Journal of Water Resource and Protection, 2014, 6, 351-362
Published Online March 2014 in SciRes. http://www.scirp.org/journal/jwarp
http://dx.doi.org/10.4236/jwarp.2014.64037

A Systemic Approach to Evaluate the Flood Vulnerability for an Urban Study Case in Southern Italy

Raffaele Albano, Aurelia Sole, Francesco Sdao, Luciana Giosa, Andrea Cantisani, Stefania Pascale

School of Engineering, University of Basilicata, Potenza, Italy
Email: albano.raffaele@tiscali.it

Received 31 December 2013; revised 28 January 2014; accepted 27 February 2014

Abstract

Currently, the urban flooding is one of the most concerning problems in hydraulic protection, both for the enormous number of people and the different elements (buildings, roads, vehicles, and so on) potentially exposed to risk, as well as the complexity of the territory at issue. At the practical level, vulnerability indicators are often predictably too narrow in their coverage of aspects of vulnerability. An important need remains to produce more conceptually informed vulnerability indicators or parameters and more satisfactory operational tools to assess weaknesses and resilience in coping with natural risks. In this paper, we present an innovative methodology that adopts a systemic approach to evaluate the vulnerability due to a flood scenario. The operative efficiency of the proposed GIS tool is validated in pilot application site, *i.e.* an urban area in Puglia Region, Southern Italy, on the basis of, studies surveys and damages carried out from a recent flood event occurred in the area. The model evaluates the direct structural damages and explores the potential operating conditions of the road network in case of the flood event. The resulting vulnerability assessment tool can guide evaluators towards a comprehensive understanding of strengths and fragilities of a territory and community where a flood occurs embedding and integrating as much as possible the multifaceted and articulated nature of an urban system.

Keywords

Urban Flooding; Vulnerability; GIS; Systemic Approach

1. Introduction

The urban flood has more serious consequences than flooding in un-urbanized areas crossed by a river [1]. This

How to cite this paper: Albano, R., *et al.* (2014) A Systemic Approach to Evaluate the Flood Vulnerability for an Urban Study Case in Southern Italy. *Journal of Water Resource and Protection*, **6**, 351-362. http://dx.doi.org/10.4236/jwarp.2014.64037

is due to a high concentration of people and objects exposed to damage or to the loss of functionality. In fact, the urban areas are a complex system of houses, emergency centers, schools, local health centers and factories connected by roads.

Floods can cause both direct and indirect suspension and loss of functionality with damage to the elements in a certain area or the loss of lives. In effect, one-third of the annual natural disasters and economic losses, and more than half of all the victims, are flood-related [2]. Between 1975-2002, floods due to drainage problems, flash and river floods accounted for 9% of all deaths from natural disasters, claiming about 175,000 fatalities worldwide [3], and affecting more than 2.2 billion people [4]. From 2000 to 2006, water-related disasters killed more than 290,000 people, affecting more than 1.5 billion, and inflicting more than US $422 billion in damage [5].

Vulnerability analysis is a helpful tool for the evaluation and the prevention of risks which can affect people, environment and human development. Modern society considers essential the vulnerability analysis to increase the safety of the people and infrastructure. The purpose of this paper was to build a tool to analyze and evaluate the vulnerability of infrastructures and other elements of territorial systems during the emergency phase of potential flood events in a populated areas with complex demographics, infrastructure and economic activity. The territorial vulnerability during a natural catastrophe depends not only on the features of its elements but also on the relations between their parts [6] [7] [8] [9]; in most cases such relations show critical points in a territory.

When the authorities have to operate in case of emergencies, they should consider the strategic importance of infrastructure in the territorial system, its evolutionary tendencies and its critical elements to increasing the efficacy and efficiency of the decisional activities. The model proposed is able to support the civil protection decision and management of an emergency due to natural catastrophes such as floods: the authorities can recognize the priorities of interventions, *i.e.* the most vulnerable elements, and can give the community a more efficient support to mitigation strategies and to delineate the emergency plans.

The validation of the method adopted was realized in the Municipality of “Ginosa Marina”, located near the mouth of the “Bradano River” and bathed by the “Ionian Sea”.

“Ginosa Marina” and the other neighboring municipalities are often afflicted by flood events. The last one, in March 2011, has caused a lot of damage to all the activities in the area and a lot of private houses have been made uninhabitable.

The proposed model is also being adopted in a project that aims to define the state of hydro-geological and structural instability and the relative degree of exposure and vulnerability of the “Provincial” road networks of “Basilicata Region”, South of Italy [10]. After this introduction (“Heading 1”), “Heading 2” describes the methodology and calculation, “Heading 3”, the validation and results on a real flood event, and “Heading 4”, the overall discussion and conclusions.

2. Method

The innovative scientific strength of the research is the implementation of a framework for dependency analysis described by [7] to evaluate the systematic vulnerability, here, suitably improved and modified to put forward a model to evaluate the vulnerability of a system when its buildings and road network is affected by a possible flood event. The system functions are highly dependent on networked systems and the operability of these systems can be vulnerable to disasters [11]. The analysis and evaluation of the connections and relation-ships in the complex systems of a city are essential after the flood event in the emergency phases. Concurrently with the occurrence of physical and functional damage, which leads to the discontinuation of most of the urban functions, the operability of the strategic emergency structures, their accessibility and connection with the territorial contest become a top priority.

This method integrates traditional data modeling approach with innovative spatial approach. The modeling steps include: 1) describe the topological characteristics of territorial system; 2) assess scenarios in terms of spatial flood hazard; 3) analyze the physical vulnerability of buildings and the vulnerability of road network directly affected by the scenarios; 4) analysis of interdependencies and evaluation of systemic vulnerability. The modeling results from this paper may support the decision making process in both urban planning and emergency response.

2.1. The Topological Characterization of the Territorial System

The first phase deals with the topological characterization of the territorial system and consists in the collecting, organization and management of data concerning its components on one hand and their connections and interactions on the other.

