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Flash flood occurrences since the 17th century in steep drainage basins in southern Italy

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Abstract

The historical floods that have occurred since the seventeenth century were collected for a study area in southern Italy. Damages caused by floods, rainfall and the main anthropogenic modifications are discussed all together.

The aim was to assess whether the frequency of floods is changing and, if so, whether these changes can be attributed to either rainfall and/or anthropogenic modifications.

In 4% of cases, mainly occurred in past centuries, floods damaged people. Hydraulic works, roads and private buildings were the more frequently damaged elements (25%, 18% and 14% of the cases, respectively).

The annual variability of rainfall was discussed using an annual index. Short duration-high intensity rainfalls were characterized considering time series of annual maxima of 1, 3, 6, 12, and 24 hours and daily rainfall.

The rainfall shows a decreasing trend, in terms of both the annual maximum of short duration and the annual amount. The population has been progressively increasing since the sixteenth century, except during the years following the catastrophic 1908 earthquake. The rate of population growth has been very high since the second half of the twentieth century; the urbanized areas greatly increased, especially following the second half of the twentieth century. At the same time, the trend of damaging floods has been increasing, especially since the seventies.

The analysis indicates that, despite a rainfall trend favourable towards a reduction in flood occurrence, floods damage has not decreased. This seems to be mainly the effect of mismanagement of land use modifications.

Key words: floods; historical research; rainfall trend; land use; anthropogenic modifications; population number; urban planning; Calabria; Italy.

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1 INTRODUCTION

The present paper can be included in the wide sector of scientific literature that uses historical data to understand both the development and the long-term trends of different types of natural disasters, such as floods, landslides or earthquakes. Within this genre, a well-developed sector is *historical hydrology*, a research field that provides data concerning various hydrological processes, among which floods are included. Particularly with regards to floods, the events that occurred during the pre-instrumental period can be investigated using historical data (Brázdil and others 2006), thereby improving long-term data series and statistical analyses of the return period, frequency, seasonality and severity of floods (Agasse 2003; Bartl and others 2009; Bullon 2011). These types of results contribute to the assessment of the role of climatic variability in floods (Seidel and others 2009). Moreover, historical data allow for the investigation of extreme floods (Bartl and others 2009; Balasch and others 2010), which cannot be directly analyzed because their recurrence periods are usually longer than the human lifespan (Naulet and others 2001).

The study of floods from historical documentary sources has been widely pursued in recent years, allowing researchers to obtain detailed reconstructions of flood records in several countries and in different climatic conditions (Glaser and Stangl 2003; Llasat and others 2005; Naulet and others 2005; Lastoria and others 2006). Based on the descriptions available in historical data, past floods are often classified by magnitude (Barriendos Vallve and Martin Vide 1998; Benito and others 2004; Mudelsee and others 2004; Rohr 2006; Copien and others 2008; Bullon 2011). Qualitative and quantitative analyses of flood variability over the centuries can be conducted to understand the driving climatic causes (Glaser and others 2010), and specific floods can be studied to identify the typical flood-generating atmospheric conditions (Böhm and Wetzel 2006; Seidel and others 2009). Comparative analyses of the monthly distribution of past and present floods can be carried out to detect particular trends in the flood series (Benito and others 2004; Glaser and others 2010) and modifications in flood risk during past centuries (Mudelsee and others 2004). The location of areas damaged by past floods can be compared to the present configuration of urbanized areas in order to map flood risk zones (Barrera and others 2005; De Kraker 2006; Coeur and Lang 2008). The knowledge of past extreme events may improve the basis for flood risk mitigation measures—i.e., flood zoning and hydraulic structures, such as dikes and dams—and can be incorporated into flood risk assessment and management. The history of extreme floods management sheds light on the ways in which societies reacted to catastrophic events (Coeur and Lang 2008) and can be useful to assess the effectiveness of the protective measures that were taken, providing guidance for future interventions (Lastoria and others 2006).

Historical data can be particularly helpful in un-gauged basins, for which measured data are unavailable. This is the case of ephemeral streams, in which the frequent channel migration impedes the installation of automatic gauges.

Previous research on the occurrence of floods in wide un-gauged basins of Calabria and/or southern Italy showed that the anthropogenic activities and the unplanned urban growth may be key factors underlying the increasing frequency and severity of catastrophic events (Polemio 1998; Petrucci and Polemio, 2007; Polemio 2010).

In this paper, we used a historical research approach to obtain both the series of floods and the main steps of urbanization that occurred in a study area frequently affected by floods. Using an annual rainfall index and an annual maximum of short duration rainfall, the series of floods was together with rainfall, highlighting trends and taking into account the modifications of urbanized sectors that have occurred over the years to identify the salient features that affected the trend of flooding.

2 THE STUDY AREA: GENERAL FRAMEWORK

Calabria, the southernmost Italian peninsular region, is characterized by mountainous morphology; the areas suitable for agriculture and urban development comprise narrow river valleys and coastal plains, although these areas are frequently threatened by floods, which systematically cause damage to agricultural activities, embankments, roads, rural settlements and people.

The region is made up of a stack of allochthonous terrains (from Paleozoic to Jurassic), composed of crystalline rocks (mainly gneiss and granite) that were derived from both continental and oceanic crusts and stacked during the middle Miocene (Tortorici 1982) over the carbonate units of northern Calabria (Ogniben 1973). The rapid neo-tectonic uplifting shaped the form of the region, which looks like a platform bounded by steep flanks. Owing to this shape, the drainage network consists mainly of ephemeral streams, named *fiumara*, which are widely observed in southern Italy. In fact, 55% of the regional area is covered by *fiumara basins* (which extend less than 200 km^2); the remaining 45% is occupied by the Crati River (the main basin of the region, which accounts for 16%) and eight other river basins (making up the remaining 29%).

