Catastrophic Geomophological Events and the role of rainfalls in South-Eastern Calabria (Southern Italy)

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ABSTRACT

South-Eastern Calabria is among the areas in Southern Italy which are hardest hit by heavy and relentless rainfalls able to induce geomorphological phenomena sometimes resulting in widespread damage. The *Catastrophic Geomorphological Events* which have occurred over a time period of 67 years across an area of about 700 Km^2 are characterised with a view to correlating major phenomena, such as landslides and flooding, with heavy rains and anthropic expansion. Igneous, metamorphic and sedimentary rocks outcrop and slope stability phenomena affecting the area vary in density and frequency accordingly. Induced phenomena are divided in landslides, floods and "secondary floods". The analysis of historical precipitation series highlighted the space and time distribution of rainfalls, determining their exceptionality as return period of daily cumulative rainfall of different duration, with respect to the various disastrous phenomena triggered. The aim of this study is to predict different scenarios characterised by various severity levels related to rainfall return periods.

1 INTRODUCTION

The study of *Catastrophic Geomorphological Events* (*CGEs*) - precipitation leading to fluvial and geomorphological disasters resulting also in the loss of life and damage to property - has been prompted by the increased demand for improved methodologies for cope with such extreme events.

If the complex of flooding and stability problems are considered as “failures”, the spatial and temporal characterisation of the failures which have occurred and of the rainfalls which are liable to trigger them may contribute to the definition and the validation of some basic criteria to address the flood-related and stability hazard evaluation and implement civil defence plans.

The analysis of historical rainfall data sets helps identify the types of precipitation with a potential for CGEs and correlate these events with the various types of resulting failures. The results of detailed surveys can be extended to broader areas exhibiting homogeneous hydrological and geo-morphological features. It can be done through the definition of hydrological hazard thresholds which characterise the unusually heavy precipitation occurring at the time of a CGE

2 METHODOLOGY

2.1 Characterisation of the study site

The geological and geo-morphological characterisation of the study site is based on the analysis of the existing bibliography and geological mapping. The air photo interpretation and the subsequent on-site surveys provide better insights into the area and help assess the proneness to failing of the various sectors.

A parallel investigation is focused on land use, settlements and communication networks servicing the residential districts and the industrial areas.

The characterisation of both the geological setting and the development of human land utilisation, allows to correlate some types of potential disasters and weigh the damage related to their occurrence. This is a valuable tool to interpret historical data concerning previous events, mostly for poorly detailed descriptions.

2.2 Analysis of failure-related historical data

A database covering the failures which have occurred in the study area over a protracted time interval (> 50 years) is set up by drawing heavily on historical, technical, scientific and journalistic records. Contemporary sources are cross-checked to gauge the reliability of data and fill time gaps in the data series.

Difficulties in the geo-reference of some reports or in the precise localisation of widespread failure phenomena that are not confined to a single site are overcome by subdividing the area in irregular cells. These cells are obtained intersecting the perimeter of the watershed with the boundaries of the communal territory. The spatial distribution of failures is analysed by processing maps on the cell-scale.

The failures recorded during each CGE are subdivided by type and the temporal distribution is evaluated with respect to the seasons and the period under study.

2.3 Analysis of rainfall data sets

Rainfall data recorded in the area at the rain gauges during the selected time interval is logged in a database and processed for further hydrological and statistical investigations.

Useful indications on the response of the sample sites to periods of high-intensity and long-duration precipitation may be derived through empirical hydrological and statistical models which quantify, in terms of return period, the above-average rainy period associated with the catastrophic event. The results allow to establish the statistical cyclicity at which the area is subjected to hydrological conditions similar to those under study.

