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 of Greece. In some of the affected areas, the precipitation height was equivalent to 140 mm, while in the center of Athens the respective quantity was more than 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 infrastructures. Dozens of homes and stores flooded, cars totally damaged, three buildings collapsed and hundreds of people trapped in cars and buildings give the outline of the disastrous impacts.

1 Introduction

1.1 Basic characteristics

1.1.1 Geographical characteristics

Kephisos River springs from Parnitha's mountain range, which is part of the National Forest and among 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 amounts to 22 km (14 km in residential area and 8 km outwards).

The history of the urban development around the Kephisos River is dated back to the disaster of Minor Asia in 1922. Many refugees moved to the Attica region looking for better living prospects, despite their low or zero-incomes. Thus, arbitrary construction took place leading to the

urbanization of «virgin» areas, such as the western part of Attika. In addition, the radical re-distribution of the country's population was dramatically increased as a result of new waves of settlers arriving in Athens after the civil war termination (1945-1949) and the internal immigration rise in general.

The urbanization of the western Attica caused an obvious socio-economic segregation in the population of Athens, something that was not mitigated as times went by. In Figures 1 and 2 the extensive urbanization that took place in the last 137 years around the river can be observed.

Fig. 1: Western Athens (1870) (Source: Laskaris 2008)

Fig. 2: Western Athens (2007) (Source: Laskaris 2008)

1.1.2 Geomorphological characteristics

The mountainous / semi - mountainous parts of the basin in Parnitha have been severely reshaped in years as a result of the recent devastating fire events. The morphology of the built-up areas is characterized by the smooth relief domination. The mountainous and semi-mountainous parts of 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) as of the high urbanization rhythms in the wider area. In addition, due to its karstic background, the watershed 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. Although the precipitation episodes are not such frequent as in the rest of Europe, these episodes are mainly short-lived storm events during the winter months. Summer months are dominated by frequent

heat waves occurring during July and August, when the temperature exceeds the 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 Kephisos' drainage basin. The upland areas are dominated by forests and bushes, while the lowland areas are now basic parts of 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 Kephisos River preserved its flow to the sea by discharging the 70% of the drainage basin, it suffered much by a significant decrease in its width as a result of the arbitrary disposition of rubbles and solid waste. The river degradation was also accelerated as of the illegal construction boom and the development of industry at the surroundings.

Nowadays, the built-up area of the Kephisos river catchment amounts to the 70% of its total extent, while this percentage is supposed to get increased in the future. In the following figures, typical examples of arbitrary construction activity are presented.

Fig. 3: Structures on river bed (Source: Laskaris 2008)

Fig. 4: Roads and houses on streambeds (Source: Laskaris 2008)

1.1.5 Protective measures

The flow management of the Kephisos river basin was initiated 35 years ago and accomplished in parts in 2004. The river has 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 in the Saronicos Gulf were considered low for current conditions and existing river training was being re-examined for flood regulation 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» up to the «Faliro» Bay and no further interventions for the discharge increase are needed
- From «Treis Gefures» up to «Agia Anna», the river is fully covered and upon the river Kifissos avenue has been constructed, as shown in figure 5.
- The river section profile is of «open form» from «Agia Anna» up to «Posidonos» Avenue
- The river is incised with an open section from «Posidonos» Avenue up to the river estuary in the sea
- From «Treis Gefures» upstream, the river is supposed to retain its open section profile
- Upwards of «Treis Gefures», 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 or liquid waste.
- Lately, after the devastating fire events in Parnitha, the restoration of damages in the existing old disposition of Kifissos from Treis Gefures up to Kokkinos Mulos (3 km length and 250 m^3/sec conveyance)

Fig. 5: 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 status in a great 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 flashing prospects for the creation of recreation parks for the local residents. At the same time, the existence and maintenance of these protected zones aims to establish a rigid open channel of communication between the residential block of Athens and the green mountainous bulges of Parnitha and Penteli, something beneficiary for the upgrading of the Athens microclimate conditions. To support this, further work is ongoing with the following aims:

a) the construction of small dams and embankments in the high river catchment area in order to protect the downstream areas of Athens along the trace of the river until the outfall in the Saronicos Gulf.
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. 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 to the river Kifissos is one of 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 Attika. It is obvious that an integrated management of the whole river basin, which suffers great pressures, as of the intense urban development in years, is a necessity.

