disasters, combining the work carried out by authorities competent to manage a disaster and the scientific research done by universities and institutes. In this way, the geo-database of the NDMS may serve as a pool of information for many users belonging to different specializations and having various purposes.

The management of the geo-database is done through Geographic Information Systems (GIS) and other supportive software packages and tools. When the GIS can be accessed through the Internet, then it is called a Web-based GIS. The latter provides many benefits to both the competent authorities for managing a disaster and the scientific community. Web-based GIS provide the ability to rapidly disseminate information. Thus, the competent authorities may receive in real-time crucial information from engineers, security forces, civilians, etc., while on the other hand scientists have remote access to the same information also in real-time. Since Web-based GIS may be accessed through the Internet, a security policy must be also applied. The NDMS must be accessed only through a secure interface, while different categories of users must have different access rights to the system and the stored information.

3. SyNaRMa overall

SyNaRMa is a NDMS built on the ESRI ArcGIS Server Enterprise Edition, programmed in Microsoft ASP .NET and uses the Microsoft SQL Server for storing its geo-database (Doukas et al., 2007). The cartographic data stored in the geo-database is in vector and raster format and was retained in its original coordinate reference system. The system transforms the data on-the-fly into a common coordinate reference system, i.e. the World Geodetic Datum 1984 (WGS84), and simultaneously projects the data using a Transverse Mercator projection. All the other information stored in the system uses the WGS84 reference system.

SyNaRMa focuses on the three main stages that constitute the disaster management circle, i.e., preparedness, response and recovery. Preparedness is the phase that comes before the occurrence of a disaster. The response phase is the first hours/days after the occurrence of the natural disaster and throughout this phase we have to confront immediately the consequences of the event. Finally, the recovery stage starts after the phenomena and follows the first period of immediate relief and rescue.

Towards the preparedness stage the system provides the definition of vulnerable and hazard sites that require attention in the case of a possible future disaster. Among these areas, a special component was developed for those vulnerable sites that are buildings, by conducting vulnerability assessment control of them and revealing weaknesses that necessitate in some cases immediate restoration actions. This information is stored in a prototype database that was designed and incorporated within the system and may also serve, for example, as a pre-seismic inspection form for buildings. This form can be accessed and filled in through the system. Moreover, in the preparedness stage there is the ability to assess the existing Civil Protection plans, such as the "Xenokratis" emergency plans in Greece, and afterwards define possible failures and inefficiencies by using tools available in the system. This approach is completed by the proposal of a concluded Civil Protection plan which identifies specific assembly and shelter areas along with the operational road network. In addition, results from scenarios that predict the effects of a potential disaster are made available through the system and can be used while preparing for probable future disasters.

After the occurrence of a natural disaster the system may be accessed through the Internet and enter data about the event in real time. As a result, the competent authorities have almost immediately a first picture of both the event itself as well as the size of the disaster. This information facilitates the response of the authorities and offers for more effective emergency actions. Moreover, throughout the response phase, while the rescue teams are on field, they may download from the system data about specific buildings, i.e., building construction plans that are very important in order to identify passages that will bring them close to trapped or injured people.

In the frame of the recovery phase the system may be used to store information about damage that was caused due to a disaster. The information is stored to a prototype building damage geo-database that was designed and incorporated within the system and can be accessed and filled in through the system. The information stored in this geo-database provides for the estimation of the overall damage caused due to the disaster and helps the competent authorities to assess the financial and social effects.