The suggested hydrological and statistical model quantifies the above-how heavy are rainfalls which can be associated with the catastrophic event (Polemio, 1997). In particular, it analyses the peak values assumed by the selected hydrological variable. The study of the annual peak of cumulative rainfall is based on the probability distribution function, the so called GEV (Generalised Extreme Value), which is defined by three parameters: scale, location and shape (Jenkinson, 1955). The GEV parameters are defined by the method of the Probability-Weighed Moments, known as PWM (Hosking *et al*, 1985). At each rain gauge, the daily cumulative rainfall variables Pc_{nj} are taken into account, where n corresponds to 1, 5, 10, 20, 30, 60, 90, 120 and 180 consecutive days, rainy or not, and j is the number of measurement days during the observation period. The peak values $PCMAX_{n,y}$ are derived per each single year y from the daily data series.

By changing *n* and the station the parameters of the GEV function are defined for each series of peak daily rainfall.

2.4 Characterisation of CGEs

The failures recorded during each CGE are subdivided into 4 types: *landslides*, *falls*, *floods* and *secondary floods*, i.e. unusual and rapid accumulation or pounding of surface waters characterized by very low or null velocity flow.

The spatial distribution of failures in the cells (see § 2.2) is analysed from the return periods of the cumulative rainfall which is significant for the single CGE and the single cell.

The analysis identifies some major types of events which exhibit the following distinguishing features:

- types of failures which are more widely triggered;
- sectors which are more intensely and/or frequently hit;
- return periods of the triggering precipitation of various duration;
- critical duration of the triggering rainfall;
- magnitude of damage.

3 CASE STUDY

3.1 Geological and hydrological features and human agency in the study area

The study site is located in the province of Reggio Calabria (Italy), along the southern Ionian border of the Calabria region. It covers a surface of about 700 km which stretches between the mouth of the Torbido di Gioiosa River and the Bonamico River, at an elevation ranging between 1,900 m *a.s.l.* and the sea level (Fig. 1). The area encloses a sequence of NE-SW oriented packs of varying lithology.

