Evaluating Emergency Scenarios using Historic Data: Flood Management

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ABSTRACT

The evaluation of an emergency scenario is often based on the use of simulation models. The specificity of these models involves the need for a complex evaluation of the problem domain, including the physical conditions behind the considered threat. Based on emergency occurrences data, provided by the Portuguese National Civil Protection Authority, we are currently developing a methodology for evaluating a real situation, based on past occurrences. The aim is to develop a platform that will enable the evaluation of a risk scenario based on existing civil protection data. The methodology under development should enable the evaluation of different scenarios based on the collected available data. This will be achieved thanks to the facilitated configuration of several aspects, such as the geographical region and relevant properties of the considered threat. In this paper, we describe the methodology development process and the current state of the platform for risk evaluation.

Keywords

Geographic information system, emergency management, cellular automata, flood forecasting model, decision support systems.

INTRODUCTION

In the last decades we have witnessed a large number of natural disasters, affecting densely populated areas, which resulted in structural and human devastation, associated with considerable socio-economic losses.

Recently, Portugal has been particularly vulnerable to extreme weather events which significantly contributed to the occurrence of natural disasters (NIACC, 2011). For example, the occurrence of forest fires is particularly important during the summer, a hot and dry period. In the winter, periods of abundant rainfall can result in flash-floods, often dangerous and deadly and covering large areas (Ramos and Reis, 2001).

The Portuguese National Civil Protection Authority (ANPC) is the entity responsible for managing emergency services, with the main purpose of preventing serious accidents, mitigating their effects and protecting and rescuing people and properties.

We are currently developing a methodology and a platform for evaluating a risk scenario based on existing Civil Protection data, collected during past occurrences. These have been defined according to the requirements specified by ANPC, focusing mainly on flood situations.

This methodology should enable the evaluation of a real situation, based on past occurrences in different geographical regions. The methodology is set to use the data of previous emergencies and current meteorological and hydrological conditions, allowing the estimation of the possible water level that can result. With this result we perform a simulation based on cellular automaton, returning the extension of the flood in a fast and simple way.

The platform plays a fundamental role, since it enables the definition of the parameters needed to initialize the whole process, as the past occurrences data and the configurable geographic area.

With this platform, the ANPC technicians can be supported, in the decision-making process, by the returned

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results, of applying the methodology to the risk scenario. This allows a quick evaluation on constantly evolving conditions and enables the adaptations of their response strategies, to minimize all the associated risks.

In this paper, we describe the methodology development process and the current state of the platform for risk evaluation. We also set the stage for the next step, which will be the confrontation of the results provided by this work with the Civil Protection's team evaluation.

RELATED WORK

Disasters are not exceptional events. They tend to be repetitive and concentrated in specific places. Furthermore, the frequency and recurrence intervals are well known, at least for the smaller and more frequent occurrences. Based on this information, it is possible understand the emergency pattern, and set an emergency plan for each event (Alexander, 2002). Being prepared is the key to reduce all types of damage that might be caused by an event of this nature (Alexander, 2002; Johnson, 2000; Sauvagnargues-Lesage, 2007).

Geographic Information Systems (GIS) play an important role in Emergency Management (EM). With the right information, GIS can quickly provide the necessary data about the evolution of emerging disasters. With this data, authorities can react and readjust their strategies while dealing with such a threat (Alexander, 2002; Johnson, 2000).

An Emergency Management System can be viewed as a Decision Support System (DSS), whose main concerns are the optimal resource allocation, scheduling and planning (Moore and Abraham, 1994). DSS are valuable work tools for decision makers, aiding them to solve various problems, using all the available information (Simonovic, 1999). DSS for EM use powerful and specialized forecast models for each kind of emergency, making it possible to estimate the evolution of potential impacts that may result from it (Cioca and Cioca, 2010). Specifically, in DSS for flooding management, hydrological models are used to perform simulations which can be used to estimate the affected areas and the depth that water can reach in certain places. With this information, alerts can be launched and strategies adopted to reduce the impact and all associated risks (Ahmad and Simonovic, 2006; Simonovic, 1999; Skotner et al., 2005; Mioc et al., 2007).

This process can be realized using a cellular automaton, instead of utilizing hydrological model-based simulations. Such an approach makes it possible to perform simulations in a fast and simple way (Parsons, 2007; Xuewei Ji and Fan, 2008). In this context, simulations are defined by a set of rules that are applied to each cell and which aim to simulate water flow (Bates, 2000; Dalponte, 2007). To be accepted by Civil Protection Teams, the projection of flooding must be subjected to a verification and validation study. This study checks if real world behavior has been successfully replicated in the computational model, and if the model is accurate enough for the purpose it was developed for (Sargent, 2008).