Rivers rise from the innermost and highest reliefs of the region, whereas fiumaras originate from the flanks of reliefs and reach the sea along steep, short and narrow beds that enlarge abruptly on coastal plains, becoming anastomosed and often wider than one kilometer. Despite appearing completely dry in the summer, major floods can flow through the entire section, redistributing the bed load and changing the geometry of the channels

(Viparelli 1972). Because of its high neo-tectonic uplift (1000 m) (Ibbeken and Schleyer 1991), Calabria is a powerful source of sediments; both erosion and landslides are sources of huge amounts of debris that are transported by floods. Because of channel migration through the beds, it is almost impossible to install gauges that work properly, so discharge data are unavailable. In such cases, the study of the effects of historical floods can be used to indirectly infer the magnitude of past floods (Petrucci and Polemio 2007; Petrucci and others 2009; Polemio 2010).

2.1 Physical characteristics and urban development of the study area

The Reggio Calabria municipality (236 km^2) was selected as the study area. It is located on the Tyrrhenian coast of Calabria, facing the Sicilian town of Messina, on the eponymous strait. It was an important *Magna Graecia* colony, and it is currently the largest town in Calabria.

The climate is Mediterranean, with dry summers and wet winters.

Eleven rain gauges located in the area (ranging from 4 to 1350 m *asl*) were selected in the drainage basins flowing through the municipal area or in the proximity of drainage divides that had collected rainfall data from 1915 to 2009 (95 years) (Fig. 1). Considering the hydrological year, which runs from September to August (in this paper, we use the solar September year to name the corresponding hydrological year), the average annual rainfall is 925 mm, and the average number of rainfall days is 92. The rainiest months are November, December and January, whereas the driest is July.

The municipal area lies on an alluvial plain deposited by eleven fiumaras (Table 1, Fig. 1), which arise from the borders of the Palaeozoic metamorphic relief named Aspromonte (1955 m asl) and reach sea level along short, steep beds.

The current structure of the town has been established through a series of modifications, mainly related to catastrophic earthquakes that strongly affected the area. The main phases of town development have been summarized in Fig. 2 (Afan de Rivera 1832; Spanò Bolani 1857; De Lorenzo 1870; De Nava 1894; Pirrello 1954; Viparelli and Maione 1959; Currò and Restifo 1991), in which all available data, even if discontinuous, about the number of inhabitants have been reported (Galanti 1792; Giustiniani 1797; Marzolla 1851; Pecora 1963; Gambi 1978; Cingari 1988; ISTAT, *various years*).

The watercourse modifications varied through the centuries. In the sixteenth century, the main modification was the diversion of fiumara Calopinace (Fig. 3). In the seventeenth century, after an earthquake in 1783, several watercourses were diverted or covered, according to a new urban town plan. The nineteenth century saw the construction of embankments, causing the elevation of the fiumara beds, which increased until the mid-twentieth century (Fig. 4). New settlements were set in flood-prone areas, encouraged by the false sense of safety created by the presence of embankments and levees.

The urbanized area was equal to 0.66 km^2 in 1844, and it increased to 0.8, 4.6, 6.9 and 11.9 times the 1844 area in 1884, 1911, 1954, and 1978, respectively (Fig. 5). The maximum rate of increase was observed after 1954 (0.49 times the 1844 area each year), and the second fastest period of growth was between 1884 and 1911 (0.17 times the 1844 area each year).

At the beginning of the twentieth century (Dec. 28 1908), a tremendous earthquake (magnitude 7.5) killed approximately 15,000 people and almost completely destroyed the town, thus requiring a long and difficult reconstruction phase. This catastrophic event represents the only period during which the population did not increase. In the sixties and seventies of the twentieth century, the increasing population caused modifications in land use and the expansion of urban areas (Fig. 5).

The construction of unauthorized buildings, which were built without realizing the destructive power of the floods, worsened the risk conditions. Moreover, in this period a countertrend of fiumara bed geometry started: until the mid-twentieth century, the amount of debris left by the floods was so huge that the fiumara beds lay at a level higher than the surrounding plain, but in the seventies and eighties, owing to both the works realized on the mountains, which trapped the debris, and the uncontrolled extraction of sand from watercourses, the fiumara beds started to become embedded.

New construction rules introduced at the beginning of twenty-first century take into consideration these environmental features, although some flood risk situations, inherited from the past, still remain.

3 THE HISTORICAL SERIES OF FLOODS

Data on the floods that caused significant damage in the past two centuries in Calabria have been collected since 2000 by means of historical research in the archives of regional agencies, such as the Regional Department of Public Works (Petrucci and Versace 2005, 2007; Petrucci and others 2009) and by means of a systematic analysis of daily newspapers.

Based on the available data, Reggio Calabria has been selected as a study area because of its long series of floods. Data have been organized in a relational geo-database in which each flood represents a single record linked to one or more damaged elements. Furthermore, using place names reported in historical data, the locations of the areas that were damaged by floods have been located on maps in a GIS environment.

The data on the series of damaging floods in the Reggio Calabria municipality consist of 150 records: the oldest data gathered concern floods that occurred in the seventeenth century (Fig. 6). The highest numbers of occurrences were in the months of October (18 events), December (18 events) and November (12 events); however, it must be taken into account that for 50 very old floods, the month of occurrence was not available. These figures are similar to the trend of average monthly rainfall measured by the selected rain gauges (Fig. 6b). In Fig. 7, the places damaged by floods have been plotted on five maps that represent the past four centuries and the first ten years of the twenty-first century. A comparison of these maps to the expansion of urbanized sectors (Fig. 5) suggests that flood damage followed the same evolution of urbanized sectors: they both stretched towards the areas located north and south of the old city.

For 129 of 150 cases, the damaged elements were clearly stated; the remaining records reported flood occurrences without further details. Damageable elements were schematized into eleven types, and the numbers of cases in which they were damaged are reported in Table 2. The most frequently damaged elements throughout the time under study were hydraulic works (25% of cases); levees were rebuilt, reinforced and raised several times after floods. Even the roads have been frequently damaged: in the worst cases, many villages were unreachable by car or completely inaccessible—even by foot—for days (Fig. 8).

The most frequently affected basins were Calopinace, S. Agata, Gallico and Valanidi (36, 23, 19 and 17 cases, respectively).

Floods causing harm to people affected only six of the eleven basins (Nos. 2, 5, 6, 7, 8 and 9). These cases, which only represent 4% of the total, occurred in previous centuries, with one exception (1743, 1793, 1795, 1872, 1880, and 2003).