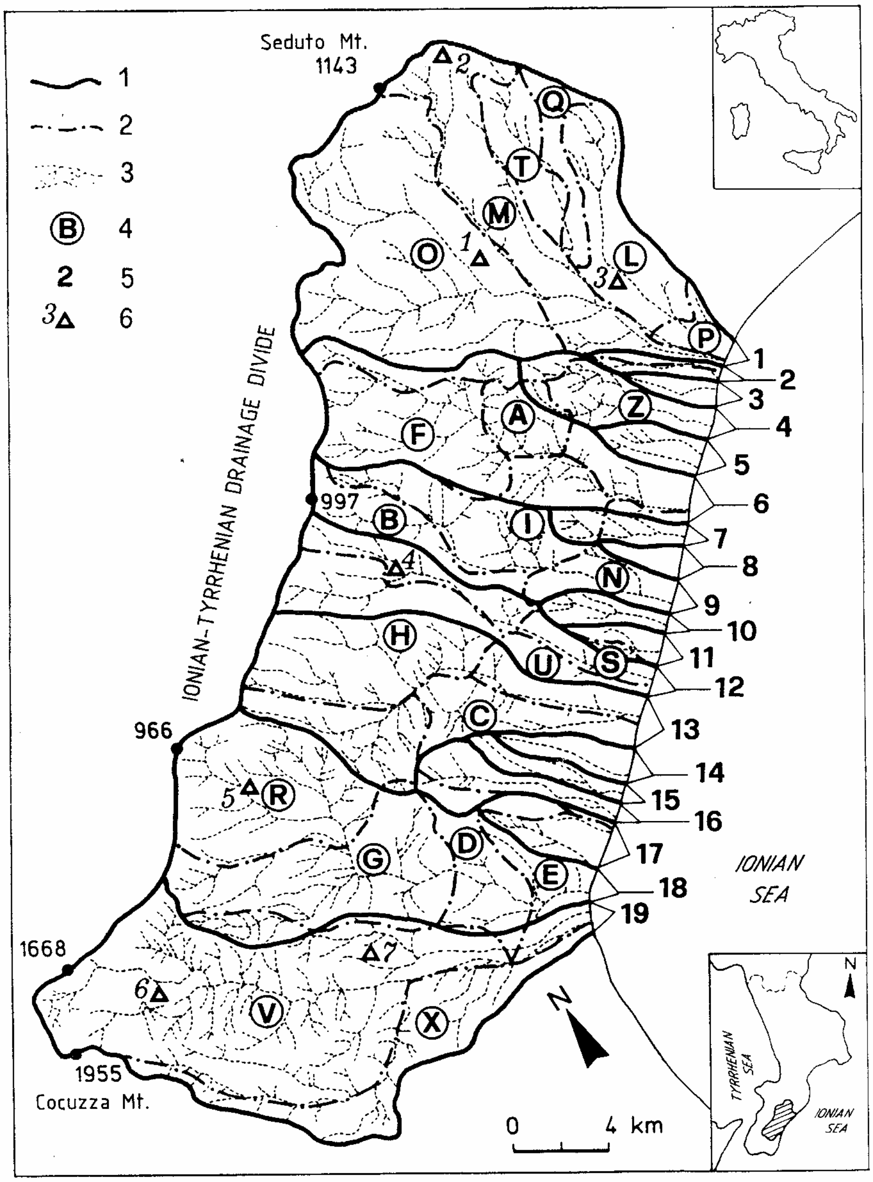

Figure 1: Drainage basins, rain gauges and cells. 1) Drainage boundary, 2) town boundary, 3) drainage pattern, 4) town code, 5) drainage basin code, 6) rain gauge.