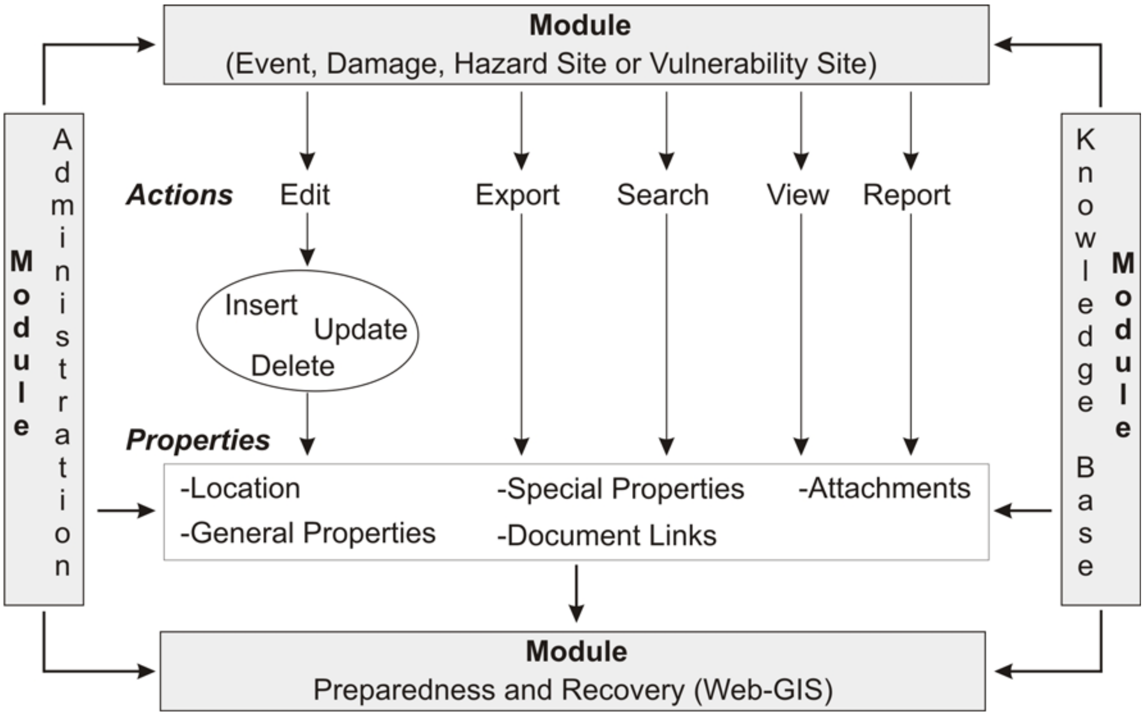

Figure 1. The SyNaRMa system structure

4. SyNaRMa structure

The system structure is examined through the system entities, events, damage, hazard and vulnerable sites, and the use of preparedness and recovery applications (Figure 1). Each of the aforementioned entities, apart from the events, include the necessary fields required for storing special information pertaining to all the natural disasters managed by the system. Hence, the user uses the same entity-specific online form to provide information to the system regardless of the type of natural disaster that occurred. This strategy allows future integration of other natural disasters only by enriching the forms and the geo-database with new fields. The system allows us to manage:

- An event, defined as an independent natural disaster, such as an earthquake, a landslide, a forest fire, etc.
- Damage, defined as the effect of an event.
- Vulnerable sites, which may be either sensitive natural areas or human constructions that are possibly affected in the case of an event, for instance public buildings, forests, parks, hospitals, schools, etc.
- Hazard sites that consist of phenomena or events and are defined as the probability of occurrence of a dangerous event or natural disaster for a certain time and area.

Apart from the abovementioned entities which will be further described next, within the SyNaRMa system a knowledge base was incorporated where the user can upload documents and attachments relevant to the event, damage, vulnerable, or hazard site (Doukas et al., 2007). Finally, with the administration section that is included in the system, the administrator can manage the users and the parameters of the application.

4.1 Event Management

Once a natural disaster has occurred, the system user can access SyNaRMa and insert the event into the system using a web form. Event properties have to be inserted before any damage information is inserted into the system. Apart from properties, the event can be linked with existing documents, event related attachments (pictures, videos, etc.) can be uploaded, and finally, event location can be inserted on the map either by entering geodetic coordinates or directly by clicking on the map. All data entry forms validate automatically the information given in order to assure the integrity of the geo-database. More specifically, the system performs a type-check and a range-check for verifying if the information provided by the user is of the correct type and the given values fall into an acceptable range of values (in case of numeric values). Additionally, wherever it was possible a list of predefined values was created in order to avoid typing errors by the user of the system and retain the homogeneity of the information stored in the geo-database.

