Flooding in Athens: The Kephisos River flood event of 21-22/10/1994

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Short description of the event

During the night of the 20th of October 1994, a cold front passed over Greece, provoking heavy precipitation and consequently catastrophic floods in many areas. In some of the affected areas, the precipitation height was equivalent to 140 mm, while in the centre of Athens precipitation height exceeded 140 mm. The Greater Athens area experienced one of the most devastating flood events in years, during which nine deaths were reported along with severe damages in the transportation, telecommunication and energy infrastructure. Dozens of homes and stores were flooded, a considerable number of cars was destroyed, three buildings collapsed and hundreds of people remained trapped in cars and buildings for several hours. An analysis of the causes and mechanism of the event, as well as considerations on potential risk-reducing interventions are presented and discussed.

1 Introduction

1.1 Basic characteristics

1.1.1 Geographical characteristics

The Kephisos River (Figure 1) springs from Parnitha's mountain range, which is part of the National Forest and is included in the «Natura 2000» protected sites. The river, which is the major recipient of the Athenian rainfall runoff, covers an area of 381 km^2, while its length is 22 km (of which 14 km are within residential areas).

The history of urban development around the Kephisos River is dated back to 1922, when following the defeat of the Greek Army by Kemal

Ataturk, the area received a massive influx of refugees fleeing the Greek cities of Asia Minor. Many refugees moved to Attica looking for better living prospects and settled in the western, less urbanized part. A new wave of immigration, followed the end of the Civil War (1945-1949) and continued for decades, drastically changing the profile and outlook of Athens.

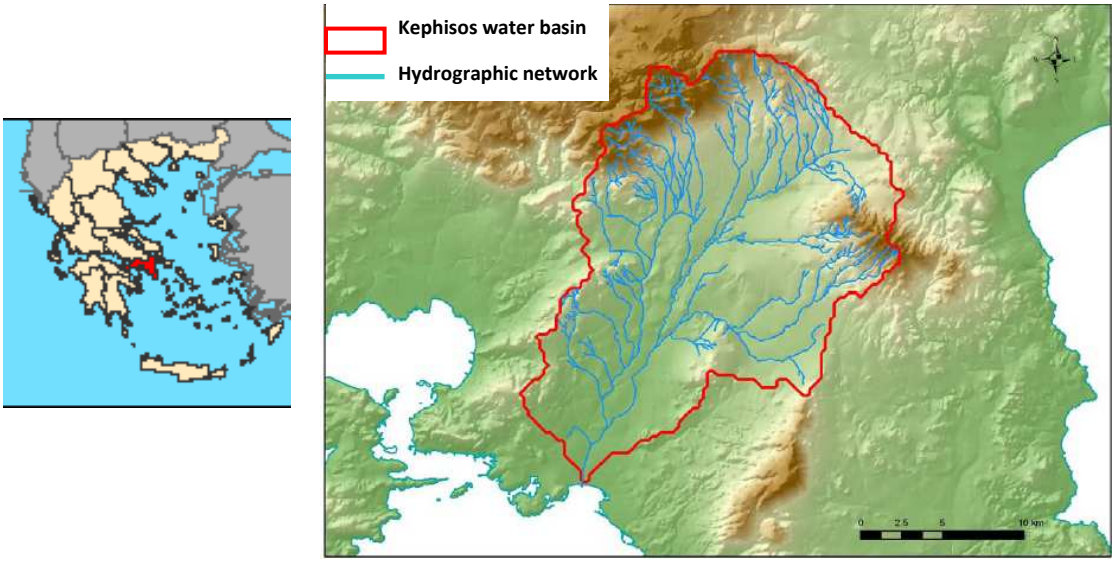

Fig.1: A schematic of the Kephisos River network

The urbanization of western Attica, primarily by refugees and internal immigration, resulted in a socio-economic segregation of the population of Athens, which still evident, to some extent, even today. In Figures 2 and 3 the extensive urbanization that took place in the last 137 years around the river can be observed.

