Mitigating flooding in a typical urban area in North Western Attica in Greece

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Abstract

Frequent floods in urban areas can pose threats to human lives and cause extensive devastation with long lasting consequences on properties and the environment. The frequency and impact of urban flooding are intensified by extended urbanization and the consequent land use change. More specifically, the expansion of impermeable areas in urban zones can cause rainfall events of low return period to produce the same or even more intense socioeconomic and environmental impact compared to rainfall events of high return period. For this reason, interventions in urban zones that are expected to deteriorate rainwater drainage conditions need to be accompanied by appropriate measures both structural and non-structural that ensure flood mitigation on the entire hydrological basin. In the absence of such measures which is usually the case, additional approaches to minimize flood impact need to be adopted. Flood effects are also intensified by poor urban design and inequitable development practices leading to greater water volumes that have to be managed in shorter times. A typical urban area that suffers from frequent flooding is the Community of Magoula, a community of 5000 habitats, located 21 km North West of Athens (Greece). The construction of a modern highway (Attiki Odos) that crosses the Community provided adequate flood protection locally, but was not accompanied by appropriate structural and non-structural measures to protect the entire basin. This paper presents an approach to expand insufficient infrastructure in order to provide adequate flood protection to the entire urban area of the Community of Magoula. In particular, the existing drainage pipe network of the area is expanded over a critical net of urbanised zones with low permeability, in order to mitigate flood events. The design of the proposed works was evaluated against both their capacity to successfully drain the flooded areas and the adequacy of the existing infrastructure to accommodate the incoming flow. The paper concludes with a set of complementary BMPs and non-structural measures that aim to ameliorate and mitigate flash flooding effects.

Keywords: Urban flooding, flash floods, rainwater drainage, flood mitigation, structural and non-structural measures

1. INTRODUCTION

Floods are natural hazards that are directly associated with socioeconomic and environment consequences, may impact cultural heritage and can also pose threats to human lives. These hazards become more frequent in urban areas, not only because of the higher concentration of people and property but also due to the extended percentage of impermeable land.

In general, when urban development is not accompanied by adequate hydraulic works, the vulnerability of the area to flooding is increased. When urbanized areas have insufficient or incomplete infrastructure for flood protection and also when urban expansion is not accompanied by appropriate measures to mitigate flood effects, the impacts of floods are further intensified (Papathanasiou *et al*., 2012).

Sometimes, infrastructure works *per se*, and in particular facilities necessary for socioeconomic development, such as the construction of road networks and buildings, have a negative impact on the response of a catchment to potential flooding. More specifically, works that affect the hydromorphology of an area and increase the percentage of impermeable areas are also increasing the volume of the water that travels to the outlet of the catchment, as infiltration and retention are decreased, and the travel time of water over the catchment is minimized.

To this end, works that affect the vulnerability of an area to flooding need to be accompanied by additional adequate flood mitigation measures, so as to minimize any potential adverse impact. However, this is not always the case. In many cases, such works are either not accompanied at all by flood mitigation measures, or they are accompanied by complementary measures which are yet not sufficient for flood mitigation and protection.

The adoption of a holistic approach towards flood management of urban areas is therefore required, especially in cases of large-scale infrastructure works that increase vulnerability to flooding. In this view isolated, independent flood mitigation measures that serve specific works need to be co-evaluated with existing works within the river basin, and complemented if necessary with additional structural or non-structural measures. The aim of this paper is to highlight the need of integrated urban flood management in areas where major infrastructure has been constructed and to investigate the need for further structural and non-structural measures.

2. STUDY AREA

The study area of this research is the Community of Magoula, which is located in North Western Attica region, in Greece and according to the recent *Kallikratis scheme* (Greek Law 3852/2010) is part of the Municipality of Elefsina. More specifically, the study area is located 21km North West of Athens, the capital of Greece.