The insertion of an event at almost real time provides for immediate and efficient actions which are required in order to ensure minimization of damage and loss of human lives. The competent authorities are informed through the system for the event and the emergency mechanism is activated.

4.2 Damage Management

As already mentioned before, within this entity of the system the user may store damage related to a building as a consequence of a disaster event. Properties that describe the building, the damage it sustained in general, per floor damage, casualties, attachments, and location data may be inserted into the system. All this information is part of the inspection forms used for recording damage after a disaster event. Thus, the forms may be filled in in-situ by the engineers using a Flybook in order to access the system. Consequently, all the inspection forms are simultaneously stored to the system and are directly accessed and processed by the competent authorities, which have an overall picture of the disaster. The overall picture can be easily obtained by viewing the livability characterization of the building in the Web-based GIS. Livability is an easy and rapid way to categorize buildings according to the damage they sustained; hence buildings may be categorized into those with no or light damage, moderate damage, serious damage and those that collapsed. All this information may be accompanied also by attachments (photos, videos and additional documents related to the building) so as to present a thorough and complete view of the situation recorded. Finally, the location of the building may be placed on the map by either providing the street name and number, the geodetic coordinates of the building’s location or manually by clicking on the map.

4.3 Hazard Sites

This module can be used in order to insert a hazard site into the system. An example could be an area near the national road, where landslides often occur. These records are very important as the information provided can be used by the authorities to take in time all the necessary measures required to prevent the cause of a disaster and prepare appropriately in case a future disaster occurs. The system user is asked among other data to insert the type of the site and state the kind of danger that the specific site exhibits. In addition, the exact location (municipality, country and street- if applicable) can be set in the same way as mentioned above for the damage information. A field stating whether the hazard site caused a disaster in the past, the number of people affected and the last year that this hazard site was evaluated can be completed. Additionally, attachments may also accompany the hazard site, while documents from the knowledge base may be related to it. For example, the attachments can be a photo showing the area prone to landslides.

4.4 Vulnerable Sites

Using this component the user may insert a vulnerable site into the system. This site could be, for instance, a protected forest area, a school, a hospital, etc. These sites are of great importance and usually are sites given greater priority in case of a disaster. In order to insert the site into the system, the user first selects the type of the site and then enters information about it, such as the total area covered by the site, the number of people in danger, the number of disabled people affected, etc. The location of the site is given to the system in the same way as for the hazard site. Moreover, one may choose to link the site with documents from the knowledge base and may relate it to attachments; as an example, in the case of a forest fire a video may show how fire fighters can access it and areas that must be cleared for easier access. In the case of a building characterized as vulnerable, e.g., a school, a prototype vulnerability assessment database was designed and inserted into the system as already mentioned. Using the benefits of the on-line application, pre-seismic building inspections can be filled in on line in-situ by the engineers using a Flybook in order to access the system and store the relative data.

4.5 Modules Functionality

All available events, damage information, vulnerable sites, and hazard sites stored in the SyNaRMa system can be viewed, updated or deleted. These operations may be accessed from a menu provided to the user after selecting a record. When viewing a record, all the stored information is given in a new window along with a map on the right side of the window. For the delete operation of a selected record, the system always validates if a deletion is possible by checking whether a) the user has rights to perform this action and b) other records are related to the selected record. The user has also the ability to view all this information through the GIS modules of the system as described in the following sections.

4.6 Preparedness

This part refers to the stage where the competent authorities prepare for a possible future natural disaster. Preparedness allows the system user to analyze, view and export the information stored within the system. A screen capture of the Web-based GIS showing the cartographic basis along with recent seismicity is given in Figure 2. To facilitate the exploitation of the numerous layers of information stored within the system, they were distinguished into two main categories, the general/basic layers of information that constitute the cartographic basis and several specialized layers of information related to each of the three natural disasters studied in the frame of the system. Continuously, these categories were further divided into subcategories that host layers specific to the selected test areas of the system. Another categorization of the layers is made between those related to parameters that affect the studied natural disasters and those related to parameters that are generated after the occurrence of an event. The last category of layers constitutes the scenarios layers. The scenario layers are created outside the system and then easily incorporated.