A recent development towards this aim is the establishment of an institutional unit for river basin management, with participation from local, regional and national stakeholders, such as the Ministry of Environment and Public Works, the municipalities along the river and private firms who are based along 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 it was installed over southern Italy (Figure 6). At 21/10/1994 18 UTC the low center was further deepened (994 hPa) while a cold front associated with the low center has 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 7, 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 8, where geographical distribution of hourly precipitation in several rain recorders that are installed in Athens area, is presented. We can see 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.

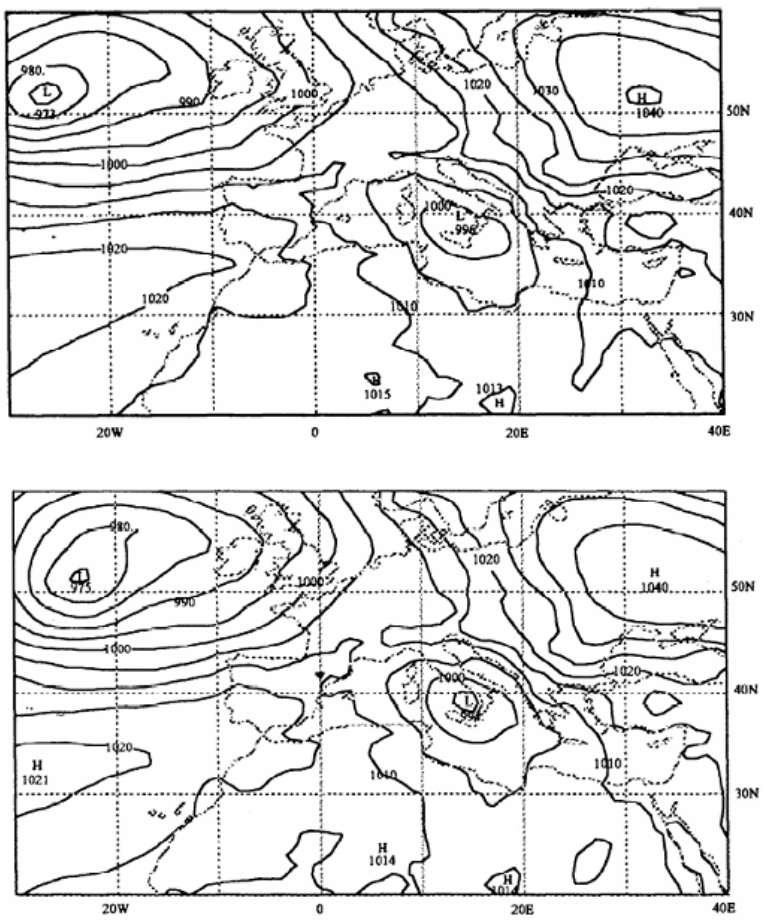

Fig. 6: Surface pressure maps (5 hPa interval) in 21/10/1994 12:00 UTC (above) and 18:00 UTC (below) (Lagouvardos et al. 1996)