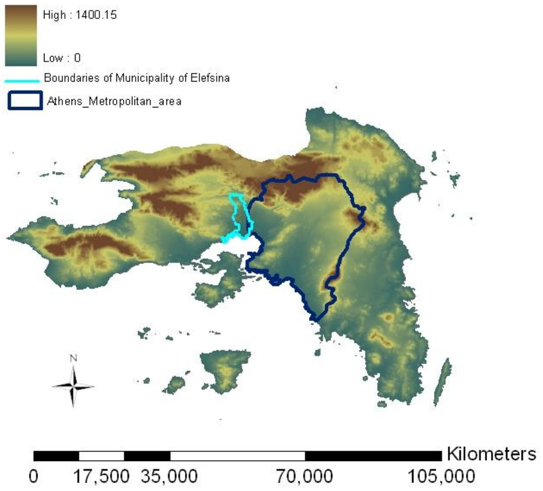

Fig 1. The DEM of the study area (cyan line over the DEM of Attica Region)

The Community of Magoula experienced a significant **population growth**, especially during the last decades. During 1991-2001 the area was characterized by intense industrial activity, accompanied by a corresponding increase in population. According to population statistics published by the National Statistical Service of Greece (as available at http://geodata.gov.gr) in 1991 the area was populated by 2663 habitants, in 2005 its population reached 4005, while according to the latest population census of 2011 the area is currently inhabited by 4,992 people.

The extended population growth of the study area was accompanied by **large-scale infrastructure works** in the area. The construction of Attiki Odos, a 52 km long motorway, which traverses the prefecture of Attica, connecting the city centre and suburbs to the international airport Eleftherios Venizelos, has been a major breakthrough in transportation terms for the metropolitan area of Athens.

The construction of the motorway altered the hydromorphological characteristics of the crossing areas, both by disconnecting flood plains and by changing the physical characteristics of natural streams (canalisation, change of time of concentration, etc.). The project has been completed with adequate provisions for flood protection regarding the safety of the motorway and most of the adjacent areas. In many cases however local authorities did not follow in taking all necessary measures to prevent floods in their areas of responsibility and as a result large areas remain vulnerable to flood events.

In geomorphological terms the study area is characterized by steep upstream slopes that minimize water travel times during intense rainfalls, and by mild slopes in the urbanized zones where most flood events are observed.

In hydrometeorological terms, the area is characterized by intense rainfall events during the winter. The Hydrological Observatory of Athens (HOA), operated by the Centre for Hydrology and Informatics (CHI) of the National Observatory of Athens (NTUA), is a state-of-art hydrometeorological network that covers adequately the greater Athens area and records hydrometeorological parameters with a 10-min temporal resolution (Papathanasiou *et al*., 2013a). One of the stations of this network, Mandra station, can be considered as representative of the study area. Based on rainfall recordings retrieved from HOA for this particular station for the hydrological years 2005-2014, the mean annual rainfall per hydrological year is approx. 570mm. This value is significantly higher than the mean annual rainfall of Attica region, which is approx. 400mm.

The hydrometeorological and geomorphological characteristics of the river basin combined with the increased urbanization rate render the study area particularly prone to floods. Despite the fact that a number of works have been completed especially in the vicinity of Attiki Odos Motorway, large areas within the boundaries of this flood prone Community remain without sufficient protection against flood events.

3. METHODOLOGY

The flood prone urban area of the Community of Magoula is receiving flows from 4 subasins extending over 208.21 ha, 32.08 ha, 19.41 ha and 23.64 ha respectively (Fig. 2). Adequate drainage is provided only in one out of the 4 sub-basins (i.e. the basin no 4 in Figure 2,) by a pipe drainage network that conveys rainwater safely downstream.