In the descriptions of the oldest events, the number of victims is sometimes indefinite; some documents refer to "countless victims", while others only mention the occurrence of victims, without providing an estimate of the number of people involved. Moreover, even for the same flood, a different number of victims has been reported by different authors, especially if they were not coeval. This is the case of 1793 flood, described by a non-coeval author (Grimaldi 1863) as follows:

> *September 27, during the night, a violent thunderstorm and sirocco hit the town, causing floods. Calopinace and S. Agata completely destroyed houses, roads, farms and vineyards of the small Sbarre neighborhood, and killed several women and children. Initially, the flood invaded the shops; then the water quickly reached the first floor of the houses, and furiously swept people and goods. Fiumara S. Agata opened a new path, and water spread out on a wide area, sweeping everything that was on the route. The economic damage was about two millions of ducati* (the currency of that time in southern Italy), *and it was a miracle if the number of victims only reached 400!*

Another non-coeval author (De Lorenzo 1870), quoting a coeval chronicle (Zappia-Catizzone *1718?*), reported that:

> *103 people died, 18 in Sbarre, and 85 in the other neighborhoods. The event gave such a scare to the town that in the same year, new levees were built along Calopinace, and in honor of two administrators (…) who headed the works, two epigraphs were placed near Sbarre.*

Notes about the geomorphologic effects caused by the modifications of Calopinace have also been found in some information sources, such as De Lorenzo (1870):

> *Up to 1547, Calopinace flowed innocuous near the town, in a low bed near S. Filippo gate* (Fig. 3)*. In that year, the watercourse was deviated in order to build a new castle (...). Since then, the bed started to accumulate debris transported by the floods; the level of the bed gradually rose and people elevated levees accordingly. Currently* (in 1870)*, during floods, furious waters flow very fast like the overpass of an aqueduct; somewhere some blocks transported by water break the levees and water flow tries to find again its ancient path.*

The 1846 flood destroyed the works for the construction of S. Filippo Bridge and carried so much debris that the basement of the adjacent S. Filippo Square was so raised that first floors of the houses were converted into shops (as, commonly, shops were at the ground floor).

The difference in the availability of the data through the centuries hinders a clear identification of a trend in flood damage. In fact, owing to the low information diffusion of the oldest epochs, data availability characterizing both XVII and XVIII centuries as well as the first half of twentieth century is low. For this reason, supplementary historical analyses were conducted in order to fill the largest temporal gaps. At the same time, a careful inspection of the data pertaining to the most recent periods (mid-twentieth to twenty-first century) was carried out, aiming to eliminate potential redundancies and avoid an overestimation of flood. In recent years, the greater data availability reflects the damage occurrence, but it is also influenced by the growing number of information sources that have paid an increasing amount of attention to environmental problems. The only trend that can be detected is the increasing rate of the number of floods in recent times. Whereas in the last 100 years there were 95 floods (almost one event per year), in the last 10 years we recorded 12 events, which is more than one event per year.

4 COMPARATIVE ANALYSIS OF RAINFALL AND FLOOD SERIES

Monthly and annual rainfall data help characterize the trend in the period for which data are available (from 1915 to 2009). Eleven gauges and time series (which include some gaps) were considered for this purpose (Fig. 1).

The simplest way to quantify the trend slope is to use a (straight) linear regression analysis. Linear regression provides an estimation of the trend slope (the slope, or angular coefficient *a*, can be calculated by least square linear fitting) and confidence interval, and it quantifies the goodness of fit, even if it is greatly affected by both outliers and cyclic data. To solve these uncertainties, the statistical reliability of the detected trends should be tested; an affordable choice is to use the non-parametric Mann–Kendall test (Mann 1945; Kendall 1975; Polemio and Casarano 2008; Wahlin and Grimwall 2010). If the quantitative assessment of the slope trend is particularly relevant, the Sen Method should be used (Sen 1968). In this paper, the statistical significance of trend and the trend slope were calculated using Mann–Kendall test, considering $p<0.05$ significant, and the Sen Method, respectively.

To assess the impact of the climatic trend, especially in terms of rainfall, an *annual rain index* (Ir_y) was calculated for each year (y) and applied to the whole area (Polemio and Sdao 1998; Petrucci and Polemio 2003):

$$Ir_y(\%) = \frac{\sum_i AP_{i,y}}{\sum_i MAP_i}\% \quad , \qquad (1)$$

where $AP_{i,y}$ is the annual precipitation at gauge i, MAP_i is the mean annual precipitation at gauge i, and i is the number of available gauges in the year y. The annual rain index Ir_y (1) was calculated for the whole area (Fig. 9). The calculation of this index, using all the gauges available in each year, does not require filling gaps (from 3 to 8 gauges were available in each year). *Ir* was in the range 44 (1919) to 148 (1953).

Starting from 1915, the number of floods causing damage (*F*) was 58. There were 38 years with at least 1 damaging flood, and 15 years with at least 2 damaging floods. The years characterized by 2 or more damaging floods occurred after 1972. *F* and *Ir* show a low but positive correlation (correlation coefficient equal to 0.15). Damaging floods are concentrated in sub-periods (1926-1934, 1948-1953, 1972-1975, 1983-1989, 2002-2003) during which *Ir* was generally greater than 100.

To highlight the occurrence of floods in shorter periods (decades), removing the annual fluctuations and simplifying the comparison with climate variability, F_{10} was calculated as an annual 10-year cumulative value of F ($F_{10,y}$ as the total number of damaging floods of the previous 10 years, starting from the year *y*, Fig. 9). F_{10} ranged between 0 and 22 from 1915 to 2009 (a mean of approximately 6 floods for a 10-year value, or 0.6 floods per year).

Higher values of F_{10} were observed from 1976 to 1995; from 1973 up to the present (except for years 1999-2001), F_{10} was greater than the mean value.

The trends of *Ir*, *F*, and F_{10} are statistically significant and show a decrease in the amount of rainfall and an increase in the number of damaging floods.

