# Assessment of an extreme flood event using rainfall-runoff simulation based on terrain analysis in a small Mediterranean catchment (Vernazza, Cinque Terre National Park)

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*Abstract*—**The main aim of this study is the assessment of an extreme precipitation event causing a flash flood in the Vernazza catchment, Cinque Terre on the 25th of October 2011. We utilized a rainfall-runoff model taking into account five important factors: i) the morphology, ii) the geological settings, iii) the landcover/ landuse distribution, iv) the soil characteristics, and v) the precipitation input. The model calculates the water balance for the soil surface, which results in the partitioning of rainfall in surface runoff and infiltration. The latter was regionalized based on measured soil infiltration data using a constant head permeameter. The runoff algorithm was implemented in a GIS environment supposing that evapotranspiration can be neglected for this event. We show that morphometric parameters yield valuable and important input information for the models and can be utilized as first hazard screening approach. Moreover, the results obtained provide important information for the preparation of plans and strategies of risk management in the Cinque Terre National Park.**

## I. INTRODUCTION

The Vernazza catchment (eastern Liguria, La Spezia province) is located along the Tyrrhenian side of the northern Apennines (Fig. 1). It shows typical geomorphological features and characteristics present in most of the Ligurian coastal catchments. It has a small catchment area of about 5.7 km², very steep slopes due to the proximity of the Apennine mountains and hence is characterized by short flow length and stream morphologies often controlled by tectonics. Finally the torrents show considerable erosive power and the capacity to transport sediments because of their steep profiles. The bedrock is mainly composed by a sandstone-claystone flysch (Macigno Fm., Tuscan Nappe), and a pelitic complex (Argille e Calcari di Canetolo Fm., Canetolo Unit). Particular land-use pattern characterize the study area. The slopes have been almost completely terraced for vineyards and olive groves during the past millennium. Following the abandonment of farmers in the last century, terraced slopes have been progressively abandoned and covered by a Mediterranean scrub and pine vegetation succession.

The climate is Mediterranean, characterized by hot and dry summers and mild winters. The mean annual precipitation at Levanto, located along the coast 10 km W of Vernazza, is 1048 mm, with maximum rainfall occurring in October with a mean value 156 mm.

In particular, on October, 25th 2011 a heavy rainfall affected the Cinque Terre area and especially the Vernazza catchment. A cumulative daily rainfall of 539 mm was recorded, with high intensities up to 153 mm/h and 328 mm/3h. [1]. This event triggered several slope movements and floods, causing 13 death casualties, severe structural and economic damages. In this study we develop a simple approach to simulate the extreme event of

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25th of October 2011 in order to assess the spatio temporal dynamics and pattern of the event. Therefore, we conducted a terrain analysis in order to derive detailed morphometric information that was subsequently utilized in the modeling procedure and also yield valuable information concerning a first flood hazard screening of the area.

## II. MATERIALS AND METHODS

Our proposed model is a simply conceptual model, schematized in figure 2 and described below.

The catchments has been equipped with a weather station measuring precipitation, air temperature, radiation, wind speed and direction, and relative humidity. Moreover we installed a multi-parametric measuring device within the river to measure river runoff and sediment discharges in terms of suspended loads.

The precipitation input was regionalized for the catchment using a co-Kriging interpolation method where also the elevation was inserted; we used precipitation data recorded during the flood in all the weather station working in the area. (Fig. 3)

A geological map and a land use map has been derived from high-resolution color aerial photos, available maps (CARG - La Spezia - sc. 1:50000) and validated by a detailed field survey.

We generated a digital elevation model (DEM) with 5 m resolution. This DEM is based on an interpolation of contour lines of a 1:5.000 topographic map (Carta Tecnica Regionale Ligure, 2007) using a thin plate spline algorithm proposed by Hutchinson (1996) [2]. The DEM was preprocessed with low pass filtering to extract artefacts and errors like local noise and terraces [3] using ARCGIS 9.2 (© ESRI, 2004). Subsequently, the DEM was hydrologically corrected eliminating sinks using the algorithm proposed by Planchon and Darboux (2001) [4].

The DEM was the basis for a detailed terrain analysis performed in Saga GIS [5]; We used SAGA 2.0.3 software to derive the topographic indices at a 5 m resolution. The layers were post-processed and transformed into ascii raster data with the same spatial reference and resolution.