All available data should be obtained (topographic, population, building typology, and so on), supplemented by more detailed data from building occupancy type (residential, factories, and so on) and by the recognition of the most important elements in the case of an emergency such as hospitals, fire stations and civil protection stations. Data about road networks are also required.

2.2. The Assessment of the Scenarios in Terms of Spatial Flood Hazard

A pre-flood assessment is required to estimate the intensity of the possible flood event. An estimation of hydraulic characteristics can be obtained from two-dimensional hydraulic models. They provide detailed information on flood hydraulics but require a high quantity of input data and parameters.

From hydraulic simulations the following characteristics of a scenario should be obtained:

- Depth: Height of flood water above ground level at the location site, which indicates flood magnitude and used for estimating direct consequences on buildings and roads;
- Velocity: Flow velocity of the flood wave, which indicates flood magnitude and is used for estimating direct and indirect consequences;
- Total flooded area: Flooded surface at the study area that determines which zones and assets are at risk.

2.3. The Analysis of the Physical Vulnerability of the Buildings Affected Directly by the Scenario

Studies of the physical vulnerability of structures from flooding have emerged for a variety of reasons. One priority has been the identification of existing structures that might suffer damage from flooding, primarily aiming to establish where damages will occur or suggest where the public is most vulnerable during flooding. In addition, in recent years focus has moved towards development control, flood-proofing and policies advocating the development of properties in flood risk areas that are more resilient and resistant to the effects of flooding.

Two main approaches have been established to assess the physical vulnerability of structures to flooding: economic damage assessment and a quantification of the structural integrity of buildings. The first of these is arguably the more widely used approach and is essentially a quantification of the expected, or actual, damages to a property or area either through the estimation of a monetary value or through an evaluation of the percentage of the expected loss. This study considers the second of these approaches and focuses on assessing the physical vulnerability of individual structures (or group of structures), and on the estimation of the likelihood of occurrence of physical damage or collapse of a single building.

This information will be incorporated within a more general estimation of vulnerability whereby the likelihood of structural collapse is combined with other information (systemic vulnerability) to provide a comprehensive assessment of flood vulnerability.

This step concentrates on the integrity of individual structures or types of structure to the physical characteristics of the flood hazard; notably the water depth.

In particular, literature studies focus on the failure of structures and the hazard conditions that are likely to cause the collapse or partial collapse of structures.

The methods are fundamentally based on the use of depth-damage relationships that assign a percentage of damage from the resulting water depth during the flood.

Depth-damage curves demonstrate the relationship between the depth of the flood relative to the first finished floor level of buildings and the damage caused to the structures.

To calculate damages, each structure must be assigned to a structure occupancy type (Residential with 1 story, Residential with more than 1 story, Commercial, Industrial, Institutional/Government, Agricultural, Transport). For each structure occupancy type, an estimated replacement value and a structure depth-damage must be defined. The depth-damage curves used in this heading are drawn from the report of [12] (**Figure 1**).

2.4. The Analysis of the Vulnerability of the Road Network Affected Directly by the Scenario

In this phase, we estimate the vulnerability of the road network due to the possible effects on those travelling on road networks, specifically concentrating on vehicles, roads and road users instead of evaluating the hazard con-

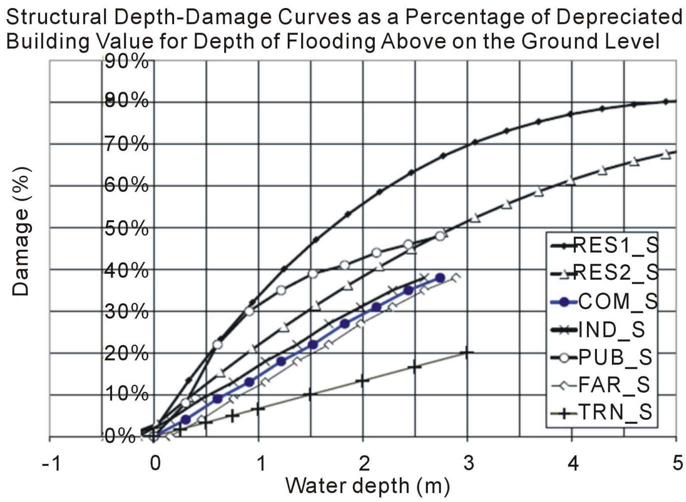

Figure 1. Depth damage curves.

ditions that are likely to cause the collapse or partial collapse of road structures. This choice derived from the difficulty to find structural information about roads and also because the intensity of flood events to cause damage to those travelling on the road is lesser than the one that causes the collapse of the road [13]. Therefore, we could estimate the vulnerability under maximum safety conditions. In addition, the collapse of the structures is greater in the riverbed where the infrastructure is often overcome by the water flow, obstructed by floating materials and showed excavations at the base of the piers of the bridges.

Scientific literature highlights the increase in the number of deaths occurring within, or escaping from motor vehicles [14] [13].

In this paper, three categories of road hazards are chosen on the basis of these literature studies [15] [16]. A weight concerning critical threshold values of hydraulic instability for idealized vehicles is assigned to each road [17] (**Figure 2**).

Referring to the envelope curves that have been developed by [17], with three color zones (*i.e.* green, yellow, and red), a novel innovative approach has been introduced first as the "Traffic Light of Hydraulic Stability System" (TLHS). Through this innovation, zones of hydraulic stability for each idealized vehicle are easily identified by color with the stable zone in green (left zone in **Figure 2**), the transition zone in yellow, (central zone) and the unstable zone in red (right zone). Thus, a straight forward envelope curve in **Figure 2**, in this study, is utilized to evaluate the potential road closures. Actually, all of the vehicles in the red zone of the graph are dragged by the water flow. Therefore, they could block, for example, an emergency vehicle during the rescue actions;, hence, the corresponding road is considered inoperable. The curves are utilized in the study only for the part when incoming flow depths are less than the vehicle height, the low part of the graph in **Figure 2**. Then, when the incoming flow depth is greater than the vehicle height, the roads are considered always inoperable.