Fig.2: Western Athens (1870)
(Source: Laskaris 2008)

Fig.3: Western Athens (2007)
(Source: Laskaris 2008)

1.1.2 Geomorphological characteristics

The mountainous / semi - mountainous parts of the Kephisos basin in Parnitha have been severely affected in recent years as a result of the devastating fire events. The morphology of the urban areas is characterized by a smooth relief domination. The mountainous and semi-mountainous parts of the drainage basin mainly consist of karstified limestones, marbles and schists, while the low-land parts have been totally covered with alluvial depositions and building materials (concrete, slabs etc) which are byproducts of the intense urbanization process in the wider area. In addition, due to its karstic background, the catchment has a significant groundwater yield (Rozos et al. 2004).

1.1.3 Climatic characteristics

The Mediterranean climate with low annual rainfall and prolonged sunny periods renders the city of Athens, one of the sunniest cities in Europe. Precipitation episodes are not as frequent as in the rest of Europe, and take the form of, mainly, short-duration storm events during the winter months. Summer months are dominated by frequent heat waves occurring during July and August, when temperatures exceed 40ºC. Winter months are mild and the temperature generally stays above 10°C, although frost layers are created during the night. The mean annual precipitation, temperature and relative humidity in the city centre are about 400 mm, 17.7^{o}C and 62% respectively.

1.1.4 Land use

Land uses vary in the Kephisos drainage basin. The upland areas are dominated by forests and bushes, while the lowland areas are now firmly within the urban fabric. In addition, there are cultivated areas and regions of industrial use.

The intense development of the wider Athenian urban complex, led to the degradation of many tributary streams. Although the Kephisos River preserved its flow to the sea by discharging 70% of the drainage basin, it suffered much due to a significant decrease in its width as a result of illegal dumping of rubbles and solid waste. The river's degradation was also accelerated due to illegal construction and haphazard industrial development on its banks.

Currently, the urbanized area of the Kephisos river catchment amounts to 70% of its total extent; a number which is set to increase in the near future. In the following figures, typical examples of arbitrary and illegal construction activity are presented.

Fig. 4: Structures on river bed (Source: Laskaris 2008)

Fig.5: Roads and houses on streambeds (Source: Laskaris 2008)

1.1.5 Protective measures

Flow management interventions on the Kephisos river basin were initiated 35 years ago and partly completed in 2004. The river had been partially trained, in the past, for discharges of 700, 900, 1100, and 1400 m3/s and return period of 1:50 years. The above discharges, which flow into the Saronicos Gulf, were considered low for current conditions and existing river training was re-examined to improve flood management of

the upstream (mountainous) part of the river catchment area. The whole system can be described as follows:

- The Kephisos river is successfully engineered from «Treis Gefures» to the «Faliro» Bay and no further interventions to increase discharge are needed
- From «Treis Gefures» to «Agia Anna», the river is covered and a highway is constructed on top of it (Figure 6).
- The river runs in an open channel cross-section from «Agia Anna» to to «Posidonos» Avenue and from there to the river estuary in the Saronikos Bay.
- From «Treis Gefures» upstream, the river is supposed to retain its open section profile, although the studies for the final engineering design have not yet been completed, while many parts of Kifissos still have serious problems with embankments along the river bed, arbitrary settlement activities and deposition of all kinds of solid and liquid waste.

Fig.6: Combination of the drainage channel with Kephisos Avenue (Source: Laskaris 2008)

In recent years, growing environmental awareness, increased interest towards a radically improved quality of life, along with the utilization of knowledge and experience from landscape architecture and sustainable urban drainage (Makropoulos et al., 2001), led to the incorporation of urban water management considerations into urban design around the world.

Stream beds are reconstructed according to the modern design tendencies of public areas by making rational use of natural-ecological materials. This tendency gives great importance to the consideration of streams as network channels connecting public areas. However, the vision

of forming urban streams that contribute to the equitable management of valuable water supplies, as well as the upgrading image of cities, is still at its infancy (Hurley et al., 2007).

The matter of urban streams is not a problem of restoration or maintenance, but a challenge of creating new functional and viable urban networks: Seoul, for example, is a city that challenged the demolition of an important highway, to achieve the restoration of an old river. Melbourne, as well as other cities of Australia, enforces strict specifications in the cleaning and collection of rain waters through open drainage networks that are incorporated in the road network. Finally, Singapore, a city with a particularly dense network of streams - equivalent in scale with that of Athens - promotes nowadays an impressive program for reforming existing open sewers.