As observed for the whole of southern Italy (Polemio and Casarano 2008) and the whole Calabria region (Polemio and Petrucci 2012), a drop in the rainfall rate occurred over the past 94 years; the decrease is approximately 10% of the current mean value. We assessed in detail the Calabria region in the period from 1880 to 2007 and found a decreasing trend of precipitation and wet days, an almost constant value of precipitation intensity (as a monthly ratio of rainfall and wet days) and an increasing trend in temperature (Polemio and Petrucci 2012).

The trend of damaging floods is increasing; this trend is coherent with the trend observed at a regional scale (Polemio and Petrucci 2012). The gradient of F_{10} is positive, and this is equivalent to an increase of 12 floods per century. This increase is reasonably over-assessed because of the probable lack of data regarding damaging floods that occurred during the first part of the previous century, but in any case, it is not negligible.

The statistical linear correlation between *Ir* and *F* or F_{10} is almost low and insignificant. However, the observed decrease in the rainfall trend could not adequately explain the recent increase in of the number of damaging floods.

The *F* increasing trend could be due to a local increase of rainfall intensity of short duration, which would be particularly significant because of the small size of the drainage basins and their short concentration times (in the range between 1 and 24 hours).

Time series data of the annual maximum of short duration rainfall were collected to deepen this hypothesis. Data on the rainfall annual maximum of 1, 3, 6, 12, and 24 hours are available from 1928 to 2004 for one gauge, R5, located in the centre of the Reggio Calabria town (Fig. 1). All the trends were negative, except the 1-hour annual maximum, but none of the trends were significant ($P<0.05$; the 24-hour annual maximum test could be considered verified at a 0.1 significant level).. The analysis was reiterated for the period of 1960-2004, for which data from the R7 gauge were also available. We found that the trends were all negative but not statistically significant.

To enlarge the analysis over the time and increase the gauge density, the annual maximum of daily rainfall, available for 7 gauges (R3, R4, R5, R7, R9, R10, and R11) from 1928-2004 were considered. Statistically significant negative trends were observed in 3 gauges (R4, R7, and R11). The analysis was reiterated for the period 1960-2004 with the same gauges, but none of the trends were significant (the sign of the slope was unchanged).

These results agree with previously reported results. The regional discussions of rainfall, wet days and rainfall intensity trends, in which a wide range of durations was considered, showed that climate trend does not seem to justify an increasing trend of damaging floods and landslides (Polemio and Petrucci 2010 and 2012). Brunetti et al. (2011) showed that the annual trend of high-daily rainfall classes (percentiles 90, 95, and 99%) was statistically significant and negative or decreasing in the period 1923-2006.

It can be affirmed that rainfall, taking into account a wide range of durations, shows negative or non-positive trends. This indicates that rainfall variability cannot be considered a determining factor in the increasing trend of floods. The recent increase of floods, starting in 1973, is probably due to the significant population increase, particularly great since the fifties (Fig. 2) and to the consequent enlargement of the urbanized area, as highlighted in the1978 map (Fig. 5).

5 CONCLUSIONS

The historical series of floods, rainfall of different durations, number of inhabitants and main phases of urban enlargement were accurately collected for a town located in southern Italy that is frequently affected by floods. The modifications of these series of data and their trends were discussed and compared.

The rainfall shows a clear decreasing trend in terms of total annual amount; in the case of time series of annual maxima of short duration (daily or sub-daily) 43% show a decreasing trend while the rest does not show significant trends.

The population of the town has been progressively increasing since the sixteenth century, except during the years following a catastrophic earthquake that occurred at the beginning of the twentieth century and almost destroyed the entire town. The rate of population increase has been very high since the second half of the twentieth century. The land use change that occurred throughout the centuries has to be taken into account: urbanized areas greatly increased, especially since the second half of the twentieth century.

At the same time, an increasing trend of damaging floods was observed, especially during the seventies.

The analysis indicates that despite the finding that the rainfall trend was favourable towards a reduction in flood occurrence, flood damage has not decreased. This seems to be the result of two combined factors. The first, less relevant, is a slight underestimation of the number of flood occurrences in the oldest part of the series, owing to a lack of information sources characterizing the oldest periods. The second factor could be defined as a "lowering of the rainfall threshold able to transform a *flood* into a *damaging flood*" caused by the wider presence of vulnerable elements on the floodplains. In fact, in the most recent decades, an increase in population and the unplanned land use modifications to satisfy the new population needs have been occurring. The combined effect is the increasing density of vulnerable elements (e.g., urban settlements and road networks) in the analyzed basins.

The progressive urban expansion that occurred regardless of both the characteristics of the drainage networks and knowledge of extreme floods is the main factor causing the increase in risk from damaging floods in the study area.

Further efforts will be realized to improve the understanding of the role of antecedent meteorological conditions on one hand and to deepen the relationship between urban enlargement and levels of damage on the other.