2.5. Framework for Dependency Analysis

This framework improves and adapts the approach described by [7]. The evaluation of the dependencies of the elements is due to the inoperability of the road network considering the functionality, in case of emergency, of each element in the system. Inoperability, *i.e.* the inability of a system to perform its intended functions, analyzes how a given amount of inoperability in one component affects the operability of other components.

This framework analyzes how the presence of dependencies between different infrastructures contributes to the spread of degradation. The approach assumes as atomic entity whose level of operability, (in addition to external causes), depends on the availability of resources supplied by other infrastructures [18].

Dependencies are complex, non-linear, geographically-dispersed clusters of systems and the task to analyze the impact of element outages on the overall system is essential.

The model describes these phenomena mathematically by associating an inoperability level with each infrastructure. The inoperability of the ith infrastructure is expressed by variable x_i between [0,1] where $x_i = 0$

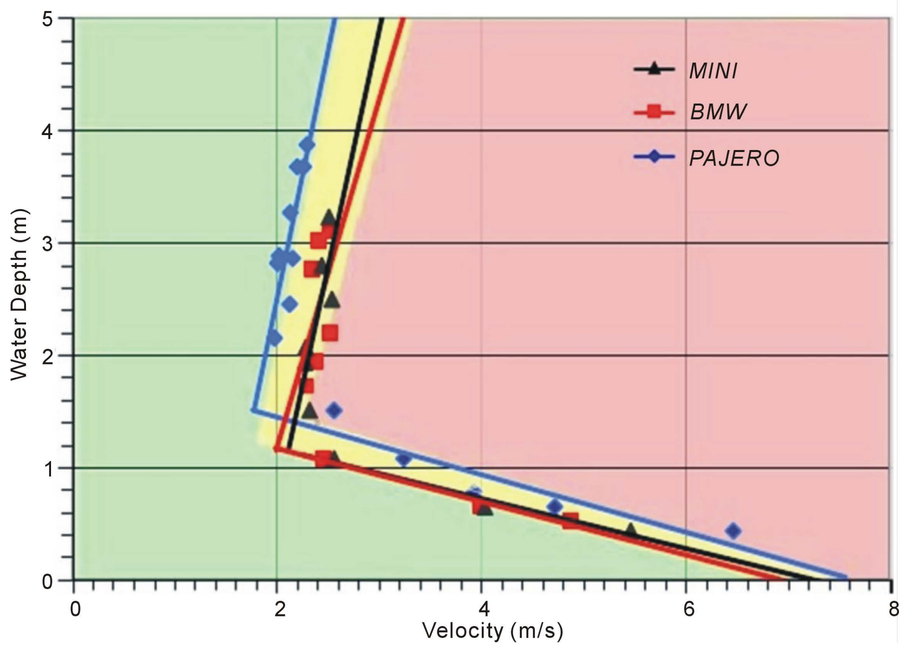

Figure 2. Critical threshold values of hydraulic instability for idealised vehicles (taken from Teo F.Y. 2012).

means that the infrastructure is fully operable and $x_i = 1$ means that the infrastructure is completely inoperable.

$$x_i = (1/n-1)\sum_{j=n} w_{ij} \tag{1}$$

The mutual dependency (interdependency) phenomena are estimated by the following equation [8]:

$$w_{ij} = \left(1-0.1\alpha_{ij}\right)\frac{\left(1-e^{-\alpha_{ij}x_j^2}\right)}{\left(1-e^{-\alpha_{ij}}\right)}+0.1\alpha_{ij} \tag{2}$$

where x_j is the index of physical vulnerability of the j element. Parameter, that represents the dependence of the ith road network on the jth elements, is calculated through the relation:

$$a_{ij} = -9.9I_{ij} + 10 \tag{3}$$

where I_{ij} is the value of influence that is evaluated by:

$$I_{ij} = (1/n-1)\sum_{j=n} \rho_{ij} \tag{4}$$

where n is the number of element affected by the inoperability of the ith arc of the road network and ρ_{ij} is parameter that evaluates the dependency of the element j on the arc i.

Parameter ρ_{ij} is evaluated through the vulnerability curves taken from the following equation [13]:

$$\rho_{ij} = (1-\alpha)\left(e^{-\alpha\xi_{j+1}^{j(k)}} \Big/ \left(1-e^{-\alpha\xi_{j+1}^{j(\lambda)}}\right)\right) \tag{5}$$

In this study parameter is the percentage elongation of the short path utilized by the element j to reach element j + 1. For example, the percentage elongation of the path utilized by an emergency vehicle to reach a house at flood risk when an arc of the road network, that the emergency vehicle usually drives on when there is not a flood event, was inoperable.

Parameters κ and λ are chosen according to the categories of the elements [7]. In this case, we divided the elements in three categories relative to the element functions for the systems in case of emergency.

In fact, we do not recognize the elements by the physical state but through the role they play in the case of an emergency and for the socio-economic and environmental damage they can cause. For instance, if a hospital is damaged the whole system is affected by an increase in the rescue workload on other forms of assistance.

The risk elements with different physical, social and economic features are set in Categories A, B and C.

The importance of these features moving from Category A to C:

- Category A includes all the most important elements in the case of an emergency such as hospitals, fire stations and civil protection stations. These are all those elements that give assistance when catastrophic events occur. It includes also the major roads;
- Category B includes all the major socio-economic and environmental elements such as factories, which can also deal with dangerous materials, and big shopping centers as well as all other public buildings including Universities, Libraries and Churches. All of these can contain a large number of people and can also be important from a historical, artistic and cultural point of view. It includes also country roads;
- Category C includes private buildings, small business activities and secondary roads.

In the Equation (5), a parameter f is added, as a corrective factor, to consider the population density. The population density is important because it provides a priori information on the number of people who may need to be rescued and on how to act in the case of danger when an appropriate emergency plan can be prepared which foresees the right kind of intervention necessary where the population density is higher.

2.6. Evaluation of the Systemic Vulnerability

The last phase is the estimation of the systemic vulnerability of each element by the equation

$$s_i = \max\left(x_i, v_i\right) \tag{6}$$

where v_i is the physical vulnerability and x_i is the influence of the road network on the elements of the territorial systems. The systemic vulnerability index s_i is chosen as cautionary because it highlights the maximum risk.