In the case of Kephisos, despite intense pressures, the biggest part of the main river and tributary streams retain their natural state, to some extent from Nea Philadelphia up to the springs of Penteli and Parnitha. In this direction, the determination of protection zones against construction and land uses alteration is enforced in an oblong extent of 12.500 acres. Around Kifissos, there are several green zones with good prospects for the creation of recreation parks for the local residents. At the same time, the development of protected zones would also aim to establish a "green pathway" of communication between the residential block of Athens and the mountainous bulges of Parnitha and Penteli, which would be beneficiary in improving Athens's microclimate conditions. To support this, further work is ongoing with the following aims:

a) construction of small dams and embankments in the upper river catchment area in order to protect the downstream areas of Athens.
b) intervention in order to avoid contamination from urban and industrial sewage in the river.

A number of targeted engineering interventions were also planned to upgrade the Kephisos river system. Specifically:

- The river Kyklovoros trained 80 years ago with different closed sections, is the principal collector of the existing mixed storm water system (storm water and waste water for an area of 110 ha) of the centre of Athens. The training of the river Kyklovoros underneath the road Constantinople, in the last section of 4 km,

is provided by a twin closed orthogonal section in reinforced concrete for a flow of 170 m^3/sec.

- The river Profitis Daniil, tributary of river Kifissos also crosses the densely populated zones of Athens and has not been trained yet. The river Ilissos, also crossing the dense urban areas of Athens, was trained 40 years ago with closed sections; roads and parks have since been constructed on top of it. The river Profitis Daniil has an open section insufficient for the receipt of the storm waters, with many additional discharges of industrial and waste waters. The training of the last section of the river (1,200 m) is provided by a closed orthogonal section for a flow of 170 m^3/sec.
- The partial diversion of river Ilissos, for a flow of 100 m^3/sec, is also provided by a closed orthogonal section in reinforced concrete.
- The common diversion / junction of rivers Kyklovoros, Pr. Daniil and Ilissos with the river Kifissos was studied for a flow of 440 m^3/sec utilising a model from the laboratory of Hydrology of the National Technical University of Athens.

The training and the diversion of the rivers Kyklovoros, Profitis Daniil and partially of the river Ilissos are the most important projects for sewerage and flood protection of Athens.

After the engineering interventions, the Kephisos River contributes substantially to the flood protection of Athens. Nevertheless, the surface elevation difference between upland and low-land areas remains a basic restrictive parameter for the complete protection of the whole region of Attica. A more integrated management of the whole river basin, which suffers from significant pressures due to years of intense urban development should be considered a necessity.

A recent development towards this aim is the establishment of a river basin management authority, with participation from local, regional and national stakeholders, such as the Hellenic Ministry of Environment and Public Works, the municipalities along the river as well as private firms and industry operating in the vicinity of the river.

2 Analysis of the event

2.1 Causes

At 21/10/1994 00 UTC a low center (999 hPa) was situated over the Golf of Genoa. The cyclonic propagated eastward and 12 hours later was deepened (996 hPa) and moved over southern Italy (Figure 7). At 21/10/1994 18 UTC the low center was further deepened (994 hPa) while a cold front associated with the low center progressed toward the Ionian Sea. During October 21-22, 1994 the cold front passed over Greece and provoked extreme precipitation in several regions. In Figure 8, the geographical distribution of 24 h precipitation (from 21/10/1994 06 UTC to 22/10/1994 06 UTC) in Greece, as measured by rain gauges, is presented. Extreme rainfall occurred mainly in the mountainous western Greece (with daily value about 150 mm) and in the Attica region where the city of Athens is located. More detailed presentation of the event is given in Figure 9, where geographical distribution of hourly precipitation in several rain recorders installed in Athens, is presented. It can be observed that the stations located in the Kephisos river basin present analogous rainfall evolution and the rainfall's peak occurs at the time interval between 18:00-20:00 of the 21/10/1994.