In the preparedness stage the user may benefit from the available tools provided through the web interface of the system. The user may select entities, measure on the map areas, perimeters and distances, identify the coordinates of a point on the map, perform queries to the geo-database or define buffer zones around selected entities. All this functionality supports the combined analysis of all available information. The security policy is applied throughout the whole system, so in the Web-GIS part of Preparedness, as well as in the Recovery part, users may have limited access to specific layers of information.

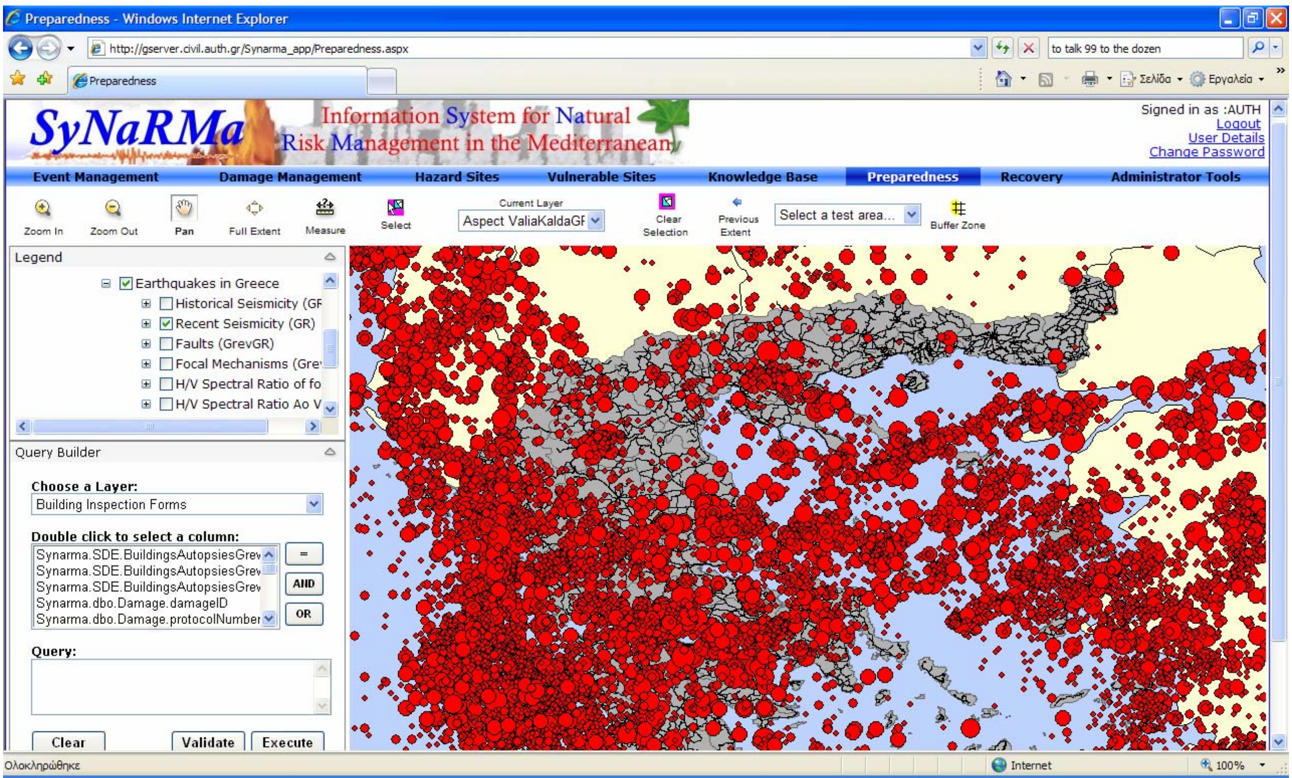

Figure 2. Display of the SyNaRMa system showing recent seismicity in the area of Greece

