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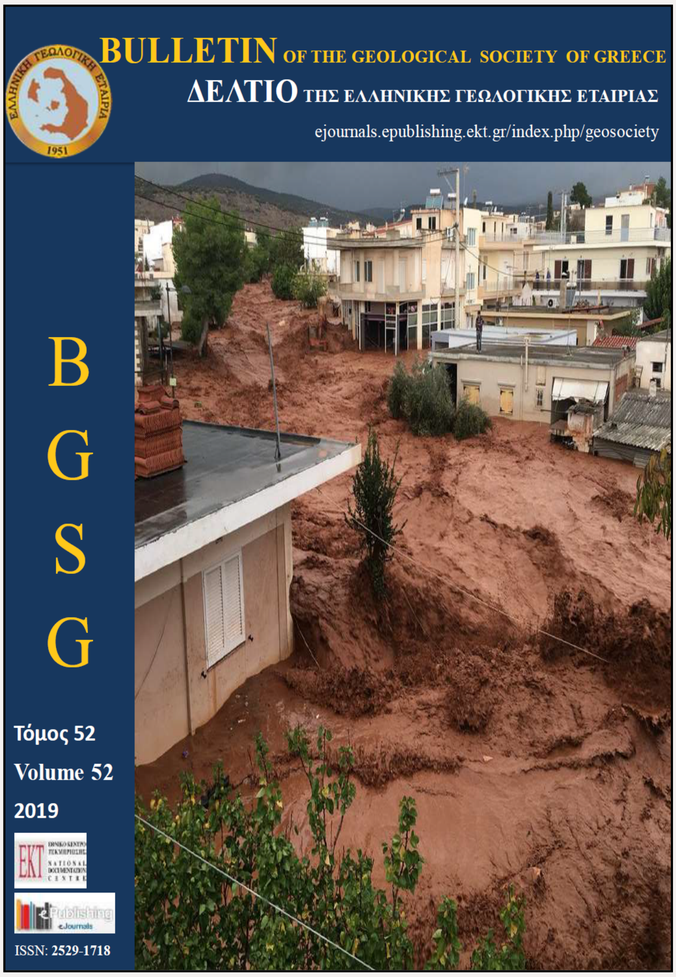

The floods in Greece: the case of Mandra in Attica

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The floods in Greece: the case of Mandra in Attica

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Abstract

Floods are one of the most common natural disasters and are extremely dangerous in a global range since they can cause extensive damage to properties or losses in human lives. According to the opinion of many expert scientists, climate change has led to the increase of flooding phenomena over the last years worldwide, as well as in Greece. The aim of this paper is to examine the flooding event that occurred in Mandra area, Attica (Greece) on 14-15 November of 2017. The peak discharge of the Agia Ekaterini and Soures streams was calculated using the rational method (Giandotti) for return periods equal to 10, 100 and 1000 years. The stream characteristics were studied and their behavior during the flood was investigated. Many of the impacts were attributed to the human intervention in the streambeds.

Keywords: *flood, rational method, Agia Ekaterini, Soures, Mandra.*

Περίληψη

Οι πλημμύρες είναι από τις συνηθέστερες φυσικές καταστροφές και εξαιρετικά επικίνδυνες σε παγκόσμια κλίμακα καθώς μπορούν να προκαλέσουν εκτεταμένες *ζημιές σε περιουσίες και σε απώλεια ανθρώπινων ζωών. Σύμφωνα με πολλούς ειδικούς επιστήμονες, η αλλαγή του κλίματος έχει οδηγήσει στην αύξηση των πλημμυρικών φαινομένων τα τελευταία χρόνια παγκοσμίως, όπως και στην Ελλάδα. Στόχος της παρούσας εργασίας είναι να εξετάσει το πλημμυρικό γεγονός που έλαβε χώρα στις 14-15 Νοεμβρίου του 2017 στην περιοχή της Μάνδρας, Αττική (Ελλάδα). Η μέγιστη πλημμυρική παροχή των ρεμάτων Αγίας Αικατερίνης και Σούρες υπολογίσθηκε με τη χρήση της ορθολογικής μεθόδου (Giandotti) για περιόδους επαναφοράς ίσων με 10, 100 και 1000 έτη. Μελετήθηκαν τα χαρακτηριστικά των ρεμάτων και ερευνήθηκε η συμπεριφορά τους κατά τη διάρκεια της πλημμύρας. Αποδόθηκαν πολλές από τις συνέπειες στην ανθρώπινη παρέμβαση στις κοίτες των ρεμάτων.*