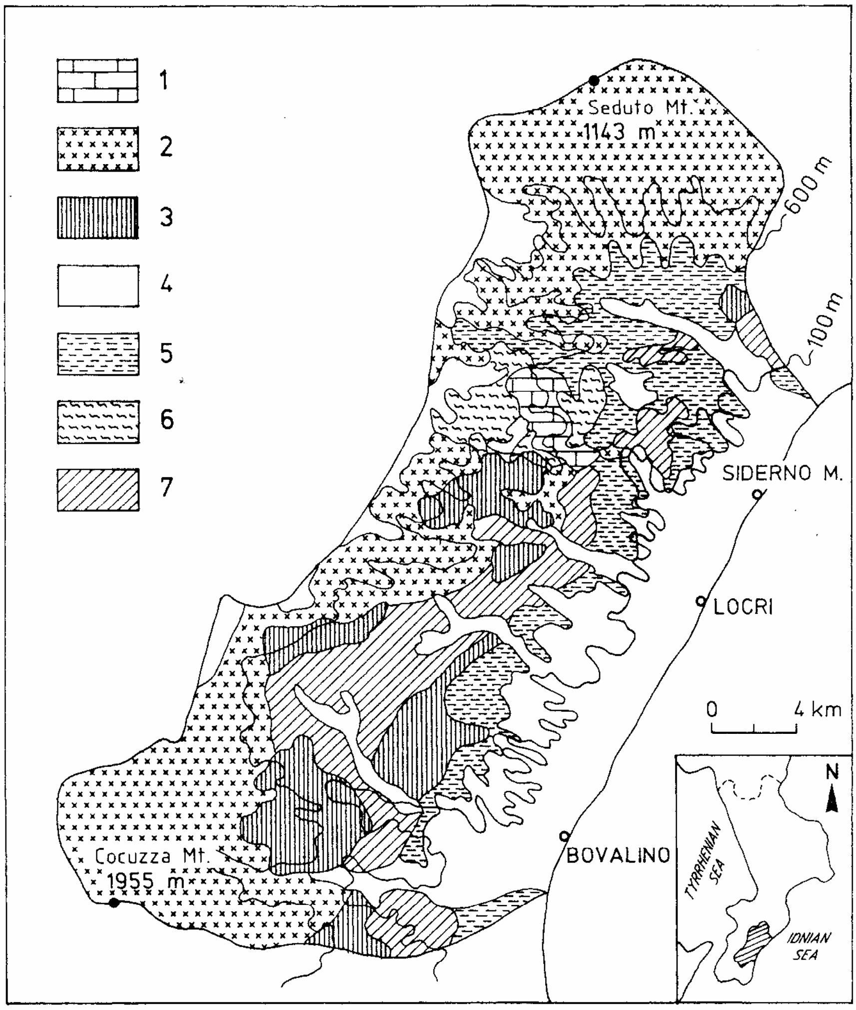

Figure 2: Geological schematic map (from: Sorriso-Valvo & Tansi, 1995, modif.). 1) Limestone and dolomite, 2) metamorphic and acid igneous rocks, 3) cohesive or slightly diagenic sedimentary soils, 4) not cohesive sedimentary soils, 5) pelites with evaporitic layers, 6) low-grade metamorphic rocks, 7) flysch.

In the mountain sectors, metamorphic and locally poorly tectonised acid intrusive rocks outcrop. In the hills, detritic sedimentary rocks are prevalent, mostly sandstone but also Jurassic limestone. In the transition zones towards the plain, flysh outcrops, followed by a sequence of pelitic sedimentary rocks interbedded with evaporite deposits.

Down to the sea, loose sedimentary rocks prevail, consisting of continental and marine Plio-Quaternary deposits. The adopted lithological classification is by Sorriso-Valvo & Tansi (1995). Formations are grouped into lithological types based on the mechanical characteristics of the investigated soils (Fig. 2).

Morphologically speaking, the area is a platform which has a round-shaped summit and is bounded by steep flanks. A coastal plain stretches below where torrential watercourses flow (the so-called *fiumare*). The relief is characterised by a marked differential neotectonic uplifting.

The population decreases inland whereas peak values, exceeding 400 residents/sqkm, are reported along the coastal areas. Communications are ensured by the Reggio Calabria - Metaponto railway line and the state road N.106 that both run parallel to the coast. A network of transversal roads connect the coastal towns to the hinterland. To reduce the effect of natural disasters, the State realised consolidation works in many towns of the area or forced residents to move out. In particular, following the 1951 catastophic event, many residents of three towns (*Canolo, Natile* and *Platì*) were forced to move out (*Law 9/52*).

3.2 Collection of CGE-related historical and rainfall data

The first step of the survey has been the collection of information on failures occurred between 1920 and 1987 for which rainfall data were available. Information was drawn from technical and scientific publications (Caloiero & Mercuri, 1980; Catenacci, 1992; CNR-GNDCI, 1995; Petrucci *et al*., 1996) as well as from national and regional newspapers. Gaps were found in the reconstructed historical series pertaining to phenomena that had not caused any loss of life or damage to property. The analysis of the air photos of the most complex situations has lead to an improved understanding of the failures and allows better interpretation of the sources.

Based on IGM maps (scale of 1:100,000 and 1: 25,000), 19 water catchment basins have been identified in the area, the widest of which reached the Ionian-Tyrrhenian watershed (Fig. 1). By intersecting the perimeter of the water basins with the borders of the 22 communal territories encompassed by the study site, the area has been subdivided into irregular cells and the reported failures have been joined to the cells.

Some 249 failures have been reported over 20 disastrous periods classified as CGE. Each CGE was quite often triggered by various sequences of rainy days, 3 to 5 generally, occurring in a temporal window of 60 to 90 days. The reported cases have been logged in a database and subdivided in 4 major types of phenomena: *landslides*, *falls*, *floods* and *secondary floods* corresponding to 91, 29, 77 and 52 reported cases, respectively.

Daily rainfall have been collected from 1920 to 1987 at 7 rain gauges located between 250 and 970 m *a.s.l.*, thus providing a good altimetric coverage (Fig. 1). The average annual rainfall ranged between 969 mm and 2175 mm and the rainy season spanned from October to March. The area was homogeneous with respect to climate, rainfall-regime and short and intense precipitation (Versace *et al*., 1989).

