

## GeoTerrace-2020-012

### Landslide susceptibility mapping with fuzzy methodology

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#### SUMMARY

This work proposes an experimental methodology for the characterization of the susceptibility to landslides in the Reggio Calabria area through the combination of remote sensing, GIS systems and soft computing. In particular, we created, a map of the susceptibility to landslides in GIS environment using a neural network and a fuzzy methodology to produce an infrastructure attention level divided into five categories (levels) of risk. Subsequently, starting from this map, we identified the areas of the road's network most exposed to landslide risk also using remote sensing techniques (classification and segmentation techniques) overlapped on the open street map. This system provides us the level of attention that affects the transport infrastructure investigated (a higher level of attention corresponds to a higher level of landslide risk).

## Introduction

This work proposes an experimental methodology for the characterization of the susceptibility to landslides in the Reggio Calabria area through the combination of remote sensing, GIS systems and soft computing. In particular, we created, a map of the susceptibility to landslides in GIS environment using a neural network and a fuzzy methodology to produce an infrastructure attention level divided into five categories (levels) of risk. Subsequently, starting from this map, we identified the areas of the road network most exposed to landslide risk also using road maps building through remote sensing techniques. This system provides us with the level of attention that affects the transport infrastructure investigated (a higher level of attention corresponds to a higher level of landslide risk) (Barrile et al. 2019b).

In Italy, the actions that can be implemented in relation to the risk of hydrogeological instability are basically: the forecast, the prevention and the mitigation of the effects. The monitoring of natural hazards, the assessment of their impact and the general risk assessment are therefore decisive steps towards the selection and sizing of adequate protection measures (Barrile et al. 2018).

In this article, we will deal with the assessment of susceptibility to landslides, a complicated subject due to the difficult assessment of the spatial and temporal distribution of past events for large areas, mainly due to the limitations and gaps of historical documents and geographical information. Due to these limitations, the most widely used tool for assessing susceptibility to landslides is the Geographic Information System (GIS), which allows analyzing and managing a considerable amount of information.

Our work presented here has the following objectives:

- Use the GIS software and soft computing techniques to create a landslide susceptibility map for the province of Reggio Calabria through the weighted combination of various factors such as slope, lithology, elevation, rainfall and land use.
- Extract the road network by analyzing remote sensing images superimposed on Open Street Map.
- Once the landslide susceptibility map has been obtained, determine the network infrastructures to pay more attention to.

## Case study

The study area considered in this research is the Metropolitan area of Reggio Calabria (Italy), a territory with high population density, where the hydrological risk is very frequent.

## Method and Theory

Input data are acquired from:

- the Hydrogeological Plan (PAI) (Figure 1) (Bernardo and Bilotta 2021) (containing landslides occurred in the past, together with an assessment of areas with a future potential risk of landslide, but without an estimate of the annual probability of occurrence).
- remote sensing data produced through the classification and segmentation of images using OBIA and traditional pixel based techniques (Figure 1 - 3).
- vectoral and raster layers and derived maps (Figure 1, 2) (Bernardo et al. 2021) (DEM, remote sensing images (Google Earth), Rainfall Map, Elevation Map, Lithology Map, Land use Map, Slope Map).

Landslide susceptibility zoning is based on MULTICRITERIA ANALYSYS integrated whit a properly implemented Neural Network (Barrile and Fotia (2019)).

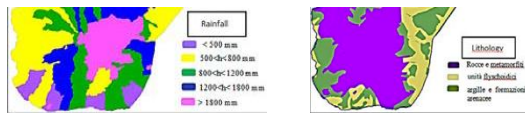


Figure 1 PAI and thematic maps

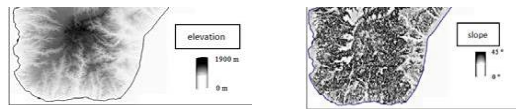


Figure 2 DEM and derived maps.



Figure 3 classification and segmentation of images using OBIA and traditional pixel based techniques

The objective of this work is to create a landslide susceptibility map for the Metropolitan area of Reggio Calabria through the weighted combination of various indices based on the values reached by the characteristic factors in the landslide areas highlighted in the PAI (Multicriteria Analysis) and on the further evaluation of the factors through the soft computing techniques (our implemented neural network) that allow to predict indices and weights useful to calculate the different study area susceptibility. The calculated indices refer to factors such as slope, rainfall, elevation, lithology, and land use. The landslide susceptibility values obtained were divided into five classes: very low, low, moderate, high, very high. The resulting network infrastructures that are particularly relevant during the emergency and which require plans to reduce the risk of landslides were highlighted by overlapping the main network infrastructures obtained from segmentation and classification of remote sensing data on the landslide susceptibility map obtained from soft computing techniques and from the use of fuzzy logic and “if-then”.

### Landslide susceptibility zoning map

The assessment of landslide susceptibility can be complicated because it is very difficult to assess both the space and the temporal distribution of past events for large areas mainly due to limitations and gaps in both historical records and geographical information. The landslide susceptibility assessment can be considered as the first step towards a hazard and risk assessment. In the proposed study, areas with different classes of landslide susceptibility are marked with different colors (from green, which indicates a very low susceptibility, to red, which stands for a very high susceptibility) (Barrile et al. 2014) (Figure 4).