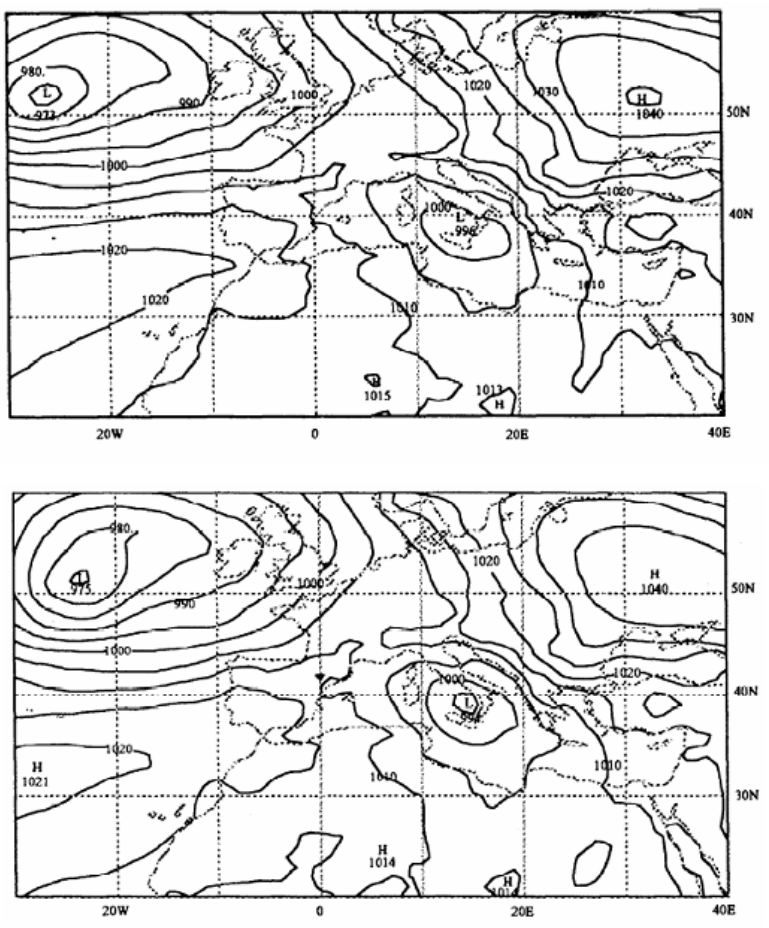

Fig.7: Surface pressure maps (5 hPa interval) in 21/10/1994 12:00 UTC (above) and 18:00 UTC (below) (Lagouvardos et al. 1996)

Fig.8: Geographical distribution of 24 h precipitation in Greece (from 21/10/1994 06 UTC to 22/10/1994 06 UTC)