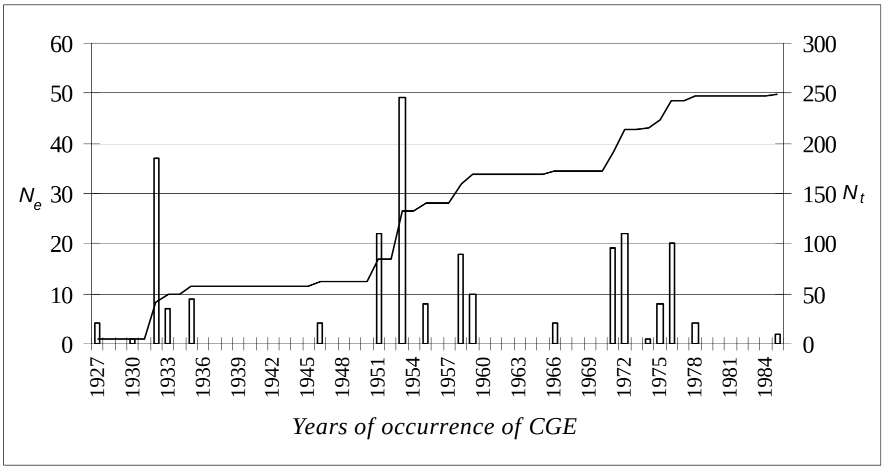

Figure 3: Number of historical data concerning scheduled *CGE*. N_e=number of data for each event; N_t=total number of data collected for the study area in the analysed period.

Rainfall data has then been analysed for validation purposes. The correlation with nearby stations has filled some duration gaps for rain events lasting less than 10 days and improved continuity in the historical sequence has been ensured. Once the GEV functions have been set for each duration/station, the reported events have been analysed based on the return period of the cumulative rainfalls occurred before the CGE or at the same time of it, for each single CGE (Fig. 3) and cell.

The torrential nature of the watercourses in the study site has made it difficult to gather systematic information on the flow rate. Only for a catchment basin (*F. Careri*) data concerning river flow have been gathered, but the time interval (12 years) is not very significant for statistical processing purposes.