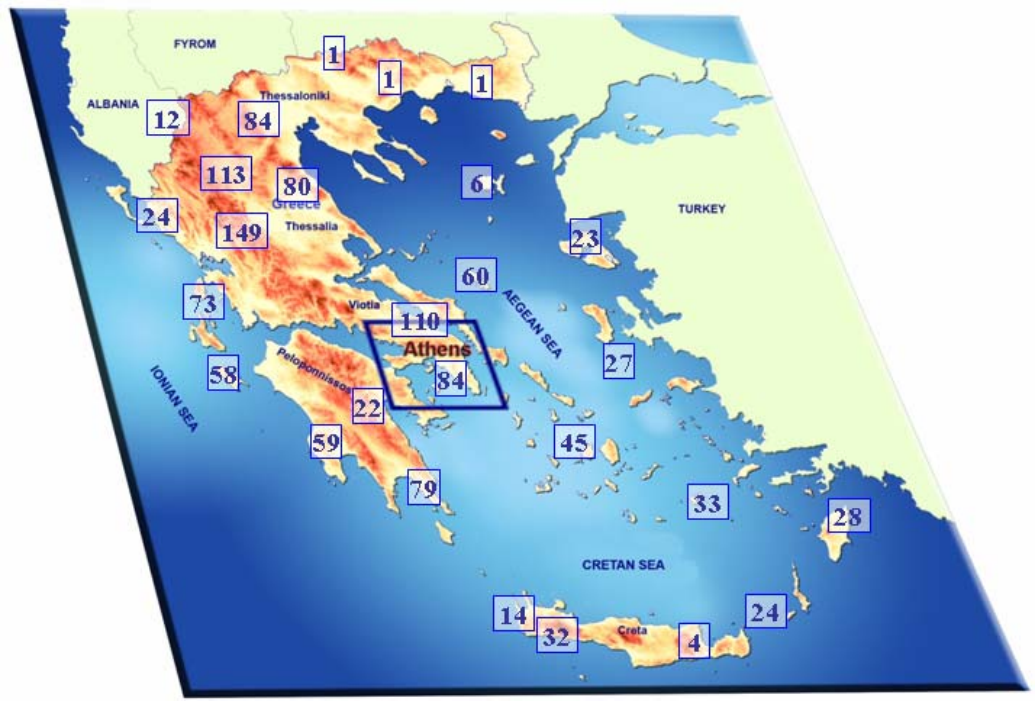

Fig. 7: Geographical distribution of 24 h precipitation in Greece (from 21/10/1994 06 UTC to 22/10/1994 06 UTC)

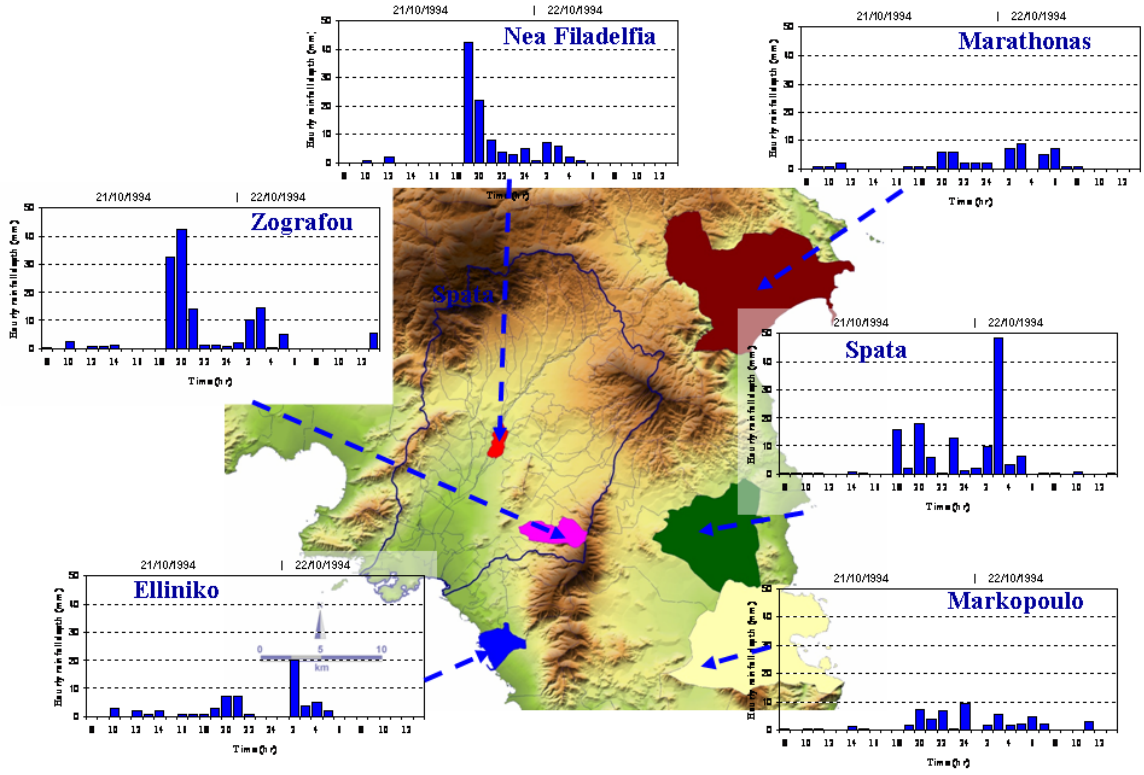

Fig. 8: Geographical distribution of hourly precipitation in Athens area

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 at Zographou suburb. In figure 9, 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 it was observed at the time interval between 19:30-20:30 of 21/10/1994.