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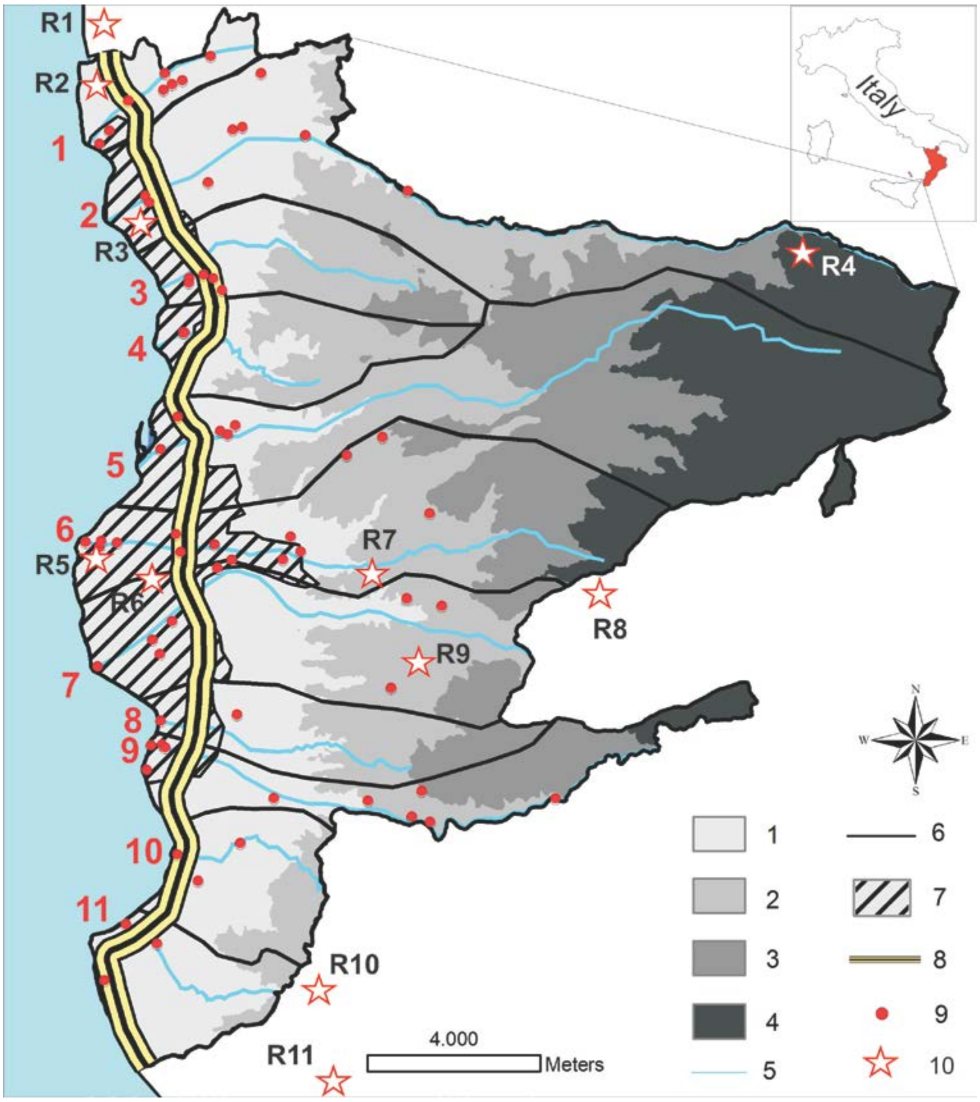

Fig. 1 Location map of the study area. Top right narrow map: Italy and Calabria region (in red). Bottom left wide map: Study area (Reggio Calabria Municipality); altitude ranges (1) 0–260, (2) 260–610, (3) 610–1350, and (4) 1030–1779 m asl; (5) rivers, named as in Table 1; (6) river basins; (7) Reggio Calabria urbanized area; (8) national road; (9) flood damage (observed from 1600 to present). (10) Rain gauge.

Reference to be cited:

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	Year	Description
XVI	1500	To stand up to maritime attacks, the city used to be surrounded by a continuous wall (about 2 km in length).
XVI	1547	Fiumara Calopinace was diverted to build a fort In the following years, during major floods, it will flow along its old path, damaging Saint Filippo neighbourhood (Fig. 3).
XVII	1650	Several neighbourhoods and rural settlements rose outside the city wall, close to the doors.
XVIII	1783	A strong earthquake destroyed the city which was abandoned, while people built shelters outside the wall. The city wall was progressively disrupted to build the Main Street on an area flattened by diverting and embanking fiumaras.
XIX	1810	Landowners built embankments. The river debris accumulation caused the elevation of beds, and required embankments elevation.
XIX	1829	The government approved the Embankments Regulation, in order to cope with floods, reclamation and irrigation. A landowner consortium had to define the embankments construction plan using own resources and under the governmental control
XIX	1853	Embankments were realized to complete both the railways and the maritime port. The expenses of embankments must be shared between landowners, and government.
XX	1908	A dramatic earthquake and tsunami caused about 12,000 victims in the town. A new and long reconstruction phases started.
XX	1911	The top portions of fiumara beds were closed to realise roads connecting the East and West portions of the town.
XX	1950	The beds bottom continued to rise and the embankments were constantly raised up.
XX	1953	To solve flood and malaric problems, the national government applied a basin-scale approach. National funds were used to realize reforestation in mountainous areas affected by erosion and landslides and check-dams. These actions caused the bottom beds erosion, which contributed to the seashore erosion.
XX	1960	The uncontrolled sand extraction from fiumare accentuated the embedding of their beds, especially close to the mouth.
XX	1970 1980	The urban development was chaotic: numerous unauthorized houses were realized. The highly fragmented agricultural estates (mainly citrus cultivation) became suburban areas and many buildings were built in flood prone areas.
XX	1990	The unauthorised building finished and redevelopment plans were undertaken to improve the structure of the town.
XXI	2001	According to the recent regional Hydrogeological Plan, several variations to the urban development plan have been undertaken, even forbidding the new building construction in flood prone areas. Nevertheless, currently, the dualism between the well organised centre of the town and peripheral outskirts still remains.

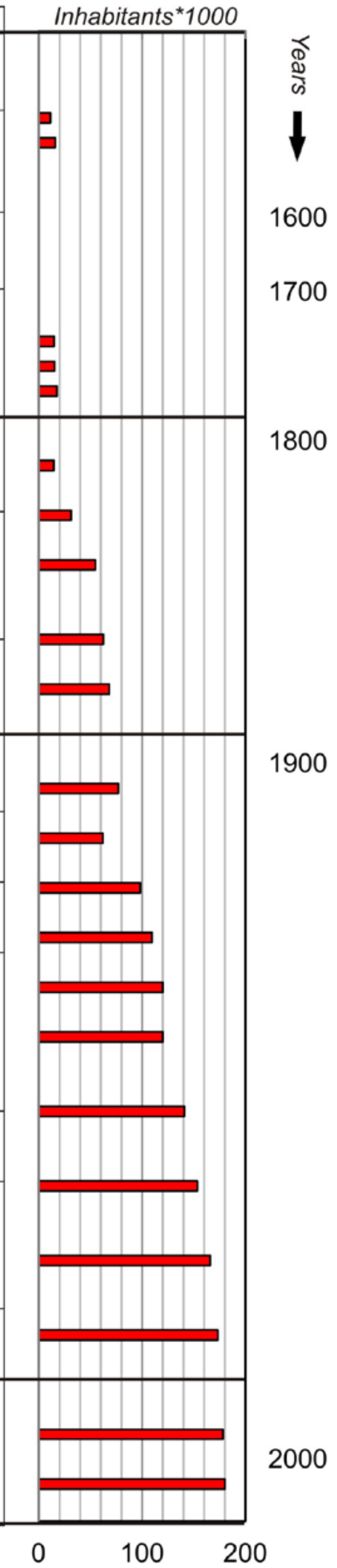

Fig. 2 Main phases of development in Reggio Calabria (table) and the trend of population (histogram on the right) throughout the centuries.