STUDY AREA AND INPUT DATA

The Vouga River basin is located in the central region of Portugal, occupying an area of 3.645 km^2. It is a hydrographic complex composed by several small and medium-sized rivers. As it reaches the sea, it forms a network of water channels set upon a plain, known as Ria de Aveiro (Guedes, 2006). The Águeda River, a tributary of the left bank of Vouga River, originates in the hills of Caramulo and crosses the city of Águeda. Its length is of 40 kilometers. The average annual runoff is 173.2 hm^3 and it has an elementary basin whose area is 167.939 km^2 (Infopédia, 2011).

Although this work aims at a generic scenario, we are focused on a particular test scenario, to evaluate the methodology while testing the platform under development. The testing scenario is set on an affluent of the Portuguese River Vouga, part of the main basin, which is a frequently flooded area and causes regular threatening events to the city of Águeda.

In order to build a knowledge model of past episodes, it was necessary to use large amounts of data, collected during several years by the meteorological and hydrological stations located in the Vouga watershed. The data used comes from observed records of rainfall and river flow.

Topographic data is crucial for flood modeling. High accuracy of the data is extremely important to produce more realistic results. The used dataset contains geo-referenced information about all rivers and waters lines in Portugal, as well as a Digital Elevation Model (DEM) of Portugal with a resolution of 30 meters. Data from meteorological and hydrological stations as topographic data will be used as input data on methodology under development.

METHODOLOGY AND PLATFORM UNDER DEVELOPMENT

The main purpose of the work presented in this paper, it is to develop a methodology for evaluating a real situation, based on past occurrences in different scenarios. This methodology comprises four main components: Historic Data Database (HDD), Water Level Estimator (WLE), Scenario Configuration (SC) and Scenario Evaluation (SE), as shown in Figure 1. Each component is described below.

A web platform is being developed where it is possible to apply the developed methodology. With this platform, the Portuguese National Civil Protection Authority technicians can easily perform a risk evaluation of emergency scenario.

The platform is composed by a set of interfaces, each being associated with one of the purposes of the methodology. For example, it is possible to add and remove meteorological and hydrological stations to the platform and edit information about them. It is also possible to insert all observed data collected by the sensing devices over the years, which will constitute the entire database of past events. The platform will allow users to integrated geo-referenced files representing the physical spaces that will be used in SE component, as well as the information about current river conditions and the precipitation forecast needed to estimate the possibly resulting water level.

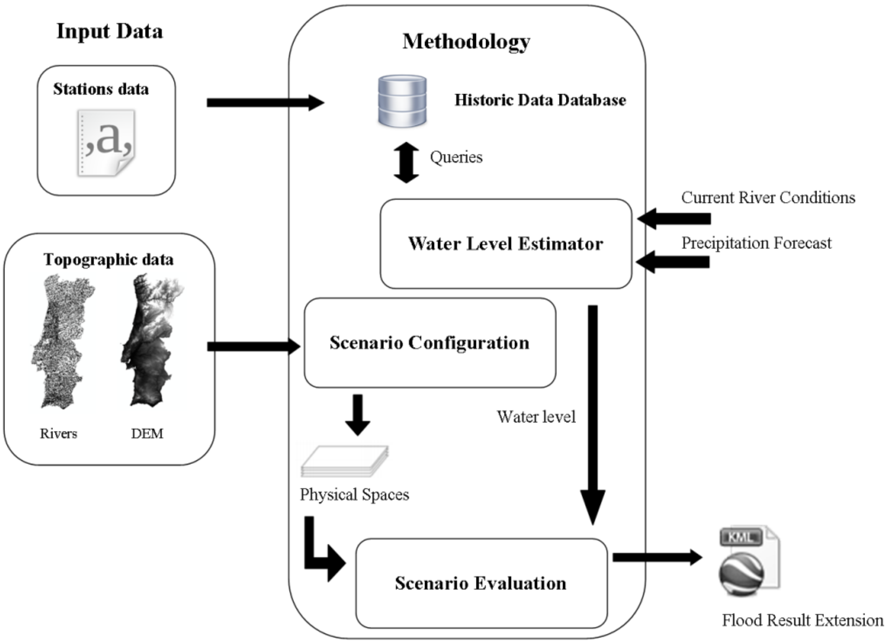

Figure 1. Methodology developed for evaluating a risk scenario based on past occurrences data

Historic Data Database (HDD)

The HDD component is a database that contains all relevant historic data, recorded by sensing devices (in this case, meteorological and hydrological stations). The database is thus organized by stations. Each station is associated with its collected data. Due to the short intervals used in data collection, hourly and daily averages were calculated as a way of optimizing the data for analysis. This data is available from the Portuguese National Information System for Water Resources[1] and it is obtained through querying the system about the area of interest. The result of these queries is saved in a file, which is then processed to be added to the HDD.