3. Case Study

"Ginosa Marina" is a city of the "Puglia Region" located near the mouth of the "Bradano River". The morphological characteristic of the river, *i.e.* area strongly flat, the great number of field data in the last years and the high resolution DTM built thanks to laser-scan data justify the choice as case study. Moreover, the "Bradano River" is crossed by "S.S. 106 Jonica" main road and the railway "Taranto-Reggio Calabria" that are some of the most important arteries of communication between border regions. All the area near the mouth of the "Bradano River" that can reasonably be considered an area at risk of flooding. This finding is derived primarily from historical information:

- The most important collection of historical information on hydrogeological disasters (landslides and floods) that have occurred across the country in the period 1918-2001, that was carried out as part of the AVI (Affected Italian Areas) by the "National Group for the Defense of Hydrogeological Disasters" (GNDCI) of the "National Research Council" (CNR) on behalf of the "Department of Civil Protection" [19];
- The data collected by ARPAB (Regional Agency for Environmental Protection of Basilicata).

These data show that the area at the mouth of the "Bradano River" has been affected in the past by a great number of natural disasters. In this area, there is an urbanized area with a considerable number of people, which usually increases during the summer season, and important roads, such as the "S.S. 106 Jonica", and a railway line that connects different Regions in Southern Italy.

The last event goes back to the 1st March 2011. It was so intense that the authorities had to declare a state of calamity. Hence, we have drawn up, in a GIS environment, the flood intensity maps of the considered urban areas with the hydrological and hydraulic simulation based on 1st March 2011 data.

3.1. Data

The hydrological and hydraulic data of the event, which occurred on 1st March 2011, was used to validate the proposed model. This flood event was particularly intense, causing damage to economic activities and residential buildings, that were evacuated, and some provincial and national roads were interrupted by water and mud. It is preferred to validate the model to an event which has actually occurred rather than to a generic simulated event.

A commercial numerical model, "MIKE Flood" by DHI, validated on remote sensing images and land survey *in situ*, was able to define the areas of the territory directly involved in the flood event, the maximum water depth and the maximum velocity of the water flow [20].

The maximum discharge of the occurred event can be assimilated to an event with 30 years return time, estimated with the VAPI method [21], recommended in Italy.

The topological characterization of the territorial system was taken from the ISTAT ("National Institute of Statistic") database coupled with data extrapolated by Remote-Sensing and orthophoto images [20].

3.2. Resolution

The first step was to identify the "Ginosa Marina" territorial network, characterized by 3358 elements: 2274 buildings, (public buildings such as schools, local health centers, hospitals, military and fire stations, industries and so on), 1084 infrastructures, (streets, railways and so on).

"Ginosa Marina" is a small town on the Ionian Sea and is crossed by the "Bradano River". Therefore, there are a great number of farming businesses and small factories. The population density is not so high but in the summer a lot of people visit the touristic town. The economy of the area is based on agriculture and tourism.

The ISTAT data is aggregated at the census areas level, therefore, a statistic method to disaggregate the data at a single building level was developed. The area of the buildings belongs to each single census area which is evaluated and multiplied by the percentage of the number of the floors of the building. Then, the total sum of the areas of the buildings is utilized to calculate the population density in each building. After the evaluation of water depth H and velocity V, and the identification of the total flooded area, see **Figures 3** and **4**, the elements directly at risk are highlighted **Figure 5**.

Only 10% of the buildings are at risk because the more populated area of the town is out of the flooded area. The 22% of the roads are directly involved in the events and the main road, "S.S. 106", in the most hazardous area. The health units and the operating unit are far from the flooded area.

