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FLOOD HISTORY ANALYSIS AND ITS CONTRIBUTION TO FLOOD HAZARD ASSESSMENT. THE CASE OF MARATHONAS, GREECE

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Abstract

Flood history analysis contributes decisively to a more realistic assessment of flood hazard. In this work, systematic data collection on past flood events in Marathonas area (Attica, Greece) together with the development of a database, allowed the thorough study of flooding phenomena and their evolution over time. The study area consists of three dominant catchments with rich flooding history, namely Rapentosa, Charadros and Kato Souli. Information gathered from governmental and insurance organizations, emergency agencies, the press, field interviews and other documentary sources, along with geomorphologic and geologic evidence, were stored, structured and analyzed in a GIS platform and were used to reconstruct flood events with detail. Valuable results were produced concerning the causes, the characteristics, the spatial distribution of damages and the extent of inundation for each event. Moreover, the rate of recurrence of flooding phenomena was calculated across the floodplain, so that the areas of higher risk were identified and delineated. The active part of the floodplain was outlined and its migration overtime was studied. Furthermore, the methodology underlined the imperfections of the existing risk mitigation strategy and the past emergency experiences were appraised in a way that they highlight the priorities and will help improve management of future situations of risk.

Key words: *flood hazard, flood history, Marathonas, flood frequency, Marathon, Attica, Greece.*

1. Introduction

In many parts of Greece flooding occurs in small, flash flood prone watersheds drained by ephemeral water courses with little or no water at all for most of the year. In this context and given the scarcity of instrumental hydrological records, classic hydraulic modeling may not be adequate in assessing flood hazard. Thus, the use of alternate methods becomes necessary for a better understanding of the flooding processes and the mitigation of the associated risk. Analysis of flooding history is a technique that can produce results within these limitations. Historical flood records have been used in the past in the Mediterranean region (e.g. Garcia & Garcia 2003) and around the world (Benito et al 2004, Hergert & Meurs 2007) to improve the knowledge in the field of hydrological extremes. Historical flood analysis focuses on identifying hazard areas based on careful reconstruction and examination of past flood events. The objective of this work is to outline a methodology that contributes to an in depth appraisal of the flooding problem in a specific area, in this case Marathonas in Greece, regardless the availability of instrumental records.

Ψηφιακή Βιβλιοθήκη Θεόφραστος - Τμήμα Γεωλογίας. Α.Π.Θ.

Fig. 1: Map showing the three catchments, the drainage network and the main settlements and landmarks. At the north east part of the map Myrtia borders with Charadros, which in turn borders with Rapentosa catchment from the south.

2. Background

2.1 Setting

The study area lies in the north-east part of Attica in Greece and consists of three relatively small catchments, namely Rapentosa, Charadros and Myrtia (Kato Souli). In terms of geomorphology, it comprises of a hilly area, with steep slopes and the famous for its battle plain of Marathonas, through which the drainage networks flow into the sea. The area is inhabited by approximately 8000 people with Marathonas and Kato Souli being the most important settlements.

The southernmost catchment (37,5 km^2) is drained by Rapentosa torrent and borders with Nea Makri from the south and with Charadros catchment from the north. The drainage network reaches the north side of Penteli and Dionysos and runs off, forming a steep gorge, into Marathonas plain and through Vranas settlement. At present the torrent is drained at the last part of its course by an artificial underground waterway. Bordering from the north with Rapentosa, Charadros is the largest of the 3 catchments, even though its drainage area was reduced to 60,2 km^2 after the construction of Marathonas' dam in 1929. It reaches the sea at the central part of the plain, passing between Kotroni and Stavrokoraki hills and through the modern village of Marathonas. The third and smallest catchment (15,2 km^2) is drained by Myrtia torrent, a poorly developed drainage network which flows into a marsh, lying on the north-east part of the plain. The water, leaving the hilly area drains into artificial channels until it reaches the swamp and subsequently the sea through a manmade canal. All three catchments are dry for most of the year.

Ψηφιακή Βιβλιοθήκη Θεόφραστος - Τμήμα Γεωλογίας. Α.Π.Θ.

In terms of geology, the study area consists of a series of Mesozoic formations, accompanied by postalpine Cenozoic sediments. From base to top, one can distinguish lower-middle Triassic marbles followed by Northeastern Attiki Schist formations with marbles intercalations of Jurassic age and Northeastern Attiki Marbles of Cretaceous age. Upper Miocene breccioconglomerates and fluviolacustrine formations can be found on top of the Mesozoic series. Fine grained fluvial deposits of Pleistocene age are abundant Charadros banks. The plain is dominated by Holocene alluvial deposits accompanied by some talus cones.

2.2 Previous works

Historical flood records have been used in the past for the study of flood risk. Potter (1978) first suggested that the past behaviour of a river is a very important ingredient in all hydrological investigations and can be exploited thoroughly with the use of information contained in historical records. Bayliss and Reed (2001) proposed flood history study as an alternative practice to improve our knowledge on hydrologic extremes. Glaser and Stangl (2003) suggest that historical records are an important source for the evaluation of frequency of such events. Both Potter (1978) and Bayliss and Reed (2001) recommended periodical journals, newspapers, chronicles, specialists reports, government databases, pictures, the world wide web and other various sources as a basis for information mining. Barriendos et al (2003) suggested local and central government, church and private collections and notarial archives as good sources of information.