We derived various Topographic Indices such as:

the Topographic Wetness Index (TWI) [6] , calculated as:

$$TWI = \ln(As / \tan(Slope))$$

and the Stream Power Index (SPI) [6], calculated as:

$$SPI = \ln(As * Slope)$$

Where As is the specific catchment area estimated using one of the available flow accumulation algorithms

Moreover we derived the Transport Capacity Index (TCI), that is the calculation of slope length (LS) factor as used by the Universal Soil Loss Equation (USLE) [7], based on slope and specific catchment area (As, as substitute for slope length).

We calculated also the Flow direction and flow accumulation indices to quantify topographic control on hydrological processes. Flow accumulation is calculated as upslope contributing (catchment) area using the multiple flow direction approach of Freeman (1991) [8].

For the hydrologic characteristics of the soil, we made field measurements in the soil; we used a Compact Constant Head Permeameter (Amoozemeter) [9] to obtain the saturated hydraulic conductivity (Ksat) of the different type of soils and a Hood-Infiltrometer [10] to measure the surface infiltration. We obtained 27 measurements with the Amoozemeter at a depth of 25 cm from the soil surface and 6 measurements with the Hood. We regionalized the data for the entire catchment using Universal Kriging of Saga GIS.

Geological, Land cover, Elevation and TWI grid were insert during the interpolation analysis, supposing that soil hydrologic characteristics are mainly related to the catchments' parent material, land cover typology and the topographic settlement. The first result is the realization of the soil infiltrability map (Fig. 4).

Finally we calculated the potential Runoff, subtracting the soil infiltrability grid from the rainfall grid, supposing that evapotranspiration can be neglected during heavy rainfall events. Consequently, the water balance is reduced to a function of precipitation input and infiltration capacity of the surface.

To obtain the real volume of water that concentrate in the river we applied a weighted Flow Accumulation procedure using SAGA GIS, and we inserted the potential Runoff raster as input raster for applying a weight to each cell.

The river runoff was calculated in $m^3$/day. The result of Flow Accumulation (Fig. 5) is a raster of accumulated flow to each cell, as determined by accumulating the weight for all cells that flow into each downslope cell. The calculation was finally validated with measured runoff registered by the multi-parametric device at the outlet of the catchment.

## III. RESULTS

The topographic indices such as catchment area and flow accumulation yield a first rough estimate of areas endangered by flood events. Moreover, indices like TWI, SPI and TCI provide information about areas at risk concerning landsliding, soil erosion and gullying. With the simple hydrological model we finally calculated potential runoff owing to an extreme precipitation event, such as during last flood event happened in 5 Terre National Park on October, 25th 201.

The result is shown in figure 5.

Our rainfall-runoff model estimate a maximum discharge of 52 thousand $m^3$ / day, which is about 6000 liter per second, in the river network.

This rainfall-runoff model could be a very important tool in the preparation of plans and strategies of risk management in the Cinque Terre National Park, above all related to possible climatic changes scenarios.