Λέξεις κλειδιά: *πλημμύρα, ορθολογική μέθοδος, Αγία Αικατερίνη, Σούρες, Μάνδρα.*

1. Introduction

On 14-15 November 2017, a major flood occurred in Mandra, Attica (reference map of Fig. 1) resulting in extended material and economic damage, but most of all in the loss of our 23 fellow humans. This again raises the issue of flood risk planning. In Greece, due to the Mediterranean climate, the occurrence of floods is frequent. In the last months of 2017 we had floods in areas such as: Samothraki, Symi, Rodopi’s Maroneia, Aitoloakarnania and of course in Mandra, with tragic consequences. Although in the last 60 years the annual precipitation has decreased (Soulios et al., 2012), however, due to climate change (Stournaras, 2007), rainfall as well as other climatic phenomena are manifested themselves by extreme conditions (IPCC 2012, EMEKA 2011, Psilovikos, 2014), resulting in more and more frequent floods.

2. The basins in Mandra area

In Mandra, there are two separate catchment areas (Fig. 1).

- The stream of Agia Ekaterini that ends in the central part of Mandra, which it crosses, and,
- The Soures stream passing through the northeastern outskirts of the city.

The two streams converge downstream of the Mandra urban area and are then diverted to the largest Sarantapotamos river, which flows to the east of Elefsis urban area into the Bay of Elefsis, passing just east of the Halyvourgiki plant before reaching its estuary.

The geomorphological data of the flood-related basins (Maroukian et al., 2005) are as follows:

The basin of Agia Ekaterini stream (Fig. 1), up to the borders of urban Mandra, has an area of 23.3 km^2. Its average altitude is h = 270 m, its highest point stands at 659 m and the lowest at 80 m. Its maximum thalweg is 9.8 km long. The basin of the Soures stream (Fig. 1) up to the borders of Mandra has an area of 18.2 km^2. Its average altitude is 305 m., the highest point at 772 m and the lowest at 80m. Its maximum thalweg is 11.6 km long.

From a geological point of view, on the basis of the existent official geological maps (Dounas, 1971; Katsikatsos et al., 1980), the two basins are comprised from the lower to the highest, from the following geological formations:

– Limestones, dolomitic limestones, unbedded to thick-bedded Upper medium Triadic sediments, with small karstification, and with soil covering in many segments, with dense vegetation.
– Limestones, locally marlly, thin bedded, upper Cretaceous in age with small-karstification, and with soil cover in several segments and dense vegetation. They are stratigraphically incompatible with the previous one and between them interbedded lenses of laterite–bauxite intercalations exist.
– Quaternary formations: alluvial plain sediments (clay-sand- pebbles) and alluvial fan sediments (clay-sand- pebbles-conglomerates).

In these basins little vegetation and olive trees are cultivated.