Previous works exploited documentary data to provide further understanding on the flooding problem of several places. Glaser and Stangl (2003) studied extreme inundation events in central Europe since 1300 using documents dating back to the middle ages and other anecdotal evidence. In their study they connected flood occurrence with historic climate and atmospheric patterns. Macdonald et al (2003) used documentary data, newspapers, epigraphic records and eyewitness observations along with instrumental records in order to examine the flood-generating mechanisms of river Ouse in UK. In their study they reconstructed flooding history since 1600AD and suggested that its analysis can improve understanding of flood risk considerably. Herget and Meurs (2007) studied past extreme events in the city of Cologne in Germany with the help of written descriptions, paintings and other evidence and recreated peak river discharges for historical floods. Past flood data were also utilized to project the evolution of flooding in time and space. Conesa Garcia and Garcia Garcia (2003) used anecdotal evidence to reconstruct flooding history of Cartagena, in Spain, identifying high and low risk locations.

Documentary hydrological data have been correlated in the past with flood event frequencies to improve risk prevention and readiness. Bayliss and Reed (2001) studied the case of river Avon at Worcestershire and suggested that it is essential in flood risk studies to review flood frequency curves by augmenting existing data with the use of historical records. Agasse (2003) collected data from the press, official telegrams, unpublished reports and interviews with local people and reconstructed Normandy’s flooding record during 17th to 20th centuries. In this study Agasse examined the trends of flood frequency and intensity. Williams and Archer (2002) collected data from unpublished reports, meteorological magazines and websites to reconstruct floods in the English Midlands. In their study, they demonstrated how flood history improves risk assessment as it is carried out through the use of conventional hydrometric record. Benito et al (2004) suggested that systematic and non-systematic data can be combined to improve flood frequency analysis with direct impact on flood risk assessment.

3. Data

The basic concept of examining flooding history is the collection of information about every single event recorded, followed by data structuring and analysis with specific techniques. Therefore, the starting point of this investigation was the identification of data sources.

Ψηφιακή Βιβλιοθήκη Θεόφραστος - Τμήμα Γεωλογίας. Α.Π.Θ.

3.1. Data types and sources

As far as local government organizations are concerned, the Prefectural Administration of East Attica provided detailed reports about flood damages on infrastructure, including damaged property owners' accounts, description of locations, of water height and extent. The municipality of Marathonas provided documents and verbal descriptions of past events. Information was also gathered from central government organizations, i.e. the General Secretariat of Civil Protection and the Earthquake Rehabilitation Service, in the form of maps demarcating flood zones and districts that were hit in the past. Greek Fire Department provided a database of emergency incidents concerning flooding in the area, reporting locations, time and type of event. Data on damages on agriculture were collected from the Hellenic National Agricultural Insurance Organization along with damage type and time specifications. National and local newspapers and were researched in depth for articles describing flood damages and conditions. Their archive was easily accessible and of very good quality and coverage through the years. World Wide Web was proved an excellent guide to locate information sources and damage compensation mandates. Pictures and videos obtained from national channels, newspapers, websites and local residents were exceptionally revealing of the conditions of flooding. Details on damages and observation on water stage and extent were collected by interviewing local people. Data were also collected from the Archaeological Society at Athens which contained a considerable amount of information in the form of diaries and written descriptions due to the continuous presence of researchers since the 19th century.

3.2. Data compilation

Since the ancient years the plain was notorious for its floods. Charadros became proverbial for its fierce floodwaters in ancient local societies (Hammond 1968). Locally, the river god was worshiped as the lord of the violent force of Charadros (Sekunda 2002), showing a form of primitive knowledge concerning the local flooding phenomena. However, the first detailed description of a flood event comes from Leake (1841). In his work, he describes a violent flood that washed away many houses in the settlements of Marathonas and Bei in the autumn of 1805, changing the landscape completely. The events occurred after Rapentosa and Charadros torrents inundated large areas of the plain. Leake (1841) also mentions that Charadros and Rapentosa are noted for their 'occasional impetuosity' and that the plain is usually subject to inundations from the two torrents ('particularly Charadros'). Davidson (1880) describes a flash flood in 1879 that carried away a lot of material from the banks of Charadros from the inner parts of the plain to the sea. Hughes (1901) also notes the strong effect that flooding from Rapentosa and Charadros has on the plain morphology and the amount of material deposited there during extreme events. The first captured picture of a flood in Marathonas comes from Charadros (in 1926) showing high velocity waters, damaging structures and equipment that were used at the time for the preparations of the construction of Marathonas dam (EYDAP 2003). Sotiriadis during his archaeological investigations (1925-1937) noted that although the two main torrents are dry even in the winter, the plain is "occasionally inundated" (Sotiriadis 1933). In 1959 (July the 3rd) overflowing of Rapentosa torrent hit the plain damaging crops and drowning animals (Empros 1959). Almost a decade later Hammond (1968) notices that Charadros and Vranas overflow occasionally transporting large amounts of materials on the plain and to the sea.

In 21st of October 1979, Kato Souli and Agios Georgios flooded after a high intensity rainfall, leading to approximately 1600m^2 of damaged crops. The event was accredited then to a debris-clogged canal in