*Description of the data and determination of the indices.* To produce the landslide susceptibility map, a total of 5 inputs were selected for the model, considering the main characteristics of the landslides: slope, lithology, elevation, rainfall and land use. Each factor was characterized in classes whose weight was determined on the basis of the relevance resulting from the analysis of the map of landslide areas identified by the PAI and from the remote sensing images. The weight of each class was determined by a properly implemented neural network (Barrile and Fotia (2019)) that allows to predict weight's values through the interconnection of different input data; this procedure is based on historical series data acquired on the same data and from the parameters behavior measured in similar events occurred during the time (same kind of: land typology, land lithology, landslide, land use, and vegetation presence). The given inputs are: - the climatic events (such as rainfall, temperature changes...) - any fires that have occurred in the area - any anthropic activities in the area - corrivation phenomena.

The importance of the five factors were instead determined using the Analytical Hierarchy Process (AHP) multicriteria analysis method, considering the slope, the elevation, the precipitation as the main factors. The resulting index was finally obtained by multiplying the weight of each class of factors and the weight of the same factor collected by the AHP model.

*Landslide susceptibility map results.* The data obtained for the assessment of susceptibility were classified into five categories: Very low, Low, Moderate, High, Very high. According to the results,

22% of the study area is classified as very highly susceptible, 36% as highly susceptible, 20% as moderately susceptible, 17% as lowly susceptible and 5% as very low susceptible.

The results mentioned above show that 64% of the entire territory of the metropolitan area is affected by a strong landslide susceptibility value. From the map obtained (Figure 4) it is possible to note that the high and very high susceptibility are the hills, that is, the areas between the coasts and the central part of the metropolitan area. These areas are particularly relevant for the connections within the various internal urban areas and the main inhabited centers (Barrile et al. 2016) and services located along the coasts (Barrile and Bilotta 2014). Furthermore, the landslide susceptibility procedure adopted is in accordance with the work carried out by the Calabria Region Basin Authority: 75% of the areas with high and very high susceptibility coincide with the landslide areas identified by the PAI maps.

### **Lifelines for transport**

Recent experiences have highlighted the extreme importance of the functioning of lifelines (networks throughout the territory connecting settlements and points of interest with essential services necessary for the functioning and survival of communities) in the emergency conditions following a catastrophic event. Some lifelines must ensure effectiveness and efficiency immediately after the disaster, in some cases it must be maintained during the event, to allow rapid and efficient access and assistance and rescue, guarantee evacuation and more generally maintain access to all emergency services.

### **Lifelines for road transport in the south Province of Reggio Calabria**

The road network of the south part of the Metropolitan area of Reggio Calabria (study area) consists of 973 km of roads (Figure 5). Road use changes with seasonal activities, and the variability is particularly significant in tourist attraction areas (Barrile et al. 2019a). The strategic roads, which are the backbone of the transport lifelines, have been classified according to the flow of traffic, population served and relevance in the national and regional transport system. This classification of the importance of the primary transport network of the Metropolitan area of Reggio Calabria (based on the level of service in the event of a disaster, the traffic flows and the population served) defining three sets (Figure 6): (i) strategic transport; (ii) transversal access routes; (iii) secondary transport routes. We created a map from satellite imagery quickly extracting roads with Remote Sensing techniques, through the Object Based Image Analysis (OBIA), with a segmentation that starts from concepts of Mathematical Morphology. We superimposed the results of the methodologies described above within the GIS on Open Street Map (OSM) layers in order to evaluate the susceptibility to landslides.

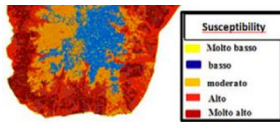
The main purpose of this study is to identify the stretches of road network considered exposed to landslide danger starting from the susceptibility map. This is obtained with the application of soft computing techniques (neural network and fuzzy logic) (Zadeh (1965)) to have the landslide susceptibility layer and the image constructed with remote sensing and OSM superimposition techniques). In particular, as mentioned, a Fuzzy logic system with 2 inputs, 15 “if-then” and 1 output representing the “attention level” was subsequently implemented in Matlab Environment. Fifteen “if-then” fuzzy rules were set to evaluate the “level of attention”, according to the following logic:

- If the “susceptibility” is LOW and the “infrastructural relevance” is MODERATE, the “level of attention” is LOW;
- If the “susceptibility” is MODERATE and the “relevance of the infrastructure” is MODERATE, then the “level of attention” is HIGH;
- If the “susceptibility” is HIGH and the “infrastructure relevance” is MODERATE, then the “level of attention” is HIGH.

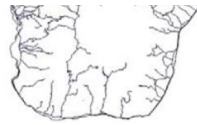
### **Conclusions**

From the results obtained (Figure 7) it is possible to note that the most relevant roads in terms of connection, such as the A3 motorway, the SS106 and the other roads that connect the Ionian coast to

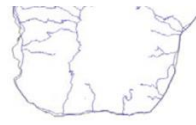
the Tyrrhenian coast are those that indicate the highest level of attention. This result highlights the weaving of the network system of Metropolitan area of Reggio Calabria. Many of the infrastructures corresponding to a high level of attention, in fact, constitute the only link for very large areas.



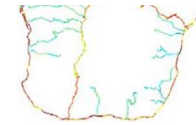
**Figure 4** Landslides susceptibility map.



**Figure 5** Principal road networks.



**Figure 6** Road network considered.



**Figure 7** Results obtained: Level of attention for the road infrastructures.

The analysis carried out highlights how impracticable the interventions are to mitigate the level of risk on the identified lifelines, highlighting that the infrastructures represent the only way to reach the areas affected by a natural hazard and to provide the first aid to the population.

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