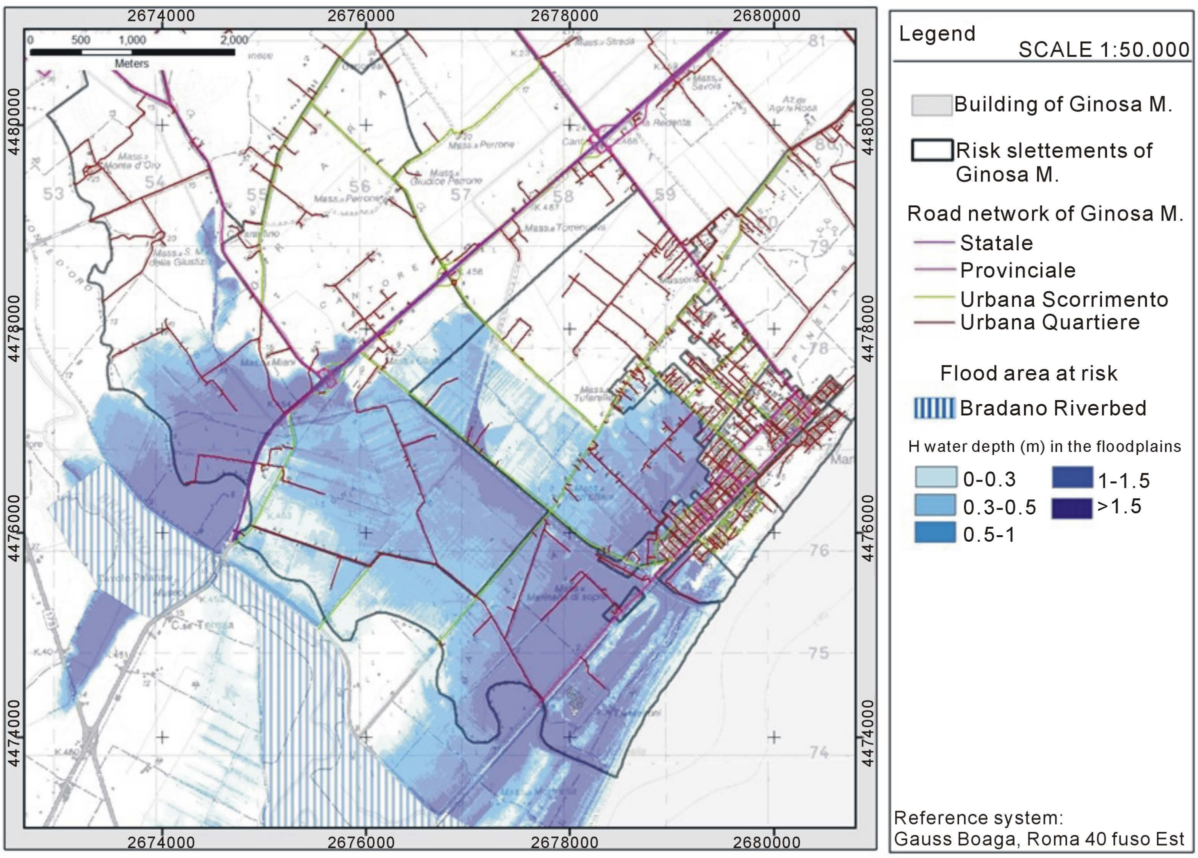

Figure 3. Water depth "H".

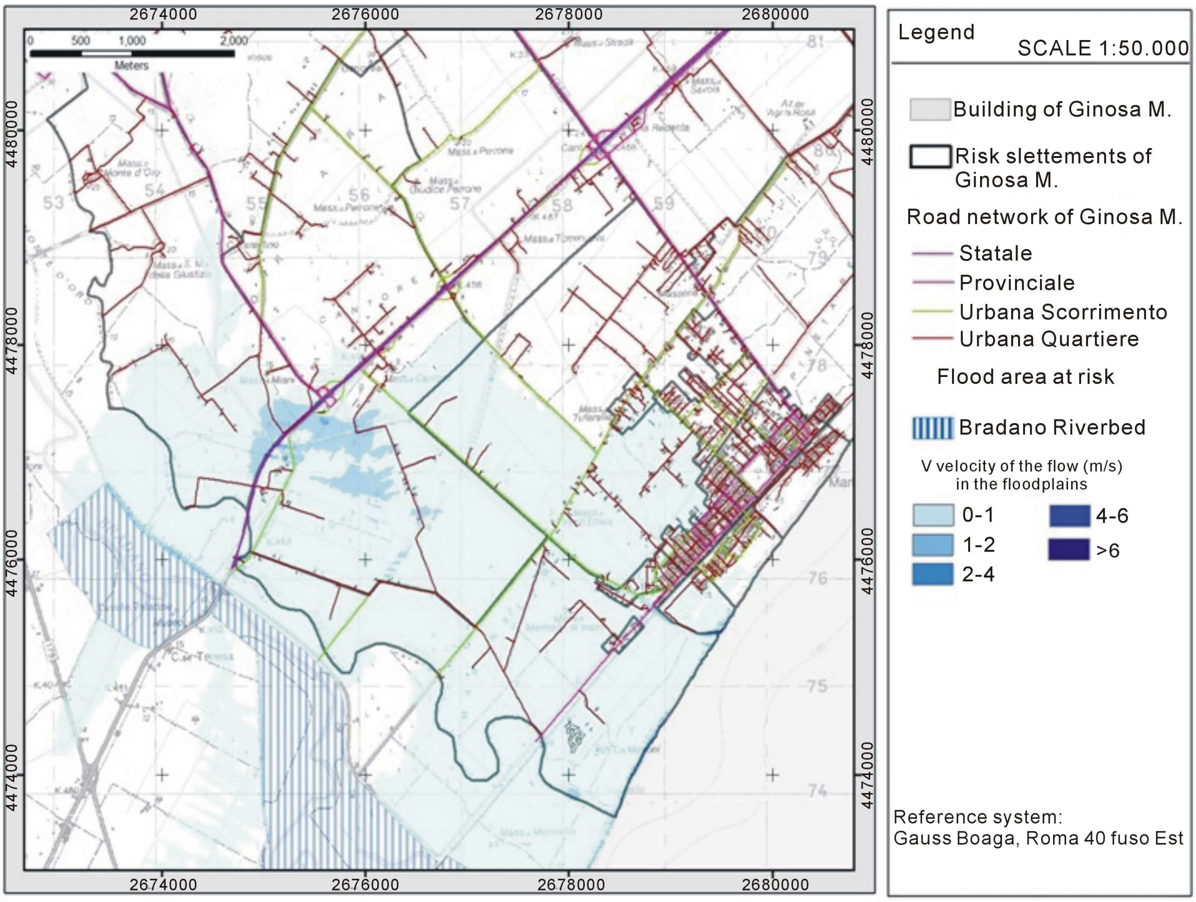

Figure 4. Velocity of the water flow "V".

The flooded area is a level land, therefore, the flow velocity, as you can deduce by the hydraulic data, reported in **Figure 4** is on average low. The flow velocity is low in most of the flooded areas but in proximity of the "S.S. 106", *i.e.* the main road of the system, it is higher.

The water depth is really high in most of the flooded area and, hence, it has influenced the value of the physical vulnerability of the buildings. The physical vulnerability of buildings and road networks are estimated respectively by the curve described in "Heading 3.3" and "Heading 3.4".

The dependency analyses are effectuated considering the elongation path method. In network GIS, computational modeling of an urban network (for example, street network or underground) is based on a graph in which the intersections of linear features are regarded as nodes, and connections between pairs of nodes are represented as edges.

In an open-source GIS, an ad-hoc tool was developed to evaluate the shortest path (pathfinding), to analyze network connectivity (tracing), and to assign portions of a network to a location based.

The result path lengths, *i.e.* the shortest path with and without the inoperable roads, are estimated, hence, the path elongation is evaluated in percentage.

The inoperable roads are chosen depending on the intensity of the flood: the roads, that belong to the extreme right zone of **Figure 2**, can be inoperable also during the post-event because the vehicles, that will be on these streets, are dragged by the water flow.

