Flash flood event of Potamoula, Greece. Hydrology, geomorphic effects and damage characteristics.

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Abstract The geoenvironmental setting is a determinative factor in catchments' response during heavy precipitation events. In this work, the flash flood of 2008 in Potamoula (Aetoloakarnania, Greece) is investigated in terms of hydrologic and geomorphologic features. The study area is a relatively small, partly forested, rural catchment situated in western Greece with steep mountainous topography and with flysch being the prevailing lithology. In 2nd of October 2008 a storm of high intensity (measured up to 280mm in 24 hours) produced noteworthy quantities of runoff which inundated the lower parts of the small valley, inflicting damage to a significant number of structures and killing two people. Field investigations were carried out to record the extent and characteristics of damage, the physical attributes of flooding such as the peak discharge, the geomorphic effects and the geological factors affecting the local hydrology. The results were investigated in comparison with geomorphological and geological evidence showing that this event, although extreme, corresponded very well to the geological record of the area. Finally, runoff response of the catchment was assessed in respect with the geology of the basin.

1 Introduction

Platanorema is a relatively small catchment (28 km^2), and a part of the drainage network of Acheloos River. It is located in Aetoloakarnania in western Greece, 216 km northwest of Athens and 15 km north of Agrinio. It is inhabited by approximately 830 people with Potamoula being the largest village (Fig. 1). Platanorema stream network drains a hydrological basin of the 5th order. The drainage network has an asymmetric dendritic form. High incision rates are obvious along the streams, along both the bedrock and the alluvial deposits. Along the main riverbed, there are well developed alluvial terraces, mainly at the southwest

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part of the basin. Due to the steep forested slopes, towns and villages in this and numerous other catchments are settled near the main rivers, in flat areas dominated by river deposits.

Platanorema has suffered floods in the past. On the basis of eyewitness accounts and web sources, one can identify at least three significant events in 1960, in 1961 and in the autumn of 1999. However, the 2008 flood is considered to be the most damaging.

The impressive intensity of the event posed a series of questions, considering the nature of the phenomena, and the role of the contributing factors. Goal of this work is to investigate the following issues:

- the peak discharge during the event
- the damage characteristics and distribution
- the geomorphic effects

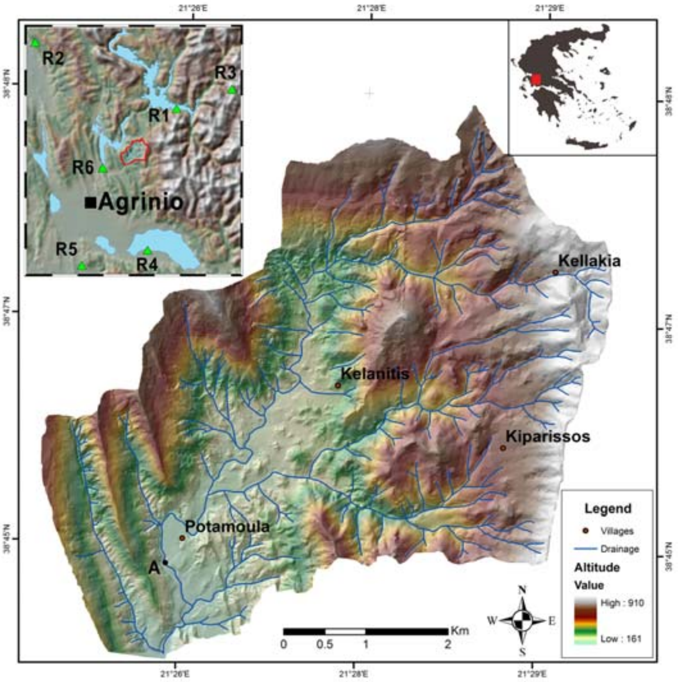

Fig. 1 Map of the catchment under study. In the upper left corner, there is a location map illustrating the rain gauge network in the area. Location A represents the peak discharge reconstruction location.

