Contemporaneity of Floods and Storms. A Case Study of Metropolitan Area of Reggio Calabria in Southern Italy

Giuseppe Barbaro[1(✉)], Olga Petrucci[2], Caterina Canale[1], Giandomenico Foti[1], Pierluigi Mancuso[3], and Pierfabrizio Puntorieri[1]

[1] Mediterranea University of Reggio Calabria, 89100 Reggio Calabria, Italy
giuseppe.barbaro@unirc.it
[2] National Research Council of Italy, Institute for Geo-Hydrological Protection, CNR-IRPI, 87036 Rende, Italy
[3] Department of Infrastructure Public Works and Mobility, Sector 8-Defense Interventions, Calabria Region, Regional Citizen, 88100 Catanzaro, Italy

Abstract. The environmental balance is being increasingly altered by mankind's direct and indirect actions. Waterproofing of territory and continuous climate change are amongst the main factors of hydrogeological risk. In the presence of complex orographies and particular geographical exposure, meteorological phenomena can have devastating consequences. Calabria, located in the southern part of Italy, stands at the confluence of the Tyrrhenian and Ionian Seas and is particularly exposed to such phenomena. Its unique geomorphological formation makes it subject to flooding and sea storms that have revealed the fragility of its territory. When such phenomena occur concurrently, the effects can be devastating, both in terms of infrastructure damage and inconvenience to the local population, as downstream flooding interacts with wave run-up. We will analyze the history of contemporary flooding and storms in the Metropolitan Area of Reggio Calabria, which is located in the south of Calabria and in the middle of the Mediterranean Sea. Two case studies will be illustrated, one relating to the Ionian coast and the other to the Tyrrhenian coast.

Keywords: Floods · Sea storms · Meteorological phenomena
Torrents · Wave run-up

1 Introduction

Anthropisation and waterproofing are amongst the main causes of the irreversible process of land consumption. The situation is exacerbated by climate change which affects both the rainfall regime, and wave action on the coasts, causing extreme events such as storms and flooding [1]. These represent worrying phenomena if they occur singularly, but devastating when occurring together. Storms and flooding frequently occur across the Italian territory, but are particularly violent in Calabria. Calabria's particular orography, geomorphology and exposure to the winds of the Scirocco in the South and the Mistral in the North influence the response of the territory to

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precipitation and to wave motion, with consequent river flooding in urban areas, and inundation in coastal areas.

These two events are almost always studied separately in existing literature. As far as flooding is concerned, many studies deal with the urban flood risk [2–4] and the dangers of such flooding [5]. From the coastal point of view we mainly study shoreline changes and erosion processes, important concepts for planning and management of areas near the sea [6–8]. It is important to analyse the main phenomena affecting coastal dynamics [9–13], in particular wave action [14–17] and the interaction between coastal and river transport [18–24]. Calabria, due to remarkable coastal development, has more than 700 km of coast, much of which is subject to erosion [25], and in particular many areas are prone to the risk of sea inundation with disastrous consequences for coastal urban areas. The separate analysis of such events can lead to an underestimation of the severity of the outcome when such phenomena occur simultaneously. It follows that events with low return times can significantly affect the territory even when such events are concomitant. In this paper the history of storms and floods in Reggio Calabria has been analysed. This analysis begins with the historical data of alluvial events, provided by the CNR-IRPI of Cosenza, and of wave data provided by ABRC MaCRO, and by identifying the storms by means of Boccotti's theory. In the first analysis, it was possible to evaluate the simultaneous manifestation of events that strongly affected the vulnerability of the territory. The concomitance is recorded both on the Ionian coast, struck several times by the Scirocco wind, and on the Tyrrhenian coast, where wave agitation is mainly due to the action of the Mistral currents. Case studies will present chronologically distant events in the two geographically distant towns of Scilla (Tyrrhenian coast) and Monasterace (Ionian coast). The results obtained allow us the possibility of extending the study to territories with the same climatic, orographic and morphological characteristics as those of the Metropolitan Area of Reggio Calabria.