## A. *Figures and Tables*

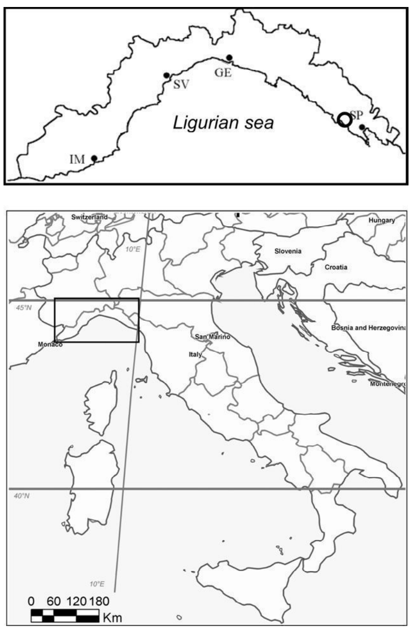


Figure 1. Study area

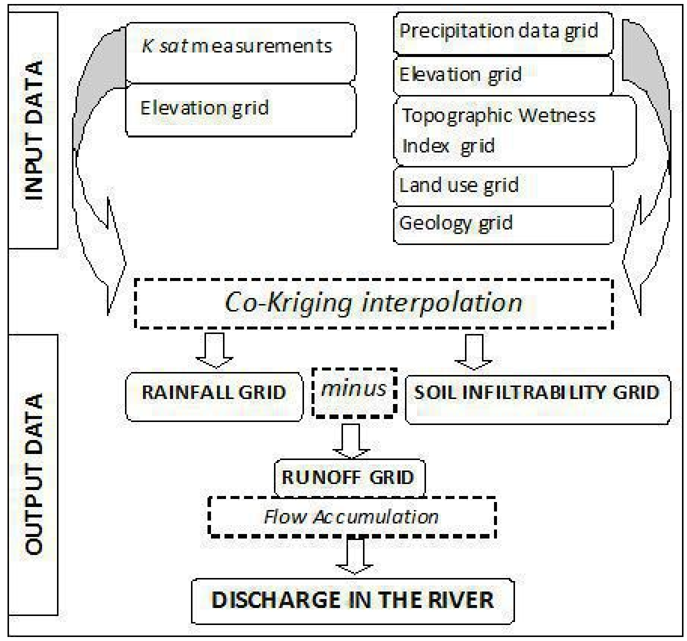


Figure 2. Conceptual map of proposed rainfall-runoff model

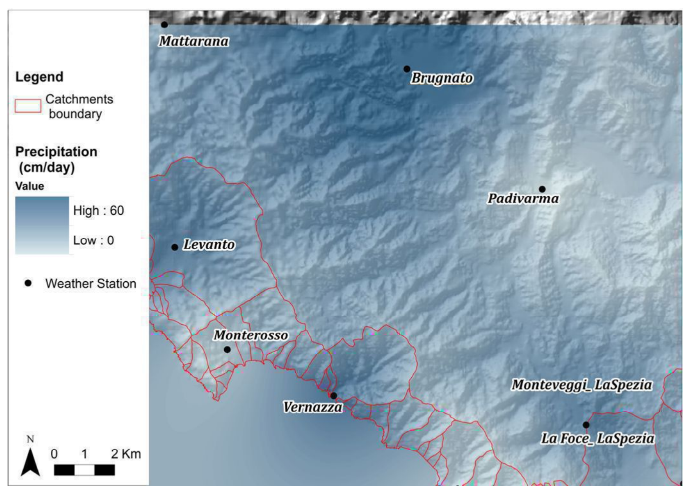


Figure 3. Regionalization of maximum precipitation event recorded during the flood of the 25th October 2011

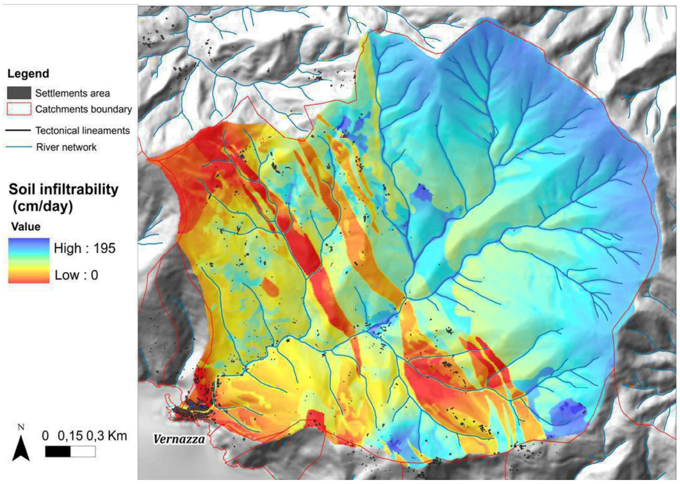


Figure 4. Soil infiltrability map

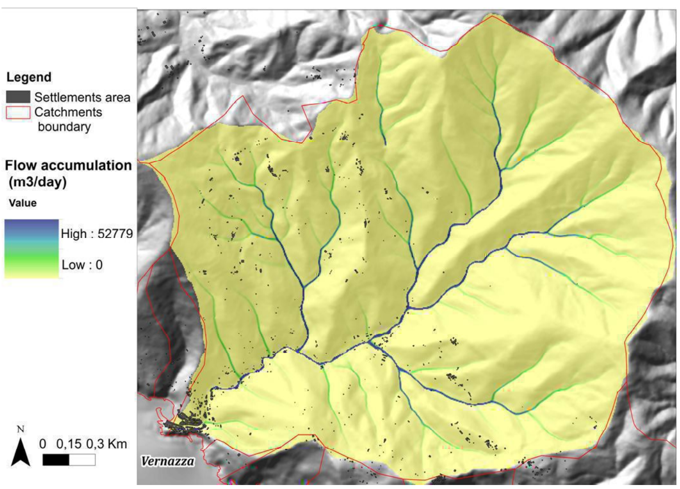


Figure 5. Flow Accumulation map resulting by the rainfall-runoff model

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