3.3. Results

This study has put forward an approach to evaluate the consequences of flood events drawn up by means of the utilization of a territorial model based on a network of influences and an estimation procedure for assessment vulnerability. The significance of such analyses in this particular territory must also be emphasized. The event of

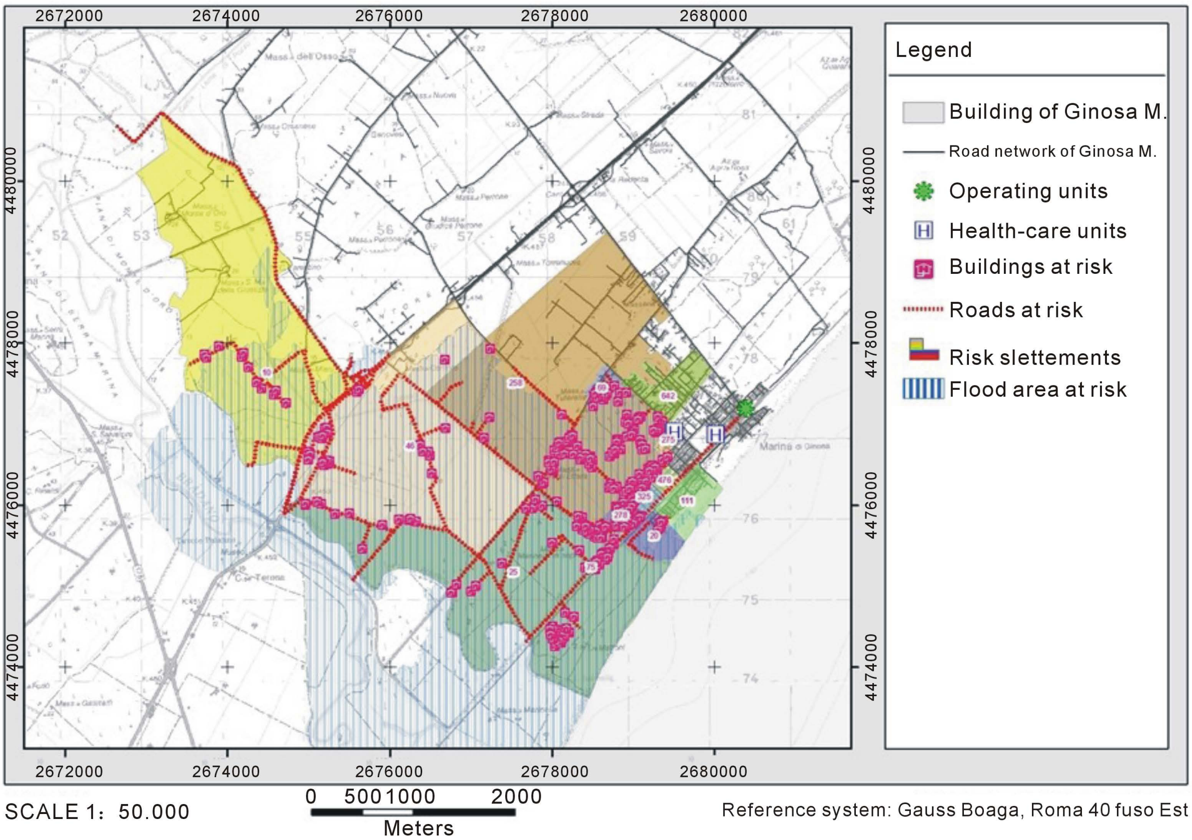

Figure 5. "Ginosa Marina" territorial network overlapped with the scenario to highlight the elements directly involved by the simulated flood event of 1st March.

1st March 2011 has caused serious damage to the main infrastructural systems as well as direct and indirect economic losses on most of the surrounding area. The scenario utilized has highlighted that the most vulnerable buildings with a value of index of systemic vulnerability over 50%, that are 20% of the total elements at risk, are concentrated in the area with the highest water depth and near "Via Lungo Galaso", a street that is almost completely inoperable. Therefore, there are the buildings around "Via Lungo Galaso", in "c/da Marinella", that are almost isolated. Emergency vehicles can reach these buildings in double the time that it usually takes. Most of these buildings are farming businesses, so the economic loss is greater for the system.

During the event of March 2011, the "Galaso Stream", a branch of the "Bradano River", created great damage to the adjacent buildings and roads. The major request for compensation for damage for this event has been made by the people that live in the proximity of this stream.

The validations, performed by comparisons with the case study, show the good reliability of the model, which allows a satisfactory representation of the fragility of the territorial system (**Figure 6**).

The street which is more affected by systemic vulnerability, index over 0.5, is the "S.S. 106" where the value of water depth and flow velocity are very high (**Figure 7**). Only 5% of the total roads at risk have an index of systemic vulnerability over 0.5 because most of the streets are urban and extra-urban. Therefore, the streets have a low classification and importance for the system. Another important factor is that the values of flow velocity are on overage low in the area. The "S.S. 106" hat is the most important road in the system, has the highest value of the systemic vulnerability, over 0.7.

The reliability of the proposed approach has been tested on a case study regarding flood risk in the district of "Ginosa Marina" and has led to identify the infrastructural elements that mainly affect the functionality of the territorial system, *i.e.* the "National Road S.S. 106" and the railway "Taranto-Reggio Calabria". Although, the same conclusion could also have been achieved by the analysis carried out by an expert in the territory, due to the relative simplicity of the territorial system studied. It can be considered as an important result, because it