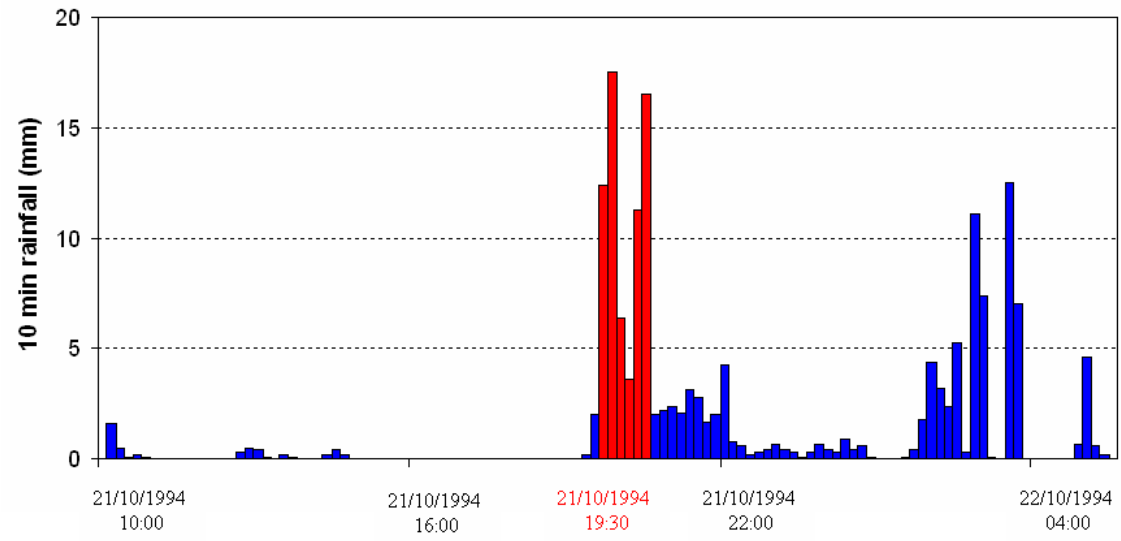

Fig. 9: 10 minutes hyetograph of 21-22/10/1994 in NTUA Campus station

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 10. 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 (exceeded the 50 years return period) for the durations greater than an

hour, were observed. On the other hand, within the same event there were not significant (about 10 years return period) rainfall intensities of 10, 20 and 30 minutes durations.

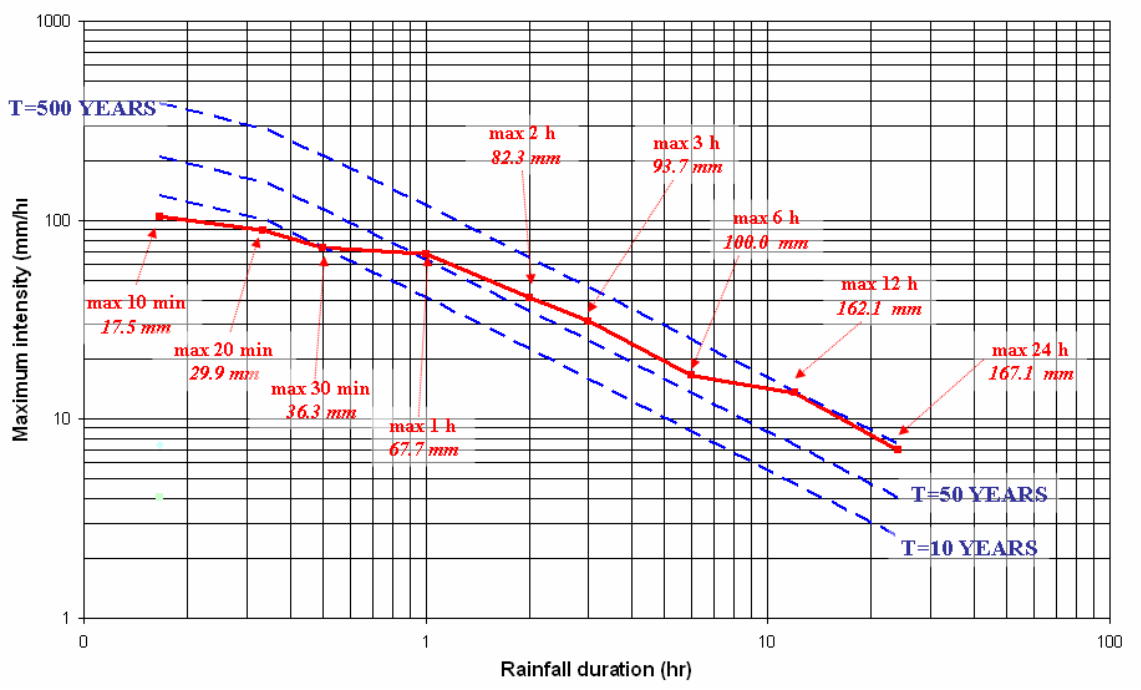

Fig. 10: Frequency analysis of the storm as measured in NTUA station

2.4 Spatial distribution of damages and losses

In Figure 11 the geographical distribution of casualties and damages is presented. 11 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 landed up into open shafts at work sites. Two buildings were evacuated because of subsidence and a small building was 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 stage. 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 waters overflowed. The

Corinth Canal closed to navigation as massive rubble, thick mud and gravel swept by rain into the canal.