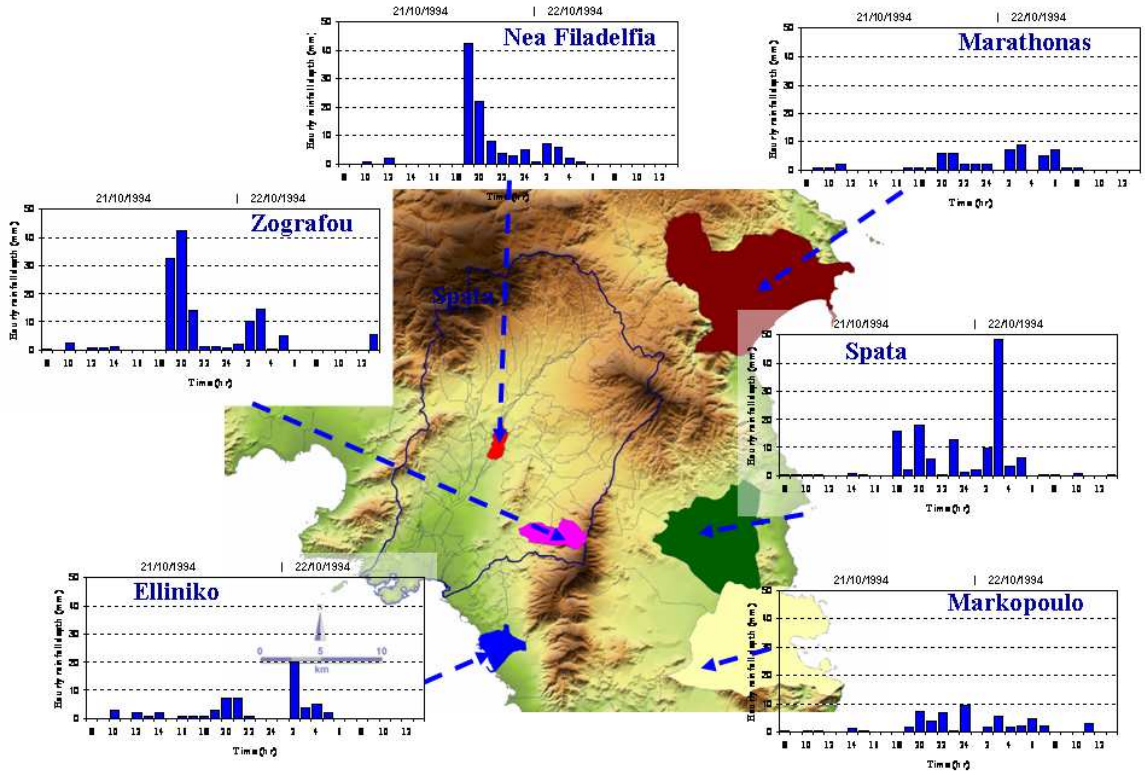

Fig.9: Geographical distribution of hourly precipitation in Athens area

2.2 Duration

Rainfall measurements of the specific event, with a time step of 10 minutes are available from the automatic telemetric meteorological station that is located in the NTUA University Campus in the Zographou area. In Figure 10, the 10 minute hyetograph of 21-22/10/1994, as measured at NTUA station, is presented. The maximum rainfall height was 17.5 mm and was observed at 19:40 of 21/10/1994. The maximum hourly rainfall height was 67.7 mm and was observed at the time interval between 19:30-20:30 of 21/10/1994.

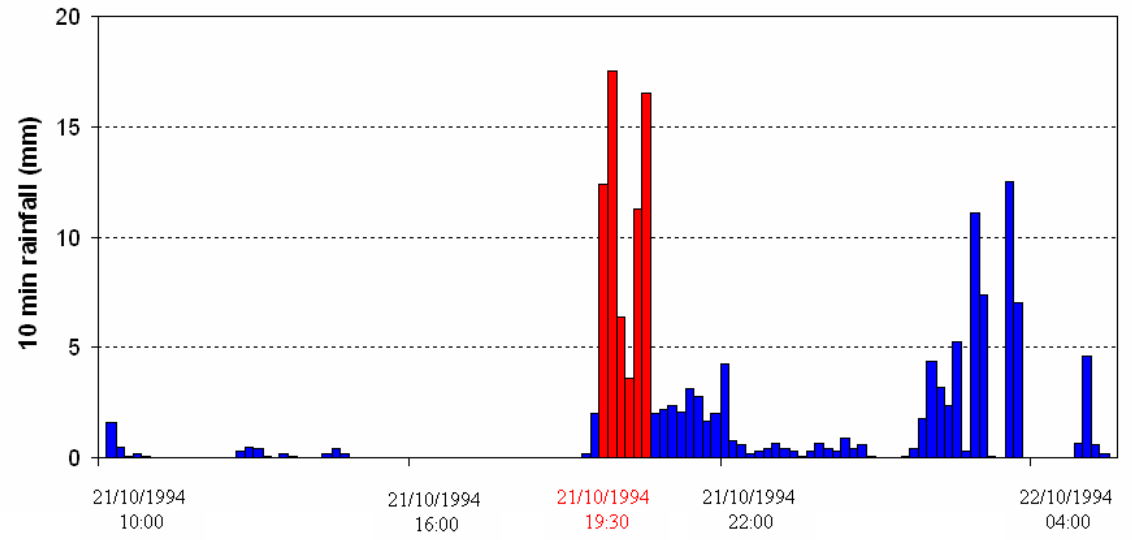

Fig. 10: 10 minutes hyetograph of 21-22/10/1994 in NTUA Campus station

2.3 Return period

In order to define the return period of the event, a frequency analysis of the storm was performed as presented in Figure 11. The event has also been studied by Mimikou and Koutsoyiannis (1995). The red curve includes the maximum rainfall intensities observed within the rainfall event for several durations (10 min, 20 min, 30 min, 1h, 2h, 6h, 12 h and 24 h). The curve is compared with the Intensity-Duration-Frequency (IDF) curves of Athens for return periods 10, 50 and 500 years. During the event evolution (21-22/10/1994) unusual high rainfall intensities (exceeding the 50 years return period) for durations greater than 1 hour, were observed. On the other hand, within the same event there were no significant rainfall intensities for 10, 20 and 30 minutes durations. The return period for these durations was estimated at approximately 10 years.