Reference to be cited:
Petrucci, O., Pasqua, A. A., and Polemio, M.: Flash flood occurrences since the 17th century in steep drainage basins in southern italy, Environ. Manage., 50, 807-818, DOI: 10.1007/s00267-012-9935-1, 2012.

Fig. 3 A Reggio Calabria sketch dating from the XVII century from G.B. Pacichelli. Letters indicate the city gates (A: Mesa gate; B: Dogana gate; C: Saint Filippo gate; D: Amalfitana gate; E: Marina gate), Fiumara Calopinace (F) (located on the map of Fig. 5) and the Castelnuovo Fort (G).

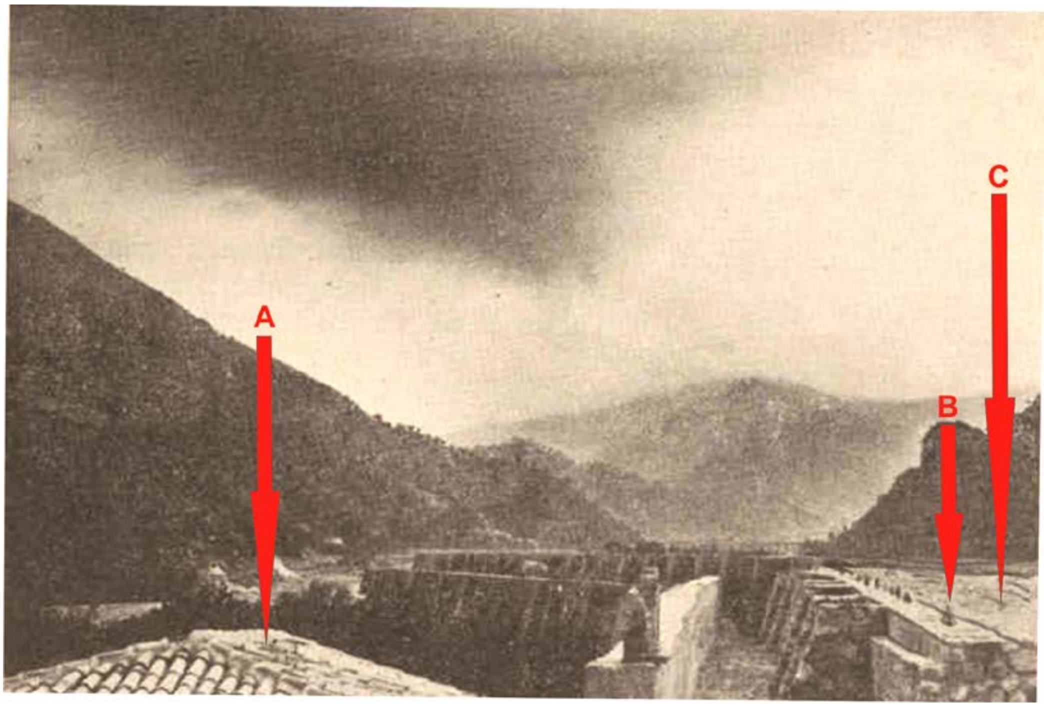

Fig. 4 Fiumara Valanidi before 1955 (Ippolito, 1955): the river bed (arrow labelled with C) was higher than the adjacent houses (arrow A indicates the roof of a house adjacent to the fiumara). To allow the forthcoming rise in the embankments, along the levees, sharp pebbles were usually left (arrow B).

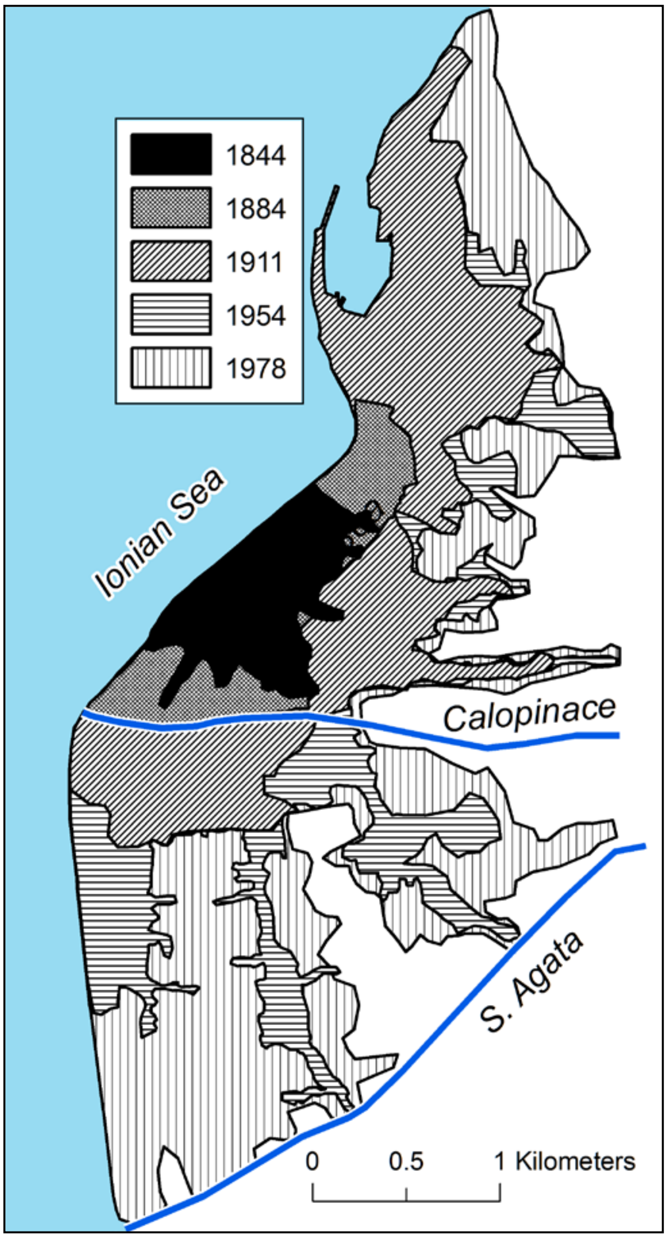

Fig. 5 The evolution of Reggio Calabria urbanized sectors since 1844 and Calopinace and S. Agata river courses. Until the beginning of twentieth century, Calopinace used to be the southern limit of the town, but since 1978 the urbanized sectors have stretched up another fiumara (S. Agata).