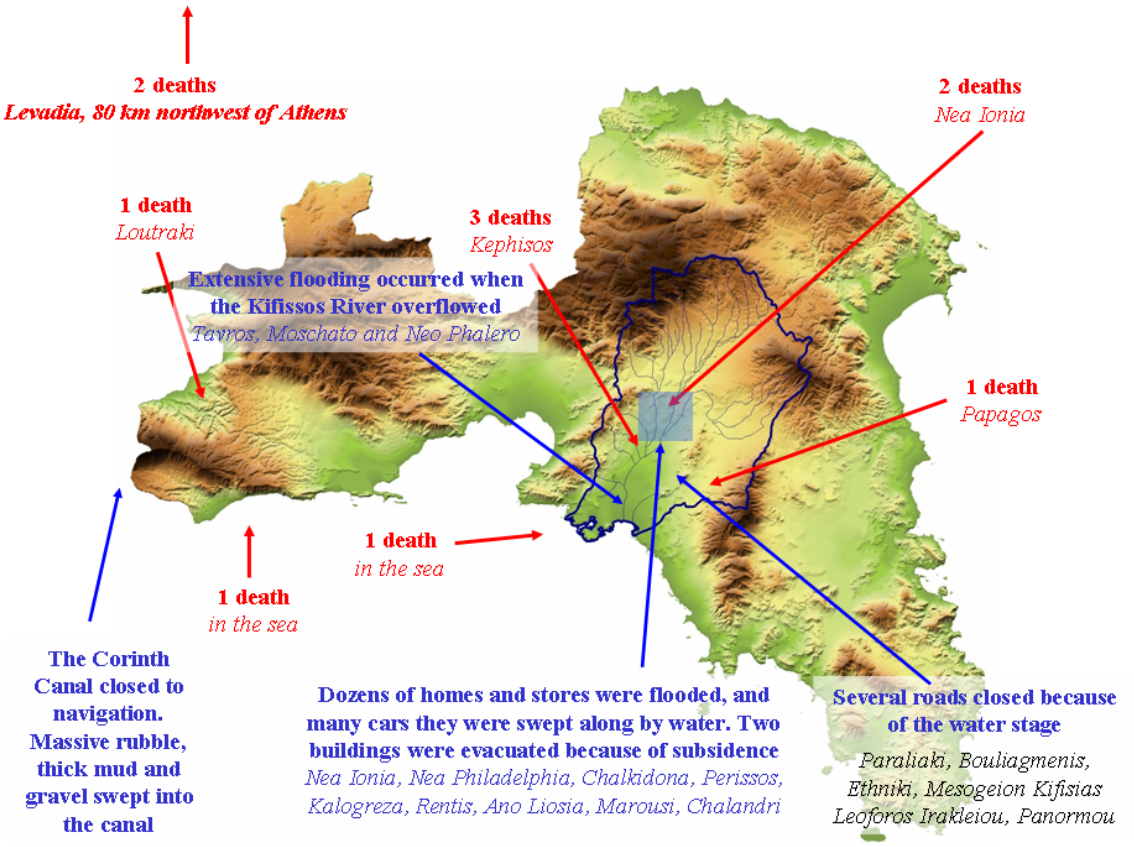

Fig. 11: Geographical distribution of casualties and damages

2.5 Structural measures

The development of Athens and the required protection of the new infrastructure projects depend mainly on the revising of the flood – preventing mechanisms. In this direction, the fist task to be done concerns the estimation of the capacities of the existing facilities along with predictions on the future status as updated by new data (i.e seismologic, hydrologic, geotechnical, hydrometric etc).

In this direction, there are several studies to be proposed as far as the Attika Basin flood protection is concerned.

- Kephisos management project: A significant update on the present status of existing works needs to be undertaken, especially concerning the hydrology and the flood protection criteria imposed, as well as the stagnant water status in the estuaries of Kephisos

- An Actualized Plan of Flood-preventing Protection: Based on this plan, the various organizations will program, study and construct the essential flood-preventing projects.
- Enforcement of Directive 2007/60 on the evaluation of flood dangers for the case of the Attica basin area

It should be pointed out that Kephisos is the main rainfall water recipient of Attika, something that renders the river as the core of flood protection planning. This issue should be carefully examined so that suitable measures be taken concerning mainly flood interception dams, pressure relief basins etc.

Finally, 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.

3 References

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