4.7 *Recovery*

The Recovery module is identical to the Preparedness module, in terms of the provided interface and tools, which share the same functionality. The only difference is that the user cannot view directly the scenarios layers whereas he has the opportunity to export data, a functionality that is not available at the Preparedness application. Recovery is used when the user has to deal with the damage caused after a disaster. Using the modules described above, one may input the damage inspection forms to the system and through the Recovery module obtain the overall picture of the damage while the damage is being recorded in the field. At the same time different layers of information may be selected and overlaid within the system, allowing the user to take effective actions and assist in the process of decision making. A very important part is that through the system it is possible to jointly analyze the predictions resulting from scenarios along with the real results of a natural disaster and therefore evaluate the scenarios and the models used in them. Consequently, the scenarios may be improved/calibrated in order to become more accurate and to better fit to local/regional conditions (Figure 3). By exploiting the available tools such as the query builder, the buffer zone tool and the export tool, the user can retrieve the expected behavior of a building (in case of an earthquake), of a forest fire (in case of a forest fire) and of an infrastructure (in case of landslide) according to the corresponding scenarios.

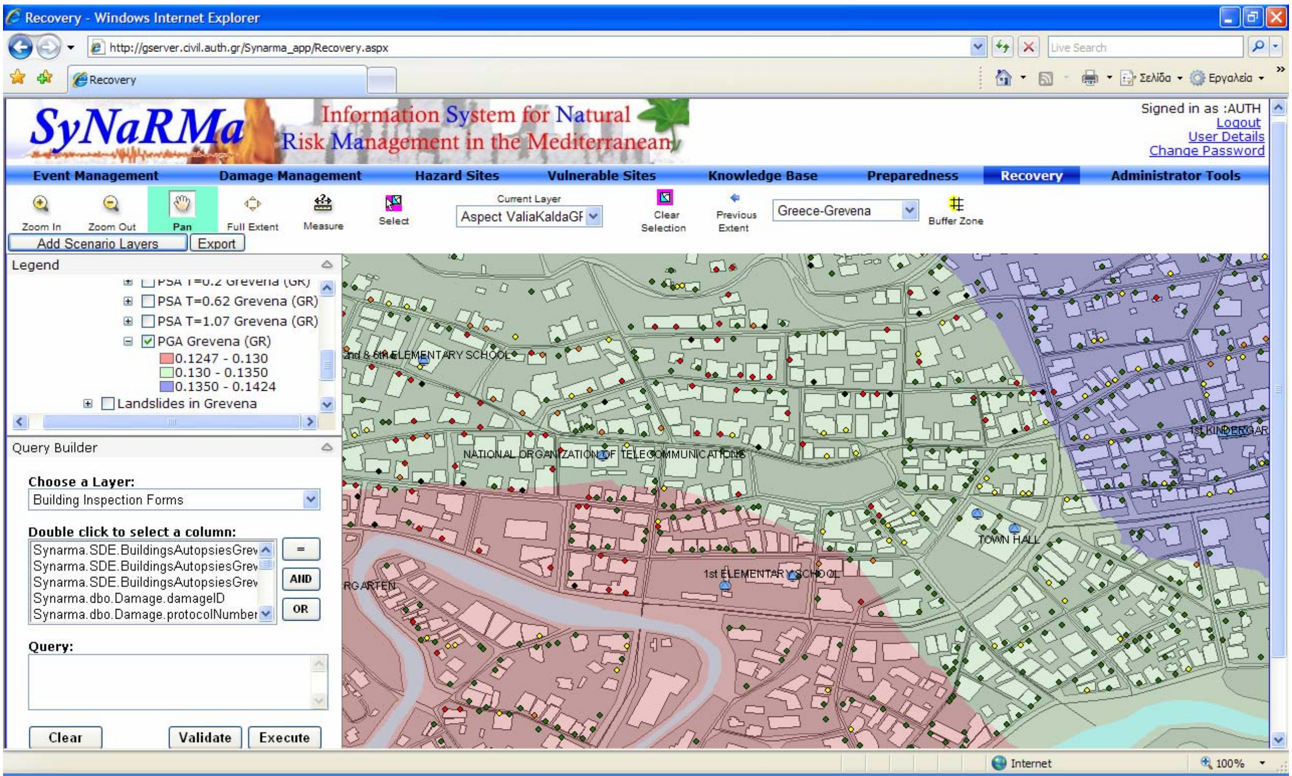

Figure 3. Display of the SyNaRMa system showing the comparison of reported building damage from the 1995 earthquake at the city of Grevena in Greece with the scenario results

5. SyNaRMa application

SyNaRMa has two primary objectives. The first objective is to provide the means for the input of an event, hazard or vulnerable site and the recording of the damage caused by a natural disaster using a Web-based entry tool, available through SyNaRMa. The second objective of SyNaRMa is the analysis and evaluation of scenarios developed in order to identify the potential impact of a possible future disaster event on the urban environment for the case of earthquake, forest fire and landslide. About 1700 damage inspection