In terms of geology, the upper Eocene - Oligocene flysch is the prevailing geological basement in the area. According to IGME (1998), the dominant lithologies of the catchment are:

- Sandstones: thin to medium bedded, alternating with fine to coarse-grained sandstones and thin layers of shales, with occasional occurrence of conglomerates.
- Shales: grey to greenish, bearing alternating layers of pelites, marly silts, silty sandstones as well as fine-grained sandstones in bands of 0.20-0.50m.

Most of the catchment area consists of the shales series (~70%), while the main sandstone occurrences outcrop along the drainage divide or near it. The tectonic deformation of the area is rather intense; with medium to large scale folds with axes trending NW-SE to N-S and plunging south, together with extensive strike-slip or oblique-slip right-lateral faults trending NE-SW.

2 Methodology

A post flood field investigation in the area was carried out to measure the channel geometric characteristics (Fig. 2) and examine the peak water level indicators. Based on these measurements, peak discharge was computed at location A (Fig 1) with the use of Manning’s formula (Manning 1891, Flamant 1891).

$$Q = \frac{A}{n} R^{2/3} S^{1/2}$$

where: n is the roughness coefficient, R=A/P is the hydraulic radius, P is the wetted perimeter, A is the cross-sectional area , S is the channel slope at the location.

In order to calculate Manning roughness coefficient necessary for the peak discharge computation, vegetation and flow type were also investigated along the main river in accordance with Cowan’s methodology (Cowan 1956).

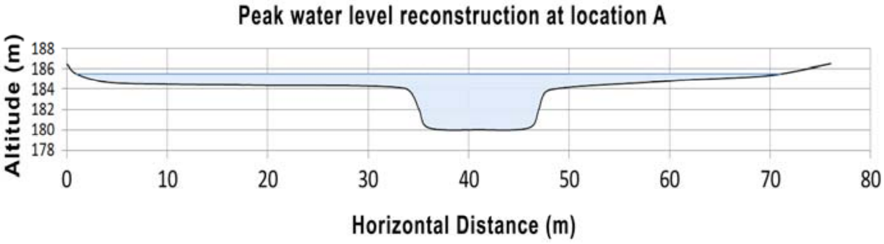

Fig. 2 Cross sectional area at location A, where peak flow discharge was calculated.

Moreover, rainfall data from 6 gauges (Fig. 1) were examined in order to study the spatial characteristics of the storm that caused the event. This examination showed a total rainfall of 201mm across the small basin (although one of the rain-gauges recorded 280mm in 24 hours). Based on the storm record, calculated peak flow rate was also cross-checked with the application of SCS-CN rainfall-runoff method (SCS 1972) to assure consistency of the result. Subsequently peak discharge in this catchment was compared to peak flow rates of other catchments in Greece during flood phenomena, in order to assess the role of flysch formation and its hydrological response.

In addition, the geomorphic effects of the flood were documented along with geological observations on the older river flood deposits in the area. For this purpose, measurements were carried out concerning the grain size of the 2008 and older flood events' sediments.

Furthermore, a field survey was carried out to record the type of damage in structures and their spatial distribution. Finally, damages were projected against older flood deposits to assess their spatial correlation. This step was carried out to examine whether the 2008 event was predictable on the basis of geomorphology in terms of extent and damage pattern.

3. Results

Peak discharge was computed at location A at 94.5 m^3/s with the use of Manning's formula as shown in Table 1.

Table 1. Calculation of peak flow rate at location A, based on Manning's formula.

Parameter	Value
A - Cross sectional area (m^2)	95
P - Wetted Perimeter (m)	72
S – Slope (m/m)	0.0198
n – Manning coefficient	0.17
Q - Peak flow (m^3/sec)	**94.5**

Based on the application of SCS-CN method, peak flow rate was computed at *87.8* m^3/s (Fig. 3) (Fountoulis et al in press) showing good correlation with the Manning formula results. The application of the SCS-CN method showed 115mm of runoff out of 201mm storm over the basin. The two results give a mean value for peak discharge of approximately *91*m^3/s which results in peak discharge per unit area of *3.65* $m^3/s/km^2$. This value was found similar compared with peak discharge calculated in other catchments in the region during notable storms (e.g. Xerias torrent in 1997 flood event, Baloutsos et al 2000, Gaume et al 2009).