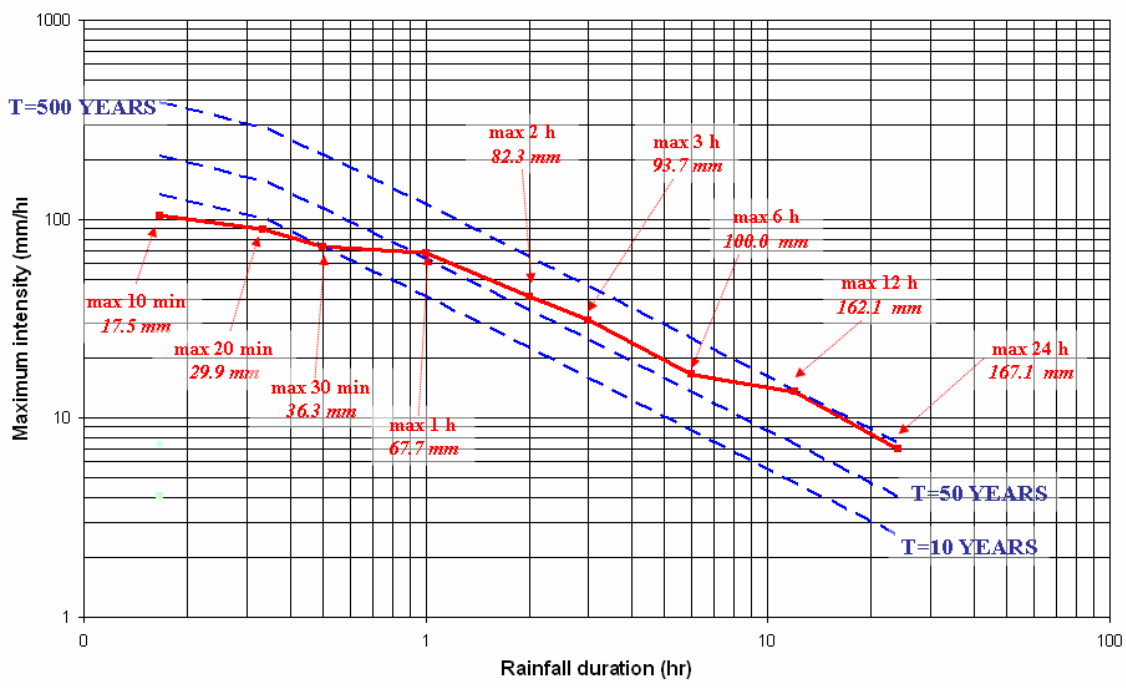

Fig.11: Frequency analysis of the storm as measured in NTUA station

2.4 Spatial distribution of damages and losses

In Figure 12 the geographical distribution of casualties and damages is presented. Eleven deaths were reported, while nine of them occurred in the greater Athens area.

The Ministry declared a state of emergency in Athens, while Army units joined to contribute to the rescuing operations. In several areas, dozens of homes and stores were flooded, while many cars were seriously damaged as they were swept along by water and some of them ended up into open shafts at work sites. Two buildings were evacuated because of subsidence and a small building collapsed. Hundreds of people were trapped in cars and buildings. In several cases the water elevation was 4 meters above the road surface. Several roads closed because of the water level. The building of the Communist Party of Greece suffered extensive damage, while the printing machinery of the Party's newspaper, was destroyed.

Extensive flooding occurred at areas neighboring to Kephisos River (Tavros, Moschato and Neo Phalero), when the river overflowed. The Corinth Canal closed to navigation as massive rubble, thick mud and gravel were swept by rain into the canal.