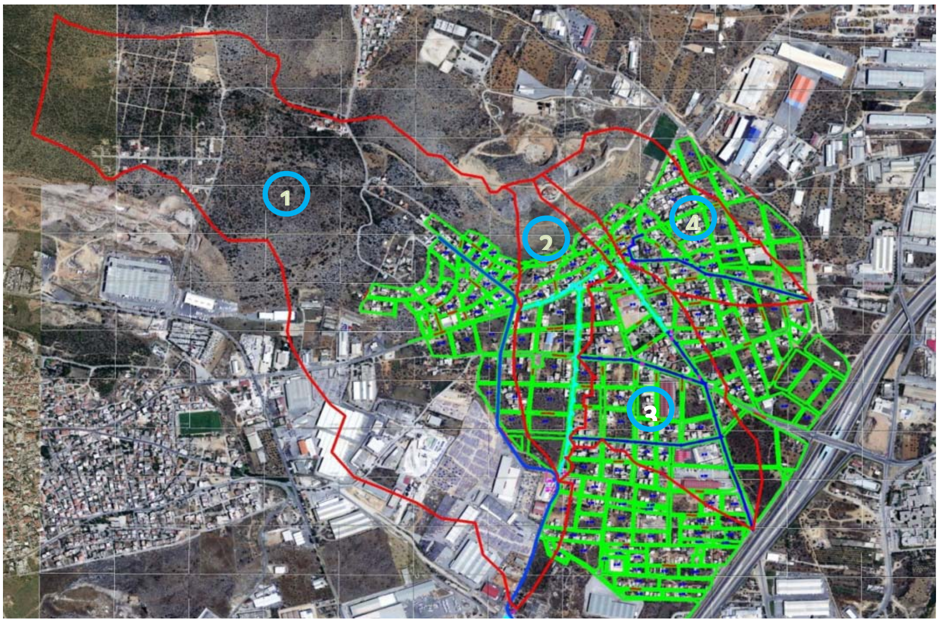

Fig.2 River basins in flood prone areas in the Community of Magoula

As mentioned earlier, physical outreaches of the basin are intercepted by Attiki Odos Motorway, and are safely conducted downstream. Large parts of the urban zones however remain unprotected during floods due to inadequate infrastructure. An incomplete pipe network constructed to drain rainwater does not cover large areas of the urban zone which remain vulnerable during flood events (Fig. 3).

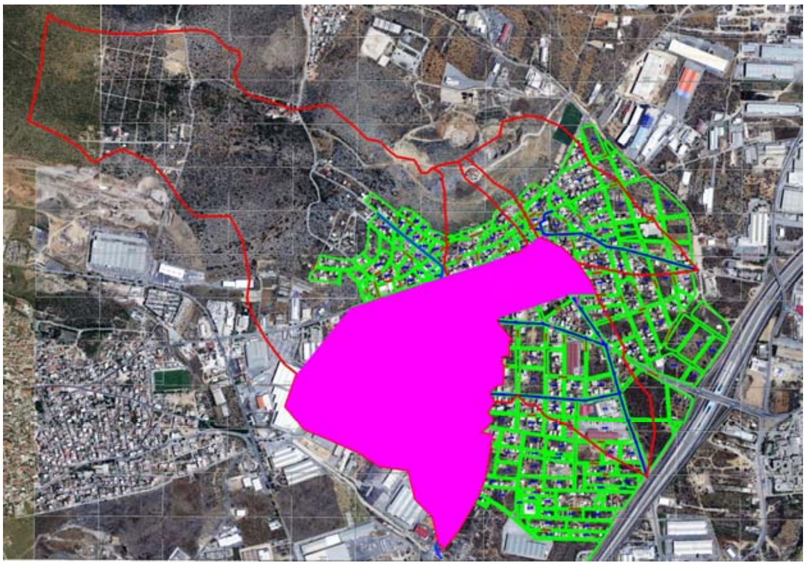

Fig.3 Flood prone areas in the Community of Magoula

To this end, targeted interventions at selected zones need to be undertaken in order to address the problem and provide adequate protection to human lives and properties. An extended study was conducted for the study area and the construction of several structural works for flood mitigation was examined. A detailed survey was carried out, in order to identify critical areas for floods within the study area, during which existing infrastructure was also recorded. Interventions include the extension of the existing pipe network (Fig 4a), while in a separate study that has been conducted independently the construction of a 2.5 km long culvert 1.5×1.3 has been proposed to collect rainwater before reaching the urban zones and conduct it safely downstream (Fig 4b).