Water Level Estimator (WLE)

The WLE component aim is to estimate water level based on past events. The water level is estimated through queries on the HDD component. This component receives the current river conditions and precipitation forecast as input. With this input data, a query is performed, to verify if a similar event exists amongst past occurrences and, if so, if it has resulted in a flood case.

[1] Portuguese National Information System for Water Resources - www.snirh.pt

If the search result does not return any occurrence in the stored data, the possible precipitation water level will be determined by another process. This process uses all available data on HDD component, and, based on this data, precipitation ranges are defined. For each range of precipitation, the average increase of flow is calculated. The accuracy of the water level resulting from the component will depend on the size of the precipitation ranges.

Scenario Configuration (SC)

Since the developed methodology can be used in different scenarios and geographic regions, the relevant data needs to be processed to enable its use by this component. To achieve this, a data model was developed using the ESRI ArcGIS/ArcMap/Model Builder[2] software. This model uses, as input, the DEM, a Shapefile of Portuguese rivers and water lines and a cutout representing the study area. After executing the geoprocessing operations, the execution of the model returns three files that represent physical spaces (in ASCII Grid format). These files (Boundary space, River space, DEM space) will be used as input for the SE component.

Scenario Evaluation (SE)

SE is the component responsible for displaying the flood risk assessment result, becoming quite complex due to the responsibility of creating the evaluation of the risk scenario, based on the input data. This component uses, as input data, both water level returned by FE component, and the files returned by SC component.

All spaces are composed by a two-dimensional grid of cells, representing the study area. For the DEM and River spaces, each cell is associated with a value that represents the proprieties of this specific space, at the cell's location. In the case of the DEM space, the value represents the terrain elevation at the cell; in the River space, the value translates the exact location of the river.

The simulation space is defined by a set of overlapping spaces. The DEM and River spaces have a primary role in this phase, since they are the basis of the evaluation/simulation process. The simulation is accomplished through the execution of a cellular automaton.

The possible flooded area is determined by the application of the cellular automata rules over the simulation space. During the simulation process, the water is conducted by the height difference between cells. Initially, the automaton identifies all cells belonging to the river. At same time, using water level information, the automaton will determine which cells have to be processed in the next step, starting with the lowest elevation value identified in DEM space. At each step, the four non-diagonal neighboring cells are checked for each cell to evaluate if their elevation value is lower than current water level. This process continues until there are no more cells to be filled with the current level of water. When this state is reached, the automaton increases the current water level, and the process is repeated for this value. The simulation ends when the current level of the water is equal to the water level value estimated by the WLE component, and when all cells with elevation lower than this value are filled.

The result is returned as a KML file that contains the representation of the flooded area, and can be made available online through a map server. In addition to KML the file, the result of the flooding is also accessible in the shapefile file format, which can be used by most Geographic Information Systems packages.

Methodology and Platform Evaluation

All the developed work on this project was monitored, at the national level, by the Risk Prevention and Alert Unit team, belonging to ANPC. The project is being evaluated at the national and regional levels, with contacts being made with local evaluation teams of Civil Protection Officers.

After presenting the results provided by this work to the national evaluation team, the feedback received was that there was no system available to them which could provide them with the extension of flooding, enabling quick evaluation of a situation, based on existing data. The results thus met the expectations and constitute an important asset in the decision-making process.

CONCLUSION

This paper presents a methodology and associates platform for evaluating an emergency scenario, focused on flood events. Due to the use of real data about previous events, the possibility of setting up different scenarios and achieving quick results through the platform makes this system a good starting point for risk evaluation of a

[2] ESRI ArcGIS 10 - http://www.esri.com/software/arcgis/arcgis10/index.html

flood. With these results, Civil Protection teams can react and readjust according to the obtained information, alert everyone in danger and mitigate associated consequences, resulting from flood impact. This work is being monitored and evaluated by Civil Protection Teams, with the aim of being integrated in the Authority's risk evaluation processes.

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