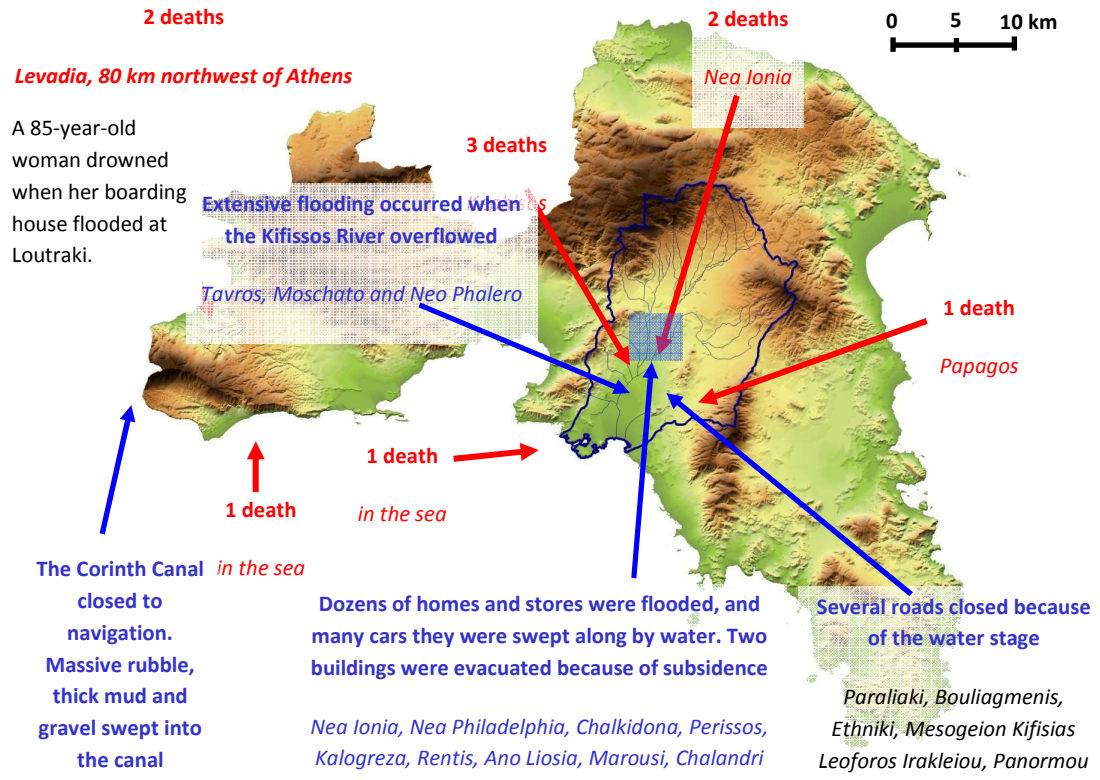

Fig.12: Geographical distribution of casualties and damages

2.5 Measures and Interventions

The development of Athens and the protection required of new infrastructure projects depend mainly on revising the flood – preventing mechanisms. In this direction, the fist task concerns the estimation of the capacities of existing facilities along with predictions on the future status of these capacities, as updated by new analysis and data (including seismologic, hydrologic, geotechnical and hydrometric data from ongoing research and new observation networks (Papathanasiou et al., 2009)).

There are several studies that need to be urgently undertaken as part of the Attika Basin flood protection plan:

- Kephisos management plan objectives: A significant re-thinking of the status of existing objectives needs to be undertaken, especially as far as the hydrological and flood protection criteria imposed are concerned, as well as the water quality status of the Kephisos estuaries.
- A flood risk analysis, in line with Directive 2007/60, which proposes a specific methodology for the evaluation of flood risks, needs to be undertaken for Attica.

- A Flood Protection Programme: Based on this plan, which should be based on the outcomes of the previous two studies, the stakeholder organizations need to study and construct essential flood-preventing interventions, including both hard and soft measures. including for example flood interception dams, pressure relief basins as well as sacrificial land. Specifically, the release of grounds, adjacent to the Kephisos River, to act as buffer zones and sacrificial land, appropriately landscaped as urban parks would constitute a beneficial action, which would give additional value to the areas around Kephisos as well as significantly enhance the overall standard of living in this part of Athens.

In closing, it should be emphasized that Kephisos is the main recipient of rainfall-runoff for Attica, and that makes it the corner stone of flood protection planning for Athens. Urgent attention, public investment and an inclusive participatory process in resolving its substantial problems is required to improve quality of life of the many inhabitants of its riparian areas as well as the flood protection level of the entire Greater Athens Area.

3 References

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