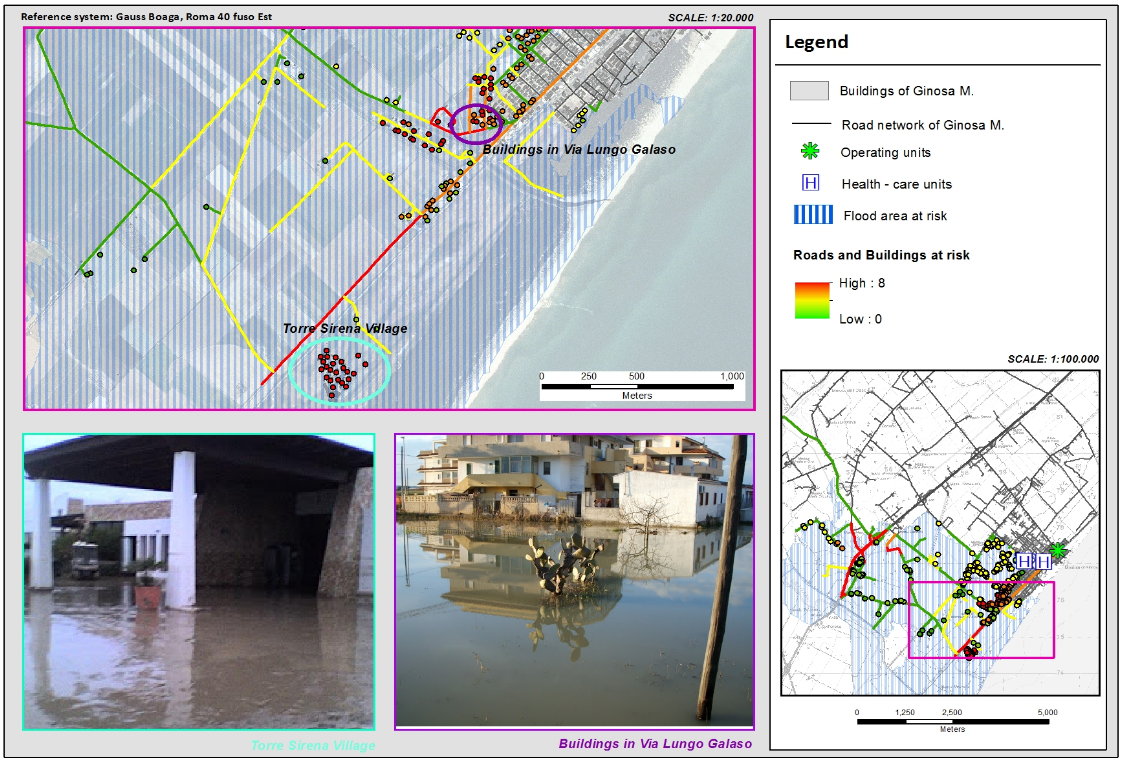

Figure 6. Examples of some critical situation of the real events comparing with the model.

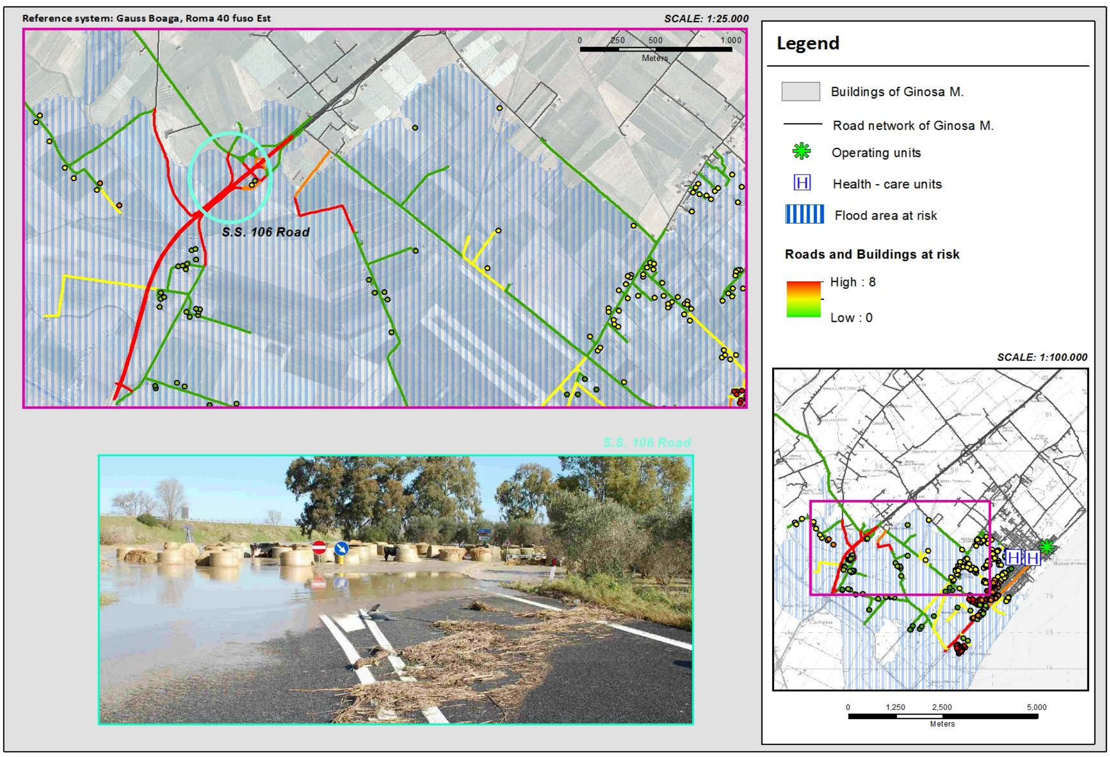

Figure 7. Example of the fragility of the system at the junction of "S.S. 106" due to the 1st March event: comparison with the model results.

highlights the reliability of the obtained results and, consequently, of the decisions to come.

4. Conclusions

We have proposed a dynamic model that analyzes the system, considering the interrelations of the elements, and evaluates the direct or indirect relationship of vulnerability among the elements as well as the effects that the fragility of a node could produce in the overall functioning of the whole system. It have identified, using spatial analysis, the most critical elements for the system and the most decisive elements in the management of rescuing. The model has been validated on a pilot site, *i.e.* an urban area in "Puglia Region", Southern Italy, to demonstrate its satisfactory operational degree to provide planners a tool to assess weaknesses in the whole urban system affected by flood. It has provided evidence for the presence of criticality in connections of the urban case study by measuring their amount through quantitative indicators. The indicators, evaluated by the GIS tool, have helped to define a hierarchy among the various structures and infrastructures by identifying those whose operation and efficiency are fundamental to the maintenance of network connectivity; hence, those whose minimal performance needs to be preserved, concurrently with the occurrence of physical damage estimated, in order to guarantee victims assistance and rescue activities.