(4a) (4b)

Fig.4 Flood protection works in the area: Fig. 4a Extension of existing pipe network and Fig.4b Drainage culvert.

Pipes capacity and dimensioning was based on the same Intensity – Duration – Frequency (I-D-F) curve used for the construction of the existing pipe network, which is outlined as follows (Equation 1):

$$i = 45.42 \times T^{-0.20} \text{ (Eq. 1)}$$

where: i = rainfall intensity (mm/hr)

T = return period (years)

Pipe stations, set at approximately 50 m intervals were used to subdivide subasins in order to improve the accuracy of calculated water volumes. For each subdivided area, a unique coefficient of permeability was used, and the corresponding runoff was calculated using the I-D-F curve presented in Equation 1. The capacity of the pipes was checked against the height of water within each pipe, which was not allowed to exceed 70% of the diameter of the pipe. Following this methodology, the appropriate dimensioning of the pipe drainage system was estimated for floods with T= 10 years return period.

Furthermore, the extension of the existing pipe network was co-evaluated with the second relevant structural work in the area, *i.e.* the drainage culvert that has been designed in a separate, independent study. In order to further reinforce the flood protection system of this flood-prone urban area, complementary Best Management Practices (BMPs) and optional non-structural measures in the area were also considered.

4. RESULTS

The results of this methodology are presented in the following tables. The proposed pipe network will have two independent branches, one in subbasin 1, which is further discretized into three sub-branches, and another one in subasin 2. The hydraulic characteristics of all four pipes of the proposed network were calculated and are presented in the following Tables.

Table 1. Hydraulic characteristics of the pipe no 1a (subbasin 2)

Station	Pipe		Runoff area				Time	Intensity	Discharge		Diameter	Slope	Velo-city
			c=0.30		c=0.60								
	Elev.	Length	Cum.	Total	Cum.	Total		1:10	Cum.	Total			
(-)	(m)	(m)	(ha)	(ha)	(ha)	(ha)	(min)	(mm/hr)	(l/sec)	(l/sec)	(m)	(‰)	(m/sec)
				0.50		0.61	10.00	64.99					
N17	54.69	55.00	0.50	1.01	0.80	1.41	10.00	64.99	207	207	0.60	19.3	2.63
N16	53.63	32.00	0.50	1.51	0.71	2.12	11.66	63.03	102	309	0.60	28.4	3.39
N15	52.72	50.00	0.50	2.02	0.64	2.76	13.87	60.88	90	399	0.60	21.0	3.25
N14	51.67	45.00	0.50	2.52	0.61	3.37	15.17	59.80	86	485	0.60	13.5	2.89

Table 2. Hydraulic characteristics of the pipe no 1b (subbasin 2)

Station	Pipe		Runoff area				Time	Intensity	Discharge		Diameter	Slope	Velo-city
			c=0.30		c=0.60								
	Elev.	Length	Cum.	Total	Cum.	Total		1:10	Cum.	Total			
(-)	(m)	(m)	(ha)	(ha)	(ha)	(ha)	(min)	(mm/hr)	(l/sec)	(l/sec)	(m)	(‰)	(m/sec)
						0.10	10.00	64.99					
ΦN19	51.88	55.00	0.50	0.50	0.81	0.91	10.00	64.99	126	126	0.60	12.0	1.93
ΦN18	51.22	55.00	0.50	1.01	0.60	1.52	11.18	63.56	91	217	0.60	2.9	1.32

Table 3. Hydraulic characteristics of the pipe no 1c (subbasin 2)