forms were incorporated into the SyNaRMa system from the earthquake of 1995 in the city of Grevena. This information was available in paper form and through the web interface they were digitally stored. Additionally, different scenarios were included for Greece and Italy related to earthquake (Grevena-Greece, Messina-Italy, Calabria-Italy), forest fire (Valia Calda-Grevena) and landslide (Grevena, Messina) events. For example, figure 4 shows areas with different susceptibility levels to mass movements. The scenarios incorporated within the system were developed through a two stage process. In the first stage, the scenarios produced the results of a previous disaster event based on historical data aiming at calibrating the parameters of the models as well as the theoretical or empirical assumptions in the relative modeling through the simulation of a past disaster event and its impact. In the second stage, once the models were calibrated, scenarios for a possible future disaster were established aiming this time at estimating the damage that will be caused to the build environment due to a future natural disaster. It is to be mentioned that these scenarios were developed outside the system and were afterwards incorporated in it.

6. Conclusions

Provided that many and different kinds of natural disasters will always happen, the question we have to answer is how we may minimize human losses and the consequences of disasters to the natural and built environment. Trying to give an answer to the previous question, SyNaRMa was developed, aiming at helping the public bodies and authorities to better prepare for possible future natural disasters and coordinate and organize actions before, during and after a natural disaster.

SyNaRMa focuses on the three main stages of disaster management that coincide with the stages of the Civil Protection circle, and along with the fact that it uses the latest leading technologies in Web-based GIS, the SyNaRMa system serves as a very useful and effective tool for the needs of Civil Protection. It is to be noted that the system usage requires minimum training, technical and scientific expertise by its potential users as it is easily operational by even small sectors of the Civil Protection mechanism (e.g., municipalities or/and prefectures).