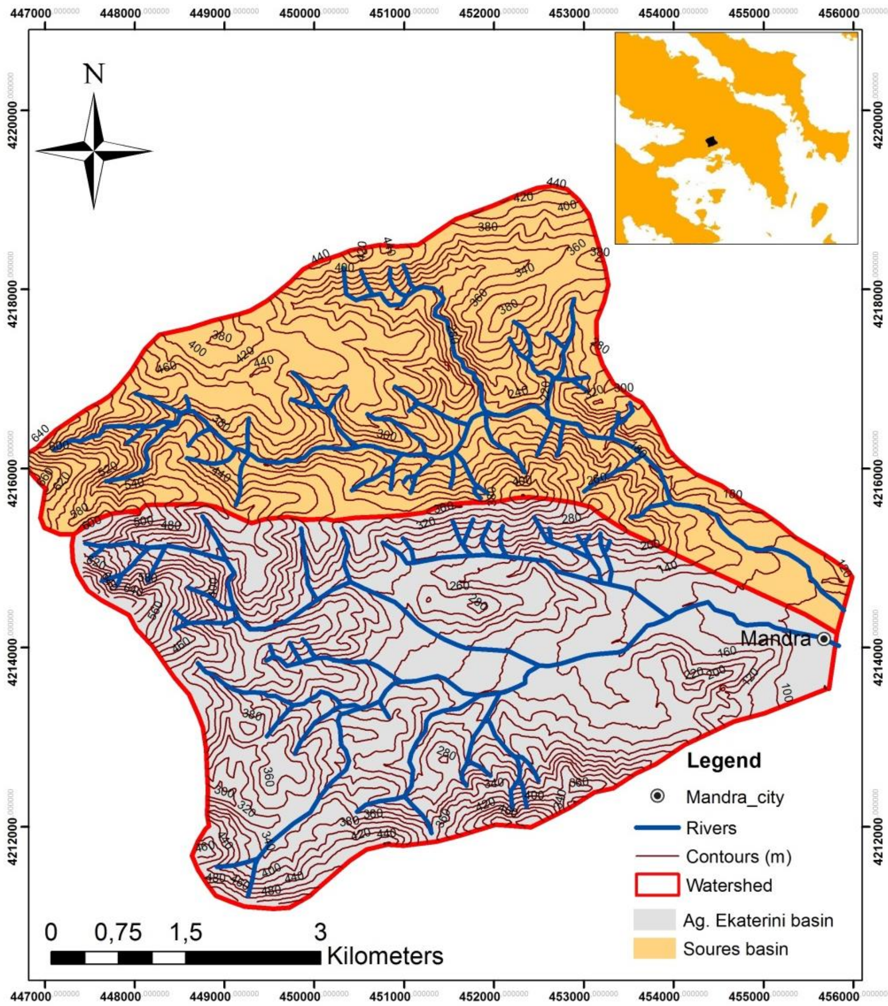

Fig. 1: Agia Ekaterini stream (in gray) and Soures stream (in brown) and their corresponding hydrographic network.

3. Flood elements of the Mandra basins

When there are no systematic, reliable, long-term stream flow data, as it is in this examining case, empirical methods are usually employed in order to calculate expected floods. There are many of them. One, perhaps the most reliable method is the so-called "rational", as this completed by Giandotti (Kotoulas, 1992; Wilson, 1977; Kotsopoulos, 2006; Soulios, 2010; Remeniera, 1965). For the application of this method, as well as for each relevant model, knowledge or estimation of the coefficient of runoff or the total overflow coefficient is required (Baloutsos et al., 2000). This coefficient gives the percentage of rain that flows out and reaches the basin outlet at the flood (it is not the mean annual runoff). We have not found bibliographic data in which this factor has been calculated on the basis of field measurements, but only estimates in which an average value of 0.65 (65%) is usually adopted. In the case study, due to the intensity of the rainfall, the geological composition, and the duration of rainfall, we consider that the appropriate value, corresponding to return period equal to 100 years is 0.70 (70%).

Based on this fact and the geomorphological elements of Agia Ekaterini basin, we calculated that the time of concentration, e.g. the time required for the runoff water to reach the exit, according to the Giandotti formula, is t_c = 2 hours and 58 minutes. That is, for a flood with a maximum flow rate for the corresponding rainfall intensity, rainfall should last at least 2 hours and 58 minutes. The flood discharge for a T = 10-year return period will be q = 106 m^3/s and for its occurrence, precipitation of P_c = 23.40 mm/h is required for t_c = 2 hours and 58 minutes.

For the calculation of the corresponding rainfall intensity, the original equation (as it was initially proposed for the rational method) was applied as following:

$Pi=(30logT+15)\ t_c^{-0,6}$,

where *Pi*= rainfall intensity (mm/h)

T= return period (10, 100, 1000 years etc)

t_c= time of concentration

Different methodologies for the calculation of the rainfall intensity have been proposed for Greece, (e.g. Koutsogiannis, 2004a; Koutsogiannis, 2004b). The results between these methods and the one applied in this paper are similar. For a 100-year flood return period, that is T = 100 years, the flood discharge will be q = 177 m^3/s with a corresponding rainfall intensity P_c = 39.50 mm/h.

Finally, for a millennium flood, that is with T = 1000 years return period, we will have q = 248 m^3/s and a rainfall intensity P_i = 54.7 mm/h.

For the Soures basin the corresponding elements are:

Time of concentration = 2 hours and 52 minutes.

Flood of decade q = 84 m^3/s with P_i = 23.90 mm/h

Flood of a hundred years q = 141 m^3/s with P_i = 39.90 mm/h

Flood of millennium q = 198 m^3/s with P_i = 55.8 mm/h

The application of the Fuller method, which only takes into account the area of the catchment area, gives values about 20% lower than those of the rational method for 100 years return period**.**

4. Rainfall data

There are no direct measurements of the rainfall of 14 to 15 November in the area under investigation. The University of Connecticut examined NASA satellite images and evaluated the space-time evolution of the storm of November 14 to November 15, 2017 (Nikolopoulos, 2017). In fact, this estimate refers to the quantity of water contained in the cloud that caused the storm. It is not certain or imperative that all this amount has reached to the ground surface, but the impacts of the storm are justified if we accept that the amount of rain is of the same order of magnitude.