Station	Pipe		Runoff area				Time	Intensity	Discharge		Diameter	Slope	Velo-city
			c=0.30		c=0.60								
	Elev.	Length	Cum.	Total	Cum.	Total		1:10	Cum.	Total			
(-)	(m)	(m)	(ha)	(ha)	(ha)	(ha)	(min)	(mm/hr)	(l/sec)	(l/sec)	(m)	(‰)	(m/sec)
							15.17	59.80					
N13	50.86	20.00	0.00	0.00	0.12	0.12	15.17	59.80	714	714	0.80	48.0	5.06
N12	49.90	60.00	0.00	0.00	0.52	0.64	18.25	57.63	50	764	0.80	13.5	3.24
N11	49.09	60.00	0.00	0.00	1.12	1.76	18.84	57.26	107	872	0.80	7.2	2.62
N10	48.66	50.00	0.00	0.00	0.66	2.42	19.08	57.12	63	934	0.80	13.0	3.36
N9	48.01	55.00	0.00	0.00	1.62	4.04	19.58	56.82	153	1,088	0.80	10.9	3.25
N8	47.21	50.00	0.00	0.00	0.55	4.58	19.94	56.62	51	1,139	1.00	5.3	2.53
N7	46.94	50.00	0.00	0.00	2.02	6.60	20.10	56.53	190	1,329	1.00	7.0	2.91
N6	46.39	50.00	0.00	0.00	0.49	7.09	20.30	56.41	46	1,375	1.20	3.1	2.17
N5	46.24	45.00	0.00	0.00	1.58	8.67	20.38	56.37	148	1,524	1.20	8.0	3.16
N4	45.88	50.00	0.00	0.00	0.42	9.09	20.63	56.23	39	1,563	1.20	4.0	2.45
N3	45.68	50.00	0.00	0.00	0.83	9.92	20.73	56.17	78	1,641	1.20	5.5	2.80
N2	45.40	45.00	0.00	0.00	0.69	10.60	20.88	56.09	64	1,705	1.20	2.2	1.98
N1	45.20	50.00	0.00	0.00	0.33	10.93	20.93	56.07	31	1,736	1.20	5.4	2.82
S1	44.93	14.00	0.00	0.00	0.33	11.26	21.15	55.95	30	1,766	1.20×1.30	2.9	2.20
S2	44.89	22.00	0.00	0.00	0.00	11.26	21.23	55.85	0	1,766	1.20×1.30	3.2	2.18

Table 4. Hydraulic characteristics of the pipe no 2 (subbasin 3)

Station	Pipe		Runoff area				Time	Intensity	Discharge		Diameter	Slope	Velocity
			c=0.30		c=0.60								
	Elev.	Length	Cum.	Total	Cum.	Total		1:10	Cum.	Total			
(-)	(m)	(m)	(ha)	(ha)	(ha)	(ha)	(min)	(mm/hr)	(l/sec)	(l/sec)	(m)	(‰)	(m/sec)
				1.40		0.84	10.00	64.99					
N24	51.23	50.00	0.00	1.40	0.25	1.08	10.00	64.99	194	194	0.60	25.4	2.85
N23	49.96	55.00	0.00	1.40	0.61	1.70	12.44	62.22	64	257	0.60	18.4	2.75
N22	48.95	60.00	0.00	1.40	0.79	2.48	13.83	60.91	80	337	0.60	17.8	2.93
N21	47.88	55.00	0.00	1.40	0.62	3.10	14.99	59.94	62	399	0.60	17.5	3.03
N20	46.92	55.00	0.00	1.40	0.66	3.76	16.02	59.15	66	464	0.60	27.7	3.55

The completion of the pipe drainage system will relieve an area extending over 2 subasins (32.08 ha and 19.41 ha respectively), thus significantly reducing the associated flood risk. This work is supported by the second structural work designed for the area, *i.e.* the drainage culvert (Fig. 3b).

As indicated in the Section Methodology, in order to reduce the permeability coefficients in the area and consequently the runoff times, complementary sustainable drainage systems and other non-structural measures are also proposed. To this end the most appropriate BMPs and non-structural works have been selected by taking into consideration their impact on the society and the environment and the morphological particularities of the study area.