Concerning spatial distribution of damages when projected against older flood deposits they showed good correlation especially with the limits of the active floodplain (Fig. 4). As far as the damage characteristics are concerned it was found that 72 structures were partly or completely damaged. Their vast majority was situated on the active floodplain or older alluvial terraces. The following table illustrates the portion of the structures situated on terraces (Table 2).

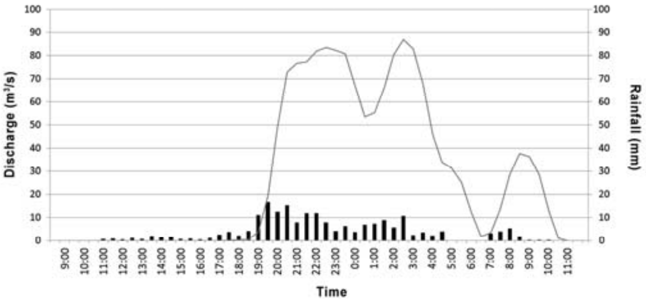

Fig. 3 Storm rainfall across the catchment during the 2nd and the 3rd of October 2008 and associated flow rate at location A, calculated through the SCS-CN method.

Table 2. Percentage of damaged structures against the respective geologic units.

Area/Zone under consideration	Total structures in considered area/zone	Damaged structures in considered area/zone	Percentage
Alluvial terraces	76	57	75 %
Lowest terrace	54	50	92.6%
Whole Catchment	617	72	11.7 %

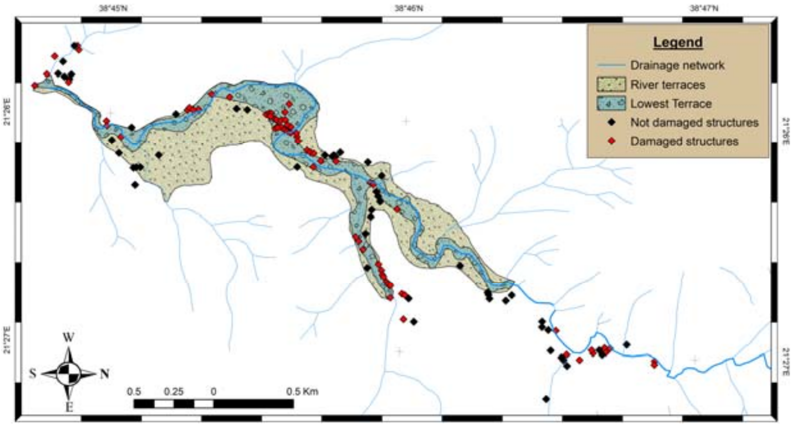

Fig. 4 Damages spatial distribution in comparison with the extent of river terraces and specifically the lower terrace (active floodplain).

As far as the type of damage is concerned, a very critical factor on the structural performance of the building was found to be the type of foundation. Buildings without deep foundations were more severely damaged because flood water eroded the ground material under their basal part (Fig. 5a,b). Buildings with deep foundations presented a better structural performance, resulting in damages only in ground floor masonry and utensils.