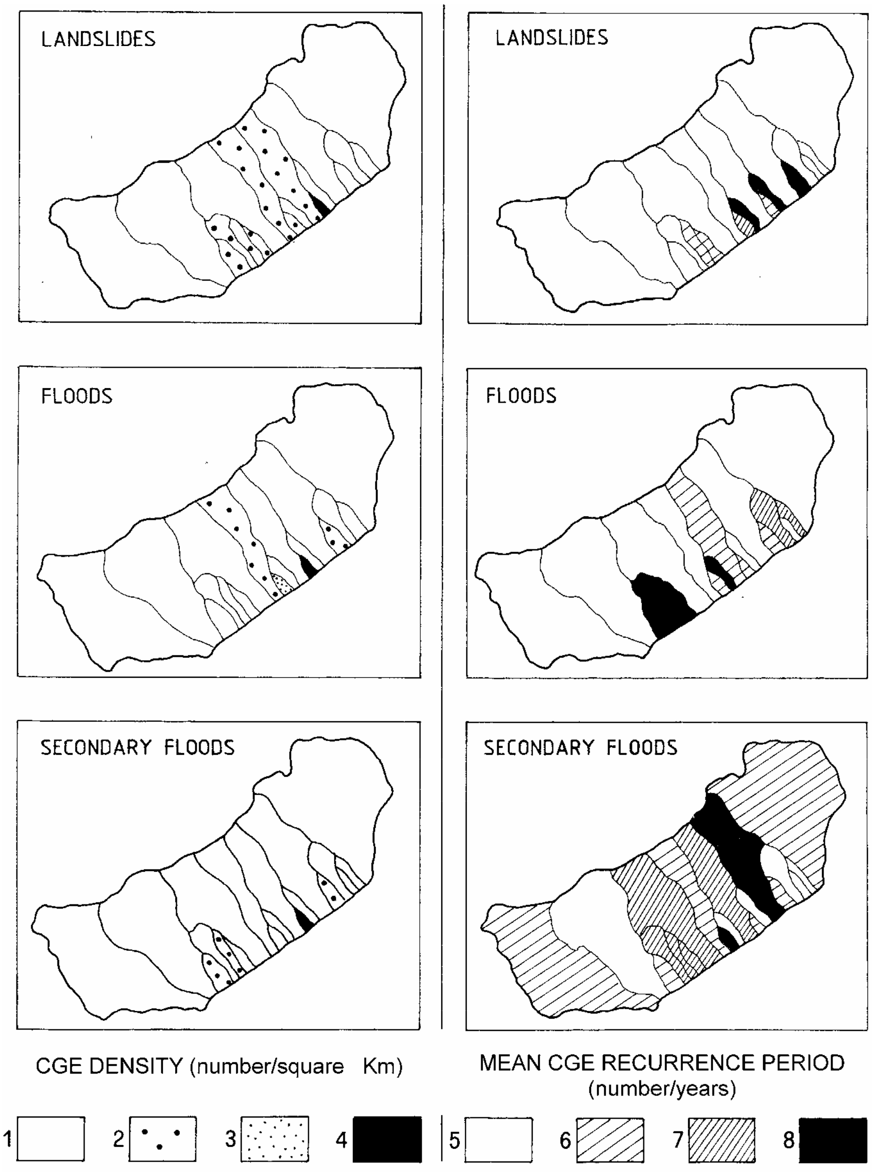

Figure 4: *CGE density* and *mean CGE recurrence period* for each drainage basin. Density: 1) less than *0.30*, 2) *0.3* to *0.65*, 3) *0.65* to *1,00*, 4) more than *1,00*; mean recurrence period: 5) less than *12*, 6) *12* to *24*, 7) *24* to *38*, 8) more than *38*.

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4 DISCUSSION AND CONCLUSIONS

Over the 67 years of analysis, only 15% of the investigated area have been reported as CGE-free. The sectors most frequently liable to landsliding (G18, R18, M1) have exhibited markedly steep slopes with flysch outcroppings particularly prone to landsliding. The coastal areas appeared to be more frequently hit by floods and secondary floods, the highest number of cases being reported in the N8 sector (Tab. 1, Fig. 1).

The mean recurrence period has been assessed for three of the 4 types of investigated phenomena, omitting falls because of its relative low number (Fig. 4). The distribution of CGE over the year, with a concentration between October and March, has provided compelling evidence for a relationship with the humid year period or season and has prompted to take into account a maximum rainfall duration of 180 consecutive days, rainy or not.

Cell	*L*	*F*	*Fl*	*Sf*	*Tot.*
G18	13	4	6	3	26
R18	8	2	1	5	16
M1	9	2	8	0	19
N8	5	2	4	5	16

Table 1: Cells characterized by the highest number of phenomena occurred. *L*: landslides, *F*= falls; *Fl*= floods; *Sf*: secondary floods; *Tot*: total number of scheduled phenomena.

The analysis has identified 4 major types of CGEs that differ as to the impact on the territory, the spatial and temporal distribution of triggering rainfall and the above-average nature of the latter:

- *type A* hits the most internal cells between January and March. It is associated with quite limited heavy rainfall and return periods below 20 years. Statistically significant cumulative rainfall events have a 1- to 10-day duration. The most commonly triggered phenomena are landslides. The severity of damage is low since the events affect sparsely populated areas.

- *type B* covers the coastal sectors and causes river outflows and widespread flooding between October and January. The most critical rainfall duration ranges between 1 and 20 days whereas the return period is below 40 years. This is a surprising result since most reported cases are floods of catchment basin with a concentration time of less than 24 hours. The impact of this type of CGE is not particularly heavy.