Regarding BMPs, an efficient practice concerns the construction of green roofs. According to this practice, each dwelling may convert roof toppings into a green roof in order to increase the evapotranspiration and consequently decrease the runoff volume. This practice has also other complementary advantages, since it contributes in reducing local temperature during the summer (Lee *et al.*, 2013). As a second measure permeable parking spaces could be considered, especially in large industrial premises that exist in the study area. Large parking areas within the urban zones may increase the permeability coefficient by replacing bituminous materials with permeable ones (Brown and Borst, 2015, Freeborn *et al.*, 2012). Additional source control measures for detention and attenuation of flood discharges could also be foreseen. For example, a number of small detention ponds can be constructed at selected areas upstream to attenuate flow before reaching the urban zones. The selection of the appropriate locations for the construction of these attenuation ponds is a project outside the scope of this paper, and should be examined with reference to the hydrological and hydromorphological characteristics of the catchment and in conjunction with the existing infrastructure.

As far as non-structural measures are concerned, the following could be applied in the flood prone areas so as to further decrease exposure to flood risk. First of all, campaigns to raise public awareness on flood risk issues can contribute to the overall public environmental awareness and force towards solutions by making environmental and in particular flood related issues personal problems. Given that the study area is a typical urban area, flood proofing can be reinforced through regular cleaning of the drainage channels, followed by a necessary removal of harmful substances that could be carried away by flood water. In addition, an Early Flood Warning System could be developed (usually in cooperation with adjacent Municipalities) to support stakeholders and local authorities in taking in-time the right decisions against flooding (Serbis *et al.*, 2013).

5. DISCUSSION AND CONCLUSIONS

In this research, the flood protection of the study area was initially designed considering the construction of appropriate structural measures. Indeed, as verified in Chapter 4, the extension of the existing pipe network contributed in safely draining flood discharges. However, it seems that in order to further reinforce flood protection of the area on the long-run, additional long-lasting solutions need to be evaluated and when necessary undertaken. Therefore, further to the construction of structural works, the undertaking of complementary BMPs and other non-structural measures, appropriate for the area, is examined.

For a typical urban area with the particularities of the study area, further to the extension of the existing network, suggested BMPs include the construction of green roofs, permeable parking spaces and additional source control measures (*e.g.* small detention ponds), to attenuate flood discharges. Additional environment-friendly and long-lasting solutions include the undertaking of non-structural measures such as public awareness raising campaigns, regular cleaning of the drainage channels and development of an Early Flood Warning System.

More specifically, structural works usually have more direct results; yet their construction cost could become prohibitive, as they need appropriate maintenance, while sometimes they are also characterized by a significant environmental footprint (Serbis *et al.*, 2013). On the other hand, non-structural measures are typically environment-friendly and they could be associated with a lower cost; yet they often need time to be accomplished and have the desired effect and usually they can be inadequate when undertaken alone. To this end, it is suggested that in order to reduce flood risk in an area, a combination of appropriate structural and non-structural measures could have the optimum results (Papathanasiou *et al.*, 2013b).

Particularly for urban environments, the undertaking of BMPs, which not only reduce flood discharges but also improve flood water quality, emerges as another effective option. In principle, most BMPs are structural works; yet several non-structural measures (such as public awareness campaigns, maintenance practices *etc.*) can be safely considered as BMPs. These environment-friendly solutions could be particularly efficient when properly designed.

To sum up, a program of measures that includes structural works, BMPs and appropriate non-structural measures seems to be the optimum option in order to achieve efficient flood risk protection in typical urban areas. A wide range of such solution can be found in literature. These solutions need to be co-evaluated with case-specific criteria, including environmental and socioeconomic criteria, as well as particularities of each area in terms of hydrometeorology and geomorphology. In such a case, the area can be effectively protected from floods on the long run.

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