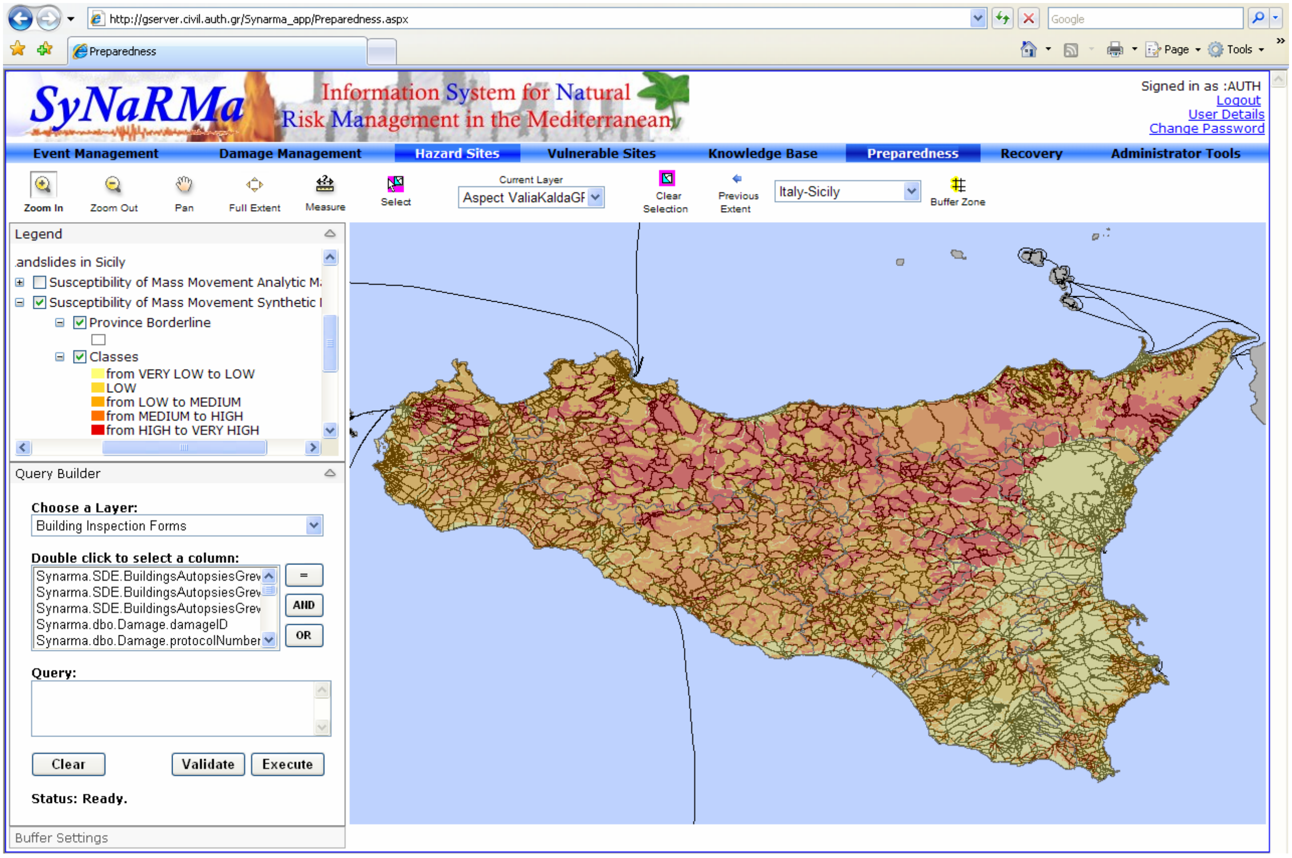

Figure 4. Display of the SyNaRMa system showing the areas with different susceptibility levels to mass movements in Sicily

Moreover, the integration of scenarios with real data allows for the localization of the most susceptible areas in case of a future disaster event and the definition of damage zones in the future. This information is of great importance for emergency planning. On the other hand, the vulnerability assessment of buildings also serves as useful information towards the actions taken at both the preparedness and response phase. The collection and management of damage information after the end of a disaster event, facilitates the competent authorities to restore damage and smooth the disaster effects by defining the areas that suffered severely and need special attention and support so as to deal effectively with the socioeconomic impacts caused.

Furthermore, the system was designed in order to combine different kinds of information for different natural disasters under a single system and therefore may aid the competent public bodies and authorities in managing and sharing their information, preparing for a natural disaster, organizing their response during a natural disaster and recovering from a natural disaster.

Finally, the SyNaRMa system may be used as a prototype for developing disaster management systems customized to the need of competent authorities. This kind of systems require the collaboration of scientists of different expertise, like in this case seismologists, surveyors, civil engineers, foresters, geologists and other geoscientists. Therefore, such a system serves as a link between the scientific community and the public bodies and competent authorities involved in disaster management.

Acknowledgments

Funding for this research was provided by the European Regional Development Fund under the EU Community Initiative Program INTERREG III B ARCHIMED (2000-2006).

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