According to this analysis, as shown in Fig. 2, the spatial distribution of the storm was locally limited, the maximum rainfall was observed in an area restricted from the northern section of the Soures basin to the further north with the total rainfall ranging from 154.6 to 164 mm. To the south, in the rest of the Soures basin and in almost all of Agia Ekaterini’s basin, the corresponding height of the rain was 138.4 to 154.7 mm. The total rainfall lasted for about 7 hours and thus can be categorized, marginally, as a flash flood.

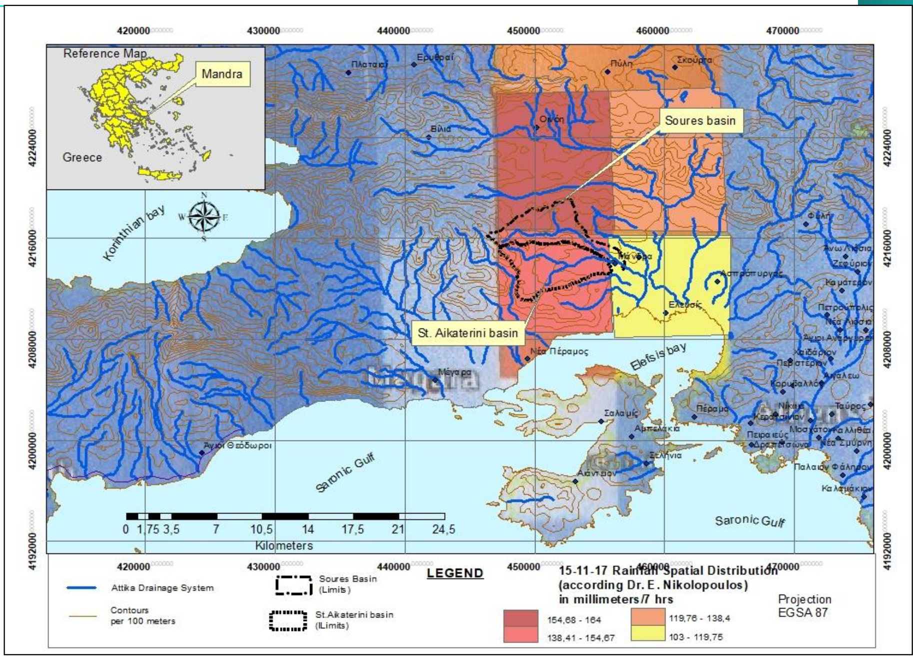

Fig. 2: The spatial distribution of the rainfall in the area of Mount Pateras of 14-15/11/2017 (according to Nikolopoulos, 2017).

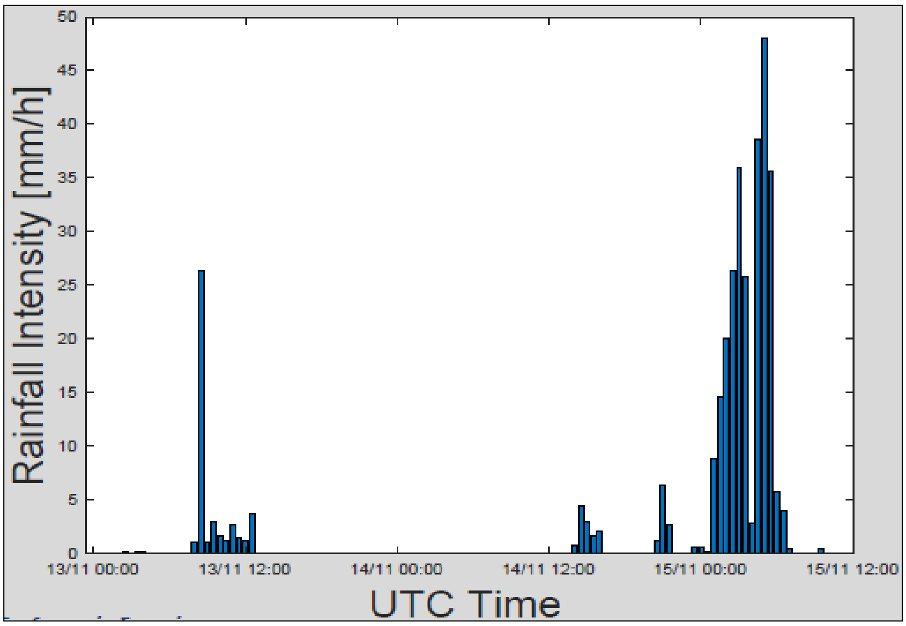

Fig. 3: The time distribution (hyetograph) of the rainfall of 14-15/11/2017 in the area of the streams of Agia. Ekaterini and Soures (according to Nikolopoulos, 2017).