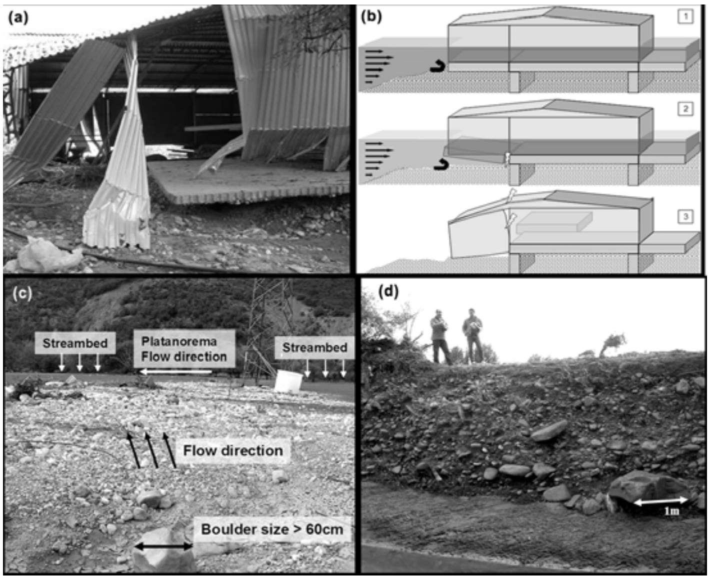

Fig. 5 Structure with superficial foundations destroyed after erosion of the ground material below their basal part (a). Illustration of the erosion mechanism (b). Cobbles deposited on the lower terrace during the flood in areas with high water velocity (c) and boulders deposited in the lower terrace during older flood episodes (d).

With respect with the geomorphic effects of the event alluvial sediments were deposited on the lower terrace mainly in the form of cobbles and boulders in places with high water velocity (Fig. 5c). Measurements that were carried out showed that most of the cobbles were lower than 30cm but a portion of them measured up to 60cm on the terrace at Potamoula settlement, indicating water velocities between 0.8 – 2.8 m^3/s according to the Hjulström curve (Novak 1973). These values show good correlation with the value extracted from the flow rate calculations in location A, further downstream, which showed a mean velocity of about *1m/s*. In addition, measurements of the grain size of older flood deposits presented boulder sizes of approximately 1m, showing even higher energy deposition environment. On the contrary, in areas with lower flow speed fine grain sediments were deposited in various thicknesses (up to 30 cm in places) (Fig. 6a).

During the event erosion processes were intensified leading to enhancement of transportation of sediment material and minor failures on the river sides (Fig. 6b)

4 Discussion & conclusions

Results showed that the portion of runoff during the storm reached 57% of the total rainfall (115mm out of 202mm total). This value is similar to the 56,9% of runoff discharged during a 201mm storm in Xerias river in Corinth in 1997 (Baloutsos et al 2000). However it is important that the two catchments have substantial differences in geology.

Damages presented a very good correlation with the spatial extent of the lower terrace proving that the study of geomorphology is a useful tool when studying flood hazard. The examination of the type of damage showed that structural standards are very important in buildings situated in high hazard areas.

Geologic material eroded from specific locations was deposited (in various grain sizes) continuing the process of terrace-building. Study of the geomorphic effects in general showed that this event although extreme, followed the pattern of fluvial geomorphic processes imprinted in the geology and the geomorphology of the catchment, proving that it was nothing but a normal part of this processes in acceleration.

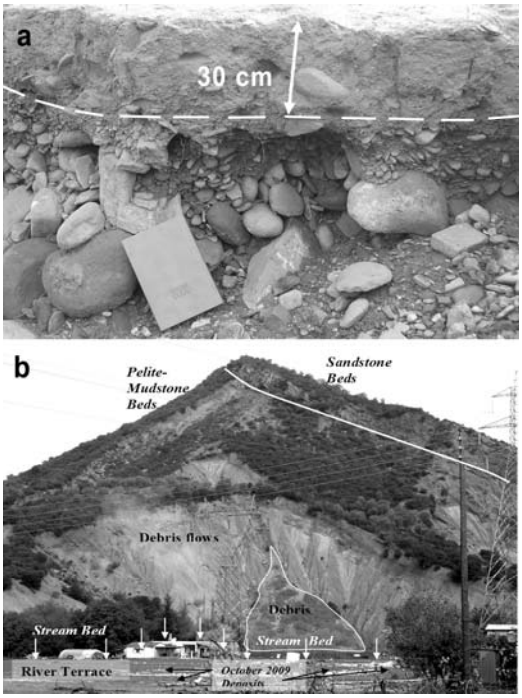

Fig. 6a Fine grain sediments deposited in areas with low flow velocity (Potamoula terrace), during the flood event of October 2008. **(b)** One of the locations where the event enhanced erosion and processes and sediment was supplied in the river

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