- *type C* results in the most devastating impact. These events occur between October and December and are characterised by widespread effects across the whole study site. The triggering rainfall has a mean duration of 180 days and is unusually heavy, with return periods exceeding 100 years (Fig.5). Generally speaking, the most unusually heavy rainfall lasts 5 to 30 days.

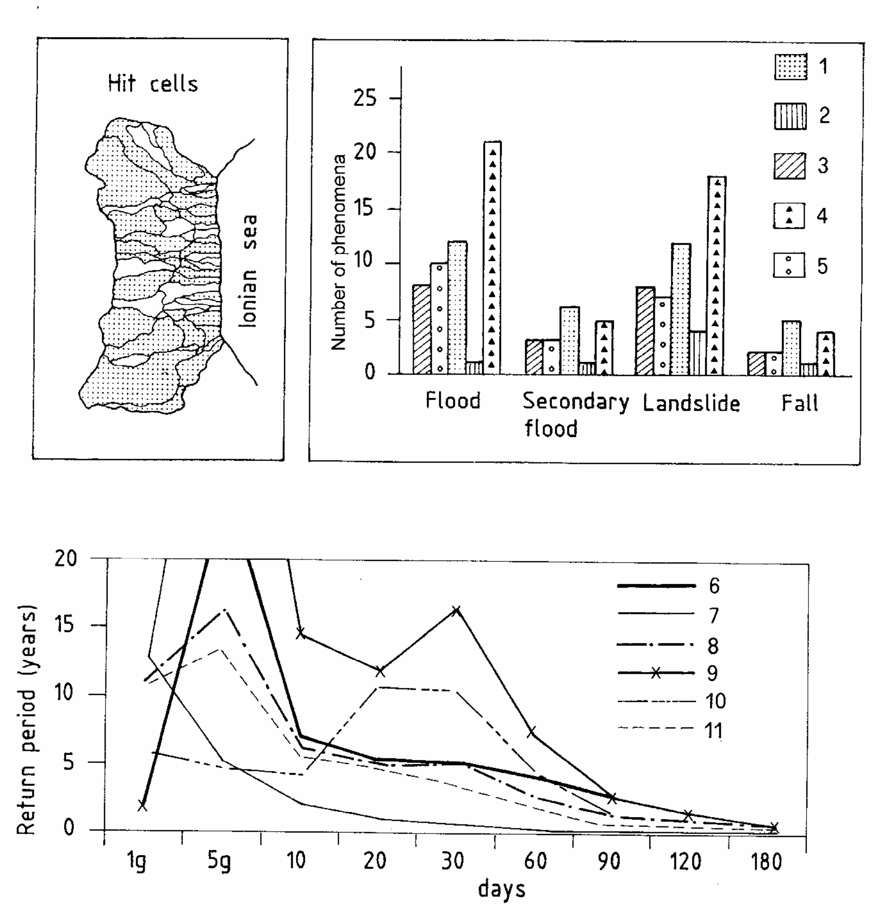

Figure 5: Characteristics of *CGE*, the *type C*. Events of years 1) *1951*, 2) *1972*, 3) *1932*, 4) *1933*, 5) *1953*. Cumulative rainfall 6) *gauge 1* year 1951, 7) *gauge 4* year 1932, 8) *gauge 4* year 1951, 9) *gauge 5* year 1951, 10) *gauge 5* year 1972, *gauge 7* year 1951. Critical period: October-December. Return period of relevant cumulative rainfall: more than 10 years, sometimes more than 100 years. Type of phenomena: landslides, floods and secondary floods. Hit cells: everywhere.

The severity of damage is extremely high, the death toll is remarkable and there are repercussions on local economy.

- type D, occurring between October and November, is similar to the above type with respect to the spatial distribution of the effects and the types of associated phenomena, but causes fewer failures. These events occur after rainy periods which last more than 60 days, the most intense rainfall lasting less than 5 days and having a return period of less than 70 years. The severity of damage is medium.

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