The time distribution for the peak height sections are given in hyetograph in Fig. 3. It appears that at night hours, on the morning of 15-11-2017, a maximum intensity of 47 mm/h was observed, but for a limited time period of about 1 hour, while for a continuous three-hour period (05:00-08:00) the average rainfall intensity was about 39-40 mm/h. These intensity and duration values correspond to one hundred years return period event. Thus, the corresponding flood discharge has been calculated equal to **180 m^3/s** for the basin of Agia Ekaterini's and **140 m^3/s** for the Soures basin, respectively**.**

5. Stream characteristics and behavior during flood

As for the behavior of the streams during the flood, they respond mainly to their basin's physical characteristics such as the composition of the geological formations, geomorphological characteristics etc. Both streams have common characteristics and differences.

Common characteristics:

- They both have ephemeral flow and they behave as torrents.
- They both manifested changes of the hydrographic network (i.e deepening or widening, either locally, at the downstream part of their streambed i.e. streambed rise due to the depositions).
- Both stream basins have similar geological composition, but the proportion of quaternary and clay material is larger in Agia Ekaterini than in Soures.

On the contrary, the following differences were observed:

- The slope value of Soures basin is 19.6%, significantly larger than the slope of Agia Ekaterini basin, which is equal to 16.7%. As a consequence, the water velocity, and therefore the erosion and transfer ability, are higher in Soures basin.
- Moreover, the aforementioned also result from the flood characteristics of the two basins: Soures has maximum thalweg equal to 11.6 km and the concentration time is estimated to 2 h 52 min, whereas Agia Ekaterini has maximum thalweg 9.8 km, i.e. 1.8 km smaller than Soures, but the concentration time is 2 h and 58 min. The surface water in Soures basin

were flowing with higher velocity and therefore had higher erosion and transport ability.

– It is concluded that Soures stream is more erosive at the upstream part transporting coarse material, such as cobbles, gravels, sand or even boulders. Agia Ekaterini stream transferred suspended material mainly clay and deposited mud on the streets of the Mandra urban fabric, inundating the broader area.

6. Remarks

Examination of the streambeds after flood, at points where there was no human intervention, showed that they were overflowing far beyond their corresponding banks (photo Fig. 4), revealing thus that the examining flood was extremely, and unusually large. If that was a normal one, the existing streambeds would have easily accommodated their stream drainage.

The negative intervention of man to the course of those two streams near and within the Mandra area (restraint of the streambed size, buildings across and inside it, artificial drainage failures etc.) had the final impact of intensifying and dramatically increasing the overall negative consequences of this great flood, with the total result being the loss of the 23 people and secondly in enormous material disasters. Many people have been caught by surprise since it occurred at sleepy night hours just a few hours before dawn.

In the picture of Fig. 5. we see a large building that has been built across the streambed of the Soures stream. This building along with other nearby similar interferences, and obstructions, essentially blocked its course towards Sarantapotamos river, resulting in overflowing the nearby road (E962) and flooding the lands and buildings of Mandra eastern urban area. A large part of the E962 lower course was also inundated. At the points of those interferences 5 people were found dead.

Fig. 4: Photograph from the river bed of Agia Ekaterini after the flood of 14-15/11/2017.

Fig. 5: Photograph of the Soures streambed which shows the existence of a massive building across the flow of the stream.

The picture of Fig. 6 shows the erosion of the national road 3 Mandra-Thebes (E962) from the flood waters of the stream Soures. That road was actually a natural stream's channel before its making.

Finally, in the photo of Fig. 7, part of the settlement of Mandra is flooded by the waters of Agia Ekaterini's stream. The waters have covered much of the ground floor of the buildings and were the cause of many deaths. The flood waters "spread" over a large part of the urban area, so the flow had a great cross section. Consequently, the flow velocity was decreased and thus huge amounts of suspended materials have been deposited in the streets, since both the transport and corrosive capacities of the flowing water vary with the third power of its flow velocity.

Fig. 6: Erosion of road 3 of Mandra-Thebes (E962) from the flood of 14-15 / 11/2017.

Fig. 7: The flood flow in the residential fabric of Mandra.

7. Conclusions

In conclusion, the flood of Mandra from 14th to 15th November 2017 was caused by:

- a heavy rainfall of approximately 7 hours with a total height of approximately 150-160 mm,
- there was a time period of continuous three hours, with the intensity of the rain to amount about 39-40 mm/h corresponding to a flood event that has one hundred years return period,
- The flood discharge of Agia Ekaterini's stream is calculated approximately 180 m^3/s and that of the Soures stream at 140 m^3/s.
- Except the severe damages that were caused to the buildings of the Mandra urban fabric we also had as a tragic consequence the loss of 23 human lives due to the lack of infrastructures.

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