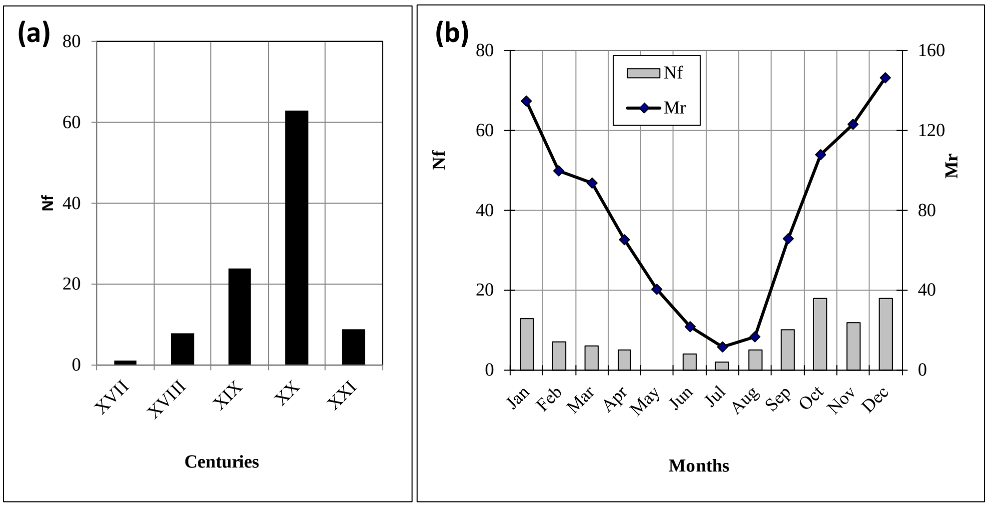

Fig. 6 (a) Number of damaging floods (Nf) recorded in the past centuries in Reggio Calabria municipality. (b) Regime of number of damaging floods (Nf) and gauge average rainfall (Mr).

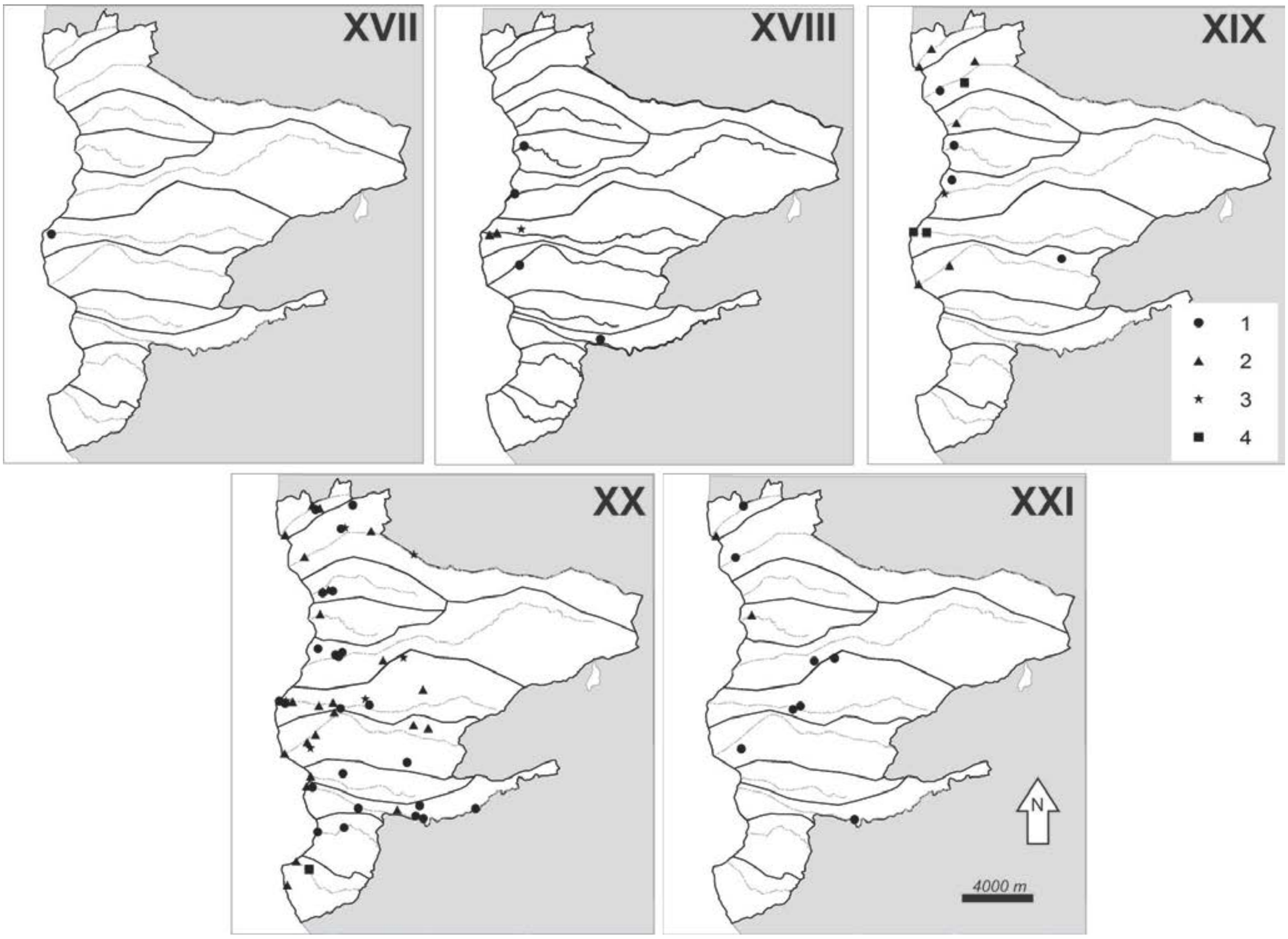

Fig. 7 Century maps of flood-damaged areas (the century is indicated in the map, top right). The symbols indicate the number of cases

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in which a pinpointed site has been affected (1= 1 case; 2 = 2 cases; 3 = 3 cases, 4 = 4 cases).