The systemic approach can offer a great potential to get more insight into potentially large disruptions resulting from hazard impact. Future developments and outcomes will have an increasing effect on flood management policies and urban planning. The integration of systemic evaluation of the vulnerability with combined with economic models may drive many strategic decisions on the perception of contemporary development policies.

References

[1] Rafiq, L. and Blasch, T. (2012) Disaster Risk and Vulnerability in Pakistan at a District Level. *Natural Hazards and Risk*, **3**, 311-323. http://dx.doi.org/10.1080/19475705.2011.626083

[2] Douben, K.J. (2006) Characteristics of River Floods and Flooding: A Global Overview, 1985-2003. *Irrigation and Drainage*, **55**, 9-21. http://dx.doi.org/10.1002/ird.239

[3] Jonkman, S.N. (2005) Global Perspectives of Loss of Human Life Caused by Floods. *Natural Hazards*, **34**, 151-175. http://dx.doi.org/10.1007/s11069-004-8891-3

[4] Jonkman, S.N., Vrijling, J.K. and Vrouwenvelder, W.M. (2008) Methods for the Estimation of Loss of Life Due to Floods: A Literature Review and a Proposal for a New Method. *Natural Hazards*, **46**, 353-389. http://dx.doi.org/10.1007/s11069-008-9227-5

[5] United Nations World Water Assessment Programme (2009) Global Trends in Water-Related Disasters an Insight for Policymakers.

[6] Ezell, B.C., Farr, J.V. and Wiese, I. (2000) Infrastructure Risk Analysis Model. *Journal of Infrastructure System*, **6**, 114-117. http://dx.doi.org/10.1061/(ASCE)1076-0342(2000)6:3(114)

[7] Pascale, S., Sdao, F. and Sole, A. (2010) A Model for Assessing the Systemic Vulnerability in Landslide Prone Areas. *Natural Hazards and Earth System Sciences*, **10**, 1575-1590. http://dx.doi.org/10.5194/nhess-10-1575-2010

[8] Sdao, F., Albano, R., Sivertun, A., Sole, A., Pascale, F. and Giosa, L. (2013) Chapter 19: Model of Systemic Vulnerability Assessment in Urbanized Areas Exposed to Combined Risk of Landslide and Flood. In: Borruso, G., Bertazzon, S., Favretto, A., Murgante, B. and Torre, C.M., Eds., *Geographic Information Analysis for Sustainable Development and Economic Planning*: *New Technologies*, IGI Global, 274-294. http://dx.doi.org/10.4018/978-1-4666-1924-1.ch019

[9] Tamura, H., Yamamoto, K., Tomiyama, S. and Hatono, I. (2000) Modeling and Analysis of Decision Making Problem for Mitigating Natural Disaster Risks. *European Journal of Operational Research*, **122**, 461-468. http://dx.doi.org/10.1016/S0377-2217(99)00247-7

[10] Cantisani, A., Cafarelli, R., Giosa, L., Mileti, C., Sole, A. and Albano, R. (2012) An Easy Hydraulic Monitoring System to Support the Road Management. *Le Colloque International des Utilisateurs de SIG*.

[11] Menoni, S., Molinari, D., Parker, D., Ballio, F. and Tapsell, S. (2012) Assessing Multifaceted Vulnerability and Resilience in Order to Design Risk-Mitigation Strategies. *Natural Hazards*, **64**, 2057-2082. http://dx.doi.org/10.1007/s11069-012-0134-4

[12] Department of Water Resources Division of Flood Management (2008) Flood Rapid Assessment Model (F-RAM) Development 2008, State of California, The Resources Agency.

[13] Sharif, H.O., Hossain, M., Terrace, J. and Bin-Shafique, S. (2012) Person-Place-Time Analysis of Vehicle Fatalities Caused by Flash Floods in Texas. *Geomatics*, *Natural Hazards and Risk*, **3**, 311-323. http://dx.doi.org/10.1080/19475705.2011.615343

[14] Gruntfest, E. (2000) Flash Floods in the United States. In: Pielke, J.R. & Pielke, S.R., Eds., *Storms*, London, Routledge, 192-206.

[15] Shu, C., Xia, J., Falconer, R.A. and Lin, B. (2011) Incipient Velocity for Partially Submerged Vehicles in Floodwaters, *Journal of Hydraulic Research*, **49**, 709-717. http://dx.doi.org/10.1080/00221686.2011.616318

[16] Xia, J., Falconer, R.A., Lin, B. and Tan, G. (2011) Numerical Assessment of Flood Hazard Risk to People and Vehicles in Flash Flood. *Environmental Modelling & Software*, **26**, 987-998. http://dx.doi.org/10.1016/j.envsoft.2011.02.017

[17] Teo, F.Y., Xia, J., Falconer, R.A. and Lin, B. (2012) Experimental Study on the Interaction between Vehicles and Floodplain Flows. *International Journal River Basin Management*, **10**, 149-160. http://dx.doi.org/10.1080/15715124.2012.674040

[18] Setola, R., De Procellinis, S. and Sforna, M. (2009) Critical Infrastructure Dependency Assessment Using the Input-Output Inoperability Model. *International Journal of Critical Infrastructure Protection*, **2**, 170-178. http://dx.doi.org/10.1016/j.ijcip.2009.09.002

[19] CNR IRPI () AVI Project: Inventory of Areas Affected by Landslides and Floods in Italy from 1918 to 2000. http://avi.gndci.cnr.it

[20] Sole, A., Mancusi, L., Giosa, L., Cantisani, A., Grippa, A., Albano, R. and Varasano, A. (2012) Effetti Della Vegetazione Nella Valutazione Delle Aree a Rischio Inondazione. *XXXIII Convegno Nazionale di Idraulica e Costruzioni Idrauliche*, Brescia, 10-15 September 2012.

[21] Claps, P. and Fiorentino, M. (2005) Valutazione Delle Piene in Italia, Rapporto di Sintesi per la Regione Basilicata (Bacini del Versante Ionico), GNDCI-CNR. Dipartimento di Ingegneria e Fisica dell'Ambiente, Università della Basilicata, Potenza.