2 Description of the Territory

The Metropolitan Area of Reggio Calabria is located in the south of Italy, in the centre of the Mediterranean, as shown in Fig. 1:

The territory is characterised by the presence of "fiumare", typical rivers of southern Italy with torrential regime. In them, the high slope of the riverbeds, the continuous erosion of the banks and the dragging action of the water favour the transport of solid material [26], while the alternation of dry periods and periods of flooding help to reactivate landslides inside the riverbeds. Most of the river basins are very small, so the response to precipitation is rapid. For the reasons outlined above, flooding is frequent especially due to the presence of short and intense rainfalls [27]. From a coastal point of view, the most violent storms are due to the exposure of the Scirocco and Libeccio winds in the south and the Mistral in the north [28]. The southern perturbations generate storm waves and intense rainfall affecting most of the Mediterranean. These phenomena are of great violence on the Ionic front, where the pluviometric regime is highly influenced by the humid currents coming from Africa, and the clash with the mountain ranges pushes these currents repeatedly on the sea.

Fig. 1. Geographic position of the metropolitan area of Reggio Calabria.

On the Tyrrhenian coast, winds from the north can generate small Mediterranean hurricanes, meteorological phenomena with an extraordinary nature. Precipitation is very frequent but not very intense, in contrast to that of the Ionian coast.

3 Methodology

The contemporaneity of flooding and storms was studied by comparing two databases. The first of these was the CNR-IRPI in Cosenza and is related to alluvial events occurring in the coastal areas of the Metropolitan Area of Reggio Calabria. Storms and flooding which posed a serious danger to the population and to the territory itself were selected. For each event it was possible to identify the date of the event, its effect on the territory and the characteristics of the rivers involved. The amount of rain data was not evaluated, only the occurrence of the event itself. The second database is related to the wave data processed by the ABRC MaCRO software, starting with the anemometric data provided by the Met Office, referring to a depth of – 200 m. From this data, time series were extrapolated for the period in which the alluvial events analysed occurred. For the study of wave motion, Boccotti's theory of equivalent triangular storms (MTE) was used. By obtaining the critical height as being 1.5 times the mean of the significant heights recorded for each time series, it was possible to specify the events during which this threshold was exceeded. Where a sea storm was identified, any concurrence with flooding was also verified.

In this phase the entity of the events were not evaluated, but only the combined events. Future studies will focus on the analysis of values of rain data, wave data and the return period of the same events.

4 Case Studies

The territory of Reggio Calabria has numerous flooding events of particularly exceptional nature. These phenomena have affected the hinterland and the coastal areas, causing devastation and irreversible damage to the territory and to its inhabitants. In certain climatic conditions such effects are amplified by the combined action of flooding and storm surges. This section describes two cases, one for each of the Ionian and Tyrrhenian coasts.

As far as the Ionian coast is concerned, the city of Monasterace was considered. Located on the border with the province of Catanzaro, it has been repeatedly hit by strong Scirocco storms that have affected and damaged the Kaulon Archaeological Park. As described above, the Ionian area is very well suited to an analysis of contemporary events. A flood took place on 5th October 1996 which involved the Fiumarella di Guardavalle torrent on the border between Monasterace and the town of Guardavalle. This river is characterized by a basin area of 28.58 km^2 and a main stream length of 18.26 km. The sea storm occurred from 4th to 6th October 1996. The highest H_s was recorded on October 5th 1996, and coincided with the alluvial event, and took on the value of H_{Smax} = 3.41 m. The critical wave height, evaluated with the expression obtained from Boccotti, was a h_{crit} = 0.93 m. From the trend of significant heights as a function of time, it wass observed that the height threshold was exceeded for more than 40 h, as shown in Fig. 2:

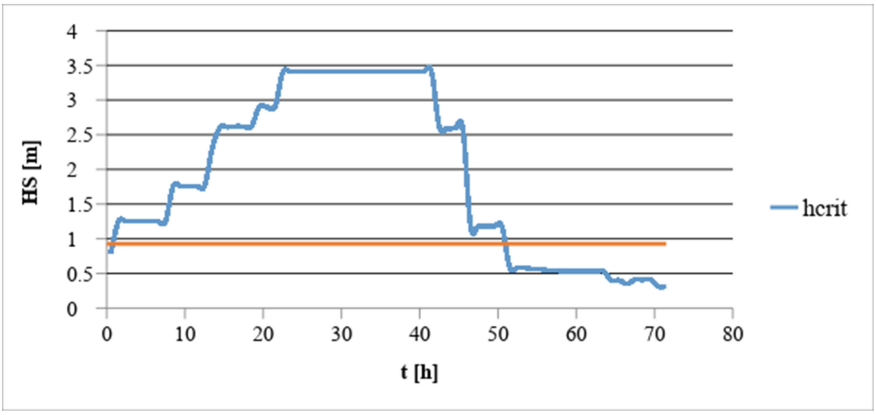

Fig. 2. Trend of the storm that hit the town of Monasterace from 4th to 6th October 1996.

On the Tyrrhenian coast the city studied was Scilla, located at the entrance to the Strait of Messina. It has just under 5,000 inhabitants and is one of Calabria's tourist

attractions. On 18th December 2003 heavy rains caused the flooding of the Vallone Oliveto. This river has a basin area of reduced extension, approximately equal to 1.5 km^2, and the length of the main stream is less than 1.5 km. From the coastal point of view a critical height equal to h_{crit} = 0.82 m was obtained.

The sea storm that struck Scilla from 16th to 18th December 2003, at the same time as flooding, had a maximum significant height of just over 2 m and a duration of about 48 h (Fig. 3).

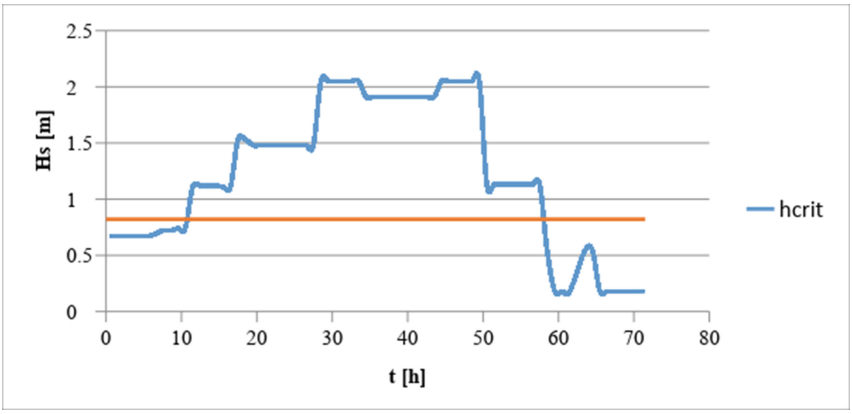

Fig. 3. Progress of the storm that hit the municipality of Scilla from December 16 to 18, 2003.

The cases analysed are typical examples of a condition common to the entire Metropolitan Area of Reggio Calabria.

5 Conclusion

The study conducted on the Metropolitan Area of Reggio Calabria is the basis for future research. From the analysis of flooding and storms, it is possible to conclude that simultaneous events are not a territorial feature but a phenomenon that is closely related to meteorological and orographic conditions which can be found in several other locations. Specifically, it was observed that in the presence of Scirocco winds, precipitation is often accompanied by intense storms. On the Ionian coast it was possible to identify a great coincidence of such events. Contrary to what is happening on the Ionian coasts, the Tyrrhenian areas are affected by precipitation and storms only in the presence of particular meteorological events caused by the Mistral wind. These results were achieved by a simple analysis of phenomena. The cases analysed can be considered as pilot studies for further exploration in the field of risk from coastal inundation and flooding. Starting from this point it will be possible to more concretely analyse the effects of such event in terms of return period, precipitation and wave height. By correlating the geomorphologic features of the river basins with the intensity of precipitation, it is also possible to identify those areas most at risk from flooding.

By correlating coastal morphology to wave run-ups, it is possible to detect coastal areas that are susceptible to flooding. Such information can be a useful tool for local and state administrations in order to improve the planning of mitigation actions for hydrological and coastal risks.

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