Reference to be cited:
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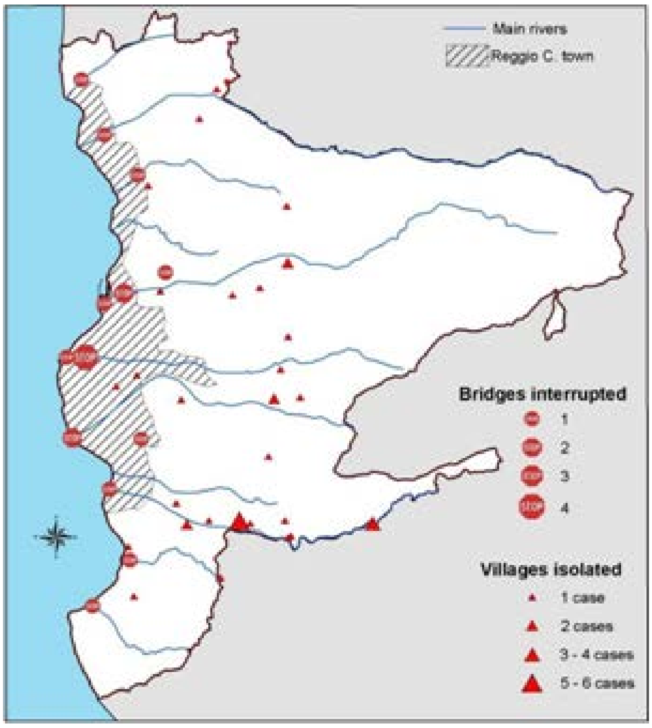

Fig. 8 Map of the occurrence of interrupted bridges and isolated villages throughout the study period.

Reference to be cited:

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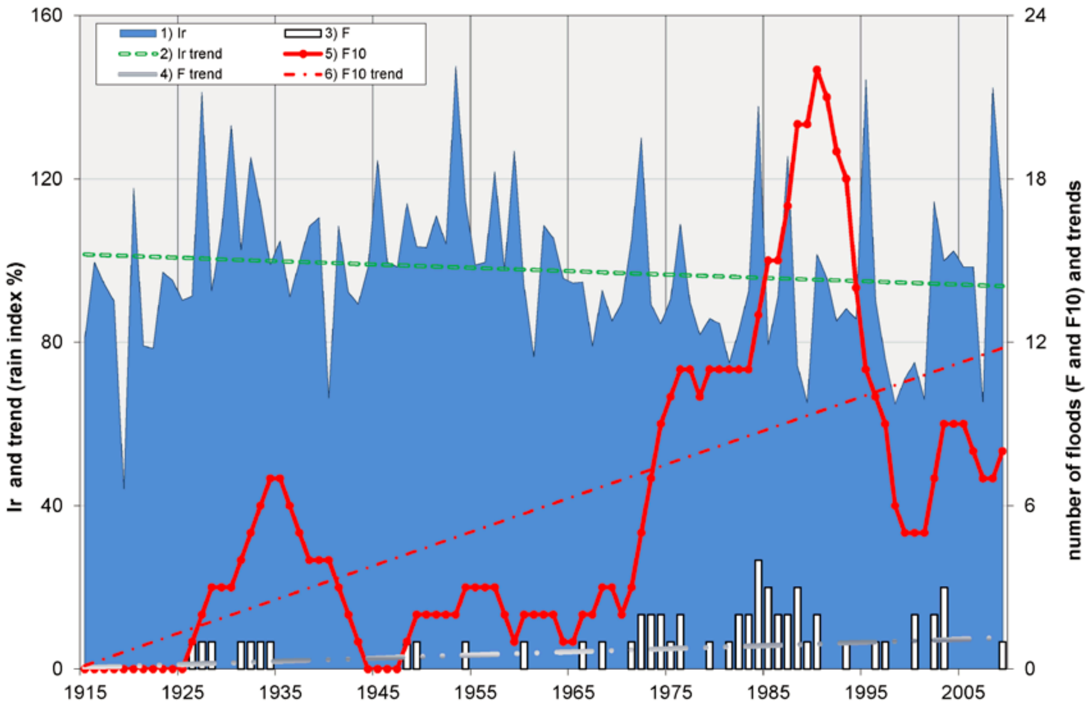

Fig. 9 Annual rainfall index (*Ir*), annual number of damaging floods (*F*), and cumulative 10-year damaging floods time series and straight line trends.

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Table 1 Summary of Reggio Calabria river basins. N, number (from north to south); *A*, area; *L*, length; Qmax, maximum elevation above sea level; S, slope of bed.

N	Name	*A*(km^2)	*L*(km)	*Qmax*(m)	*S*(%)
1	Catona	6	4.6	101	2.2
2	Gallico	38	21.2	1707	8.1
3	Scaccioti	14	6.7	601	8.9
4	Torbido	13	4.8	443	9.2
5	Annunziata	61	18.2	1349	7.4
6	Calopinace	26	12.8	1077	8.3
7	S. Agata	28	11.5	412	3.6
8	Armo	13	6.4	564	8.7
9	Valanidi	15	13.7	1024	7.4
10	Macellari	11	4.5	401	8.9
11	Lume	10	4.5	201	4.4

Table 2 Number of cases in which the types of elements listed were damaged by floods, in total and as a percentage of the total.

	Tot.	%
People	9	4
Private buildings	35	14
Public buildings and structures	12	5
Roads	45	18
Road bridges	17	7
Railways	9	4
Railway bridges	4	2
Life lines	11	4
Hydraulic works	64	25
Productive activities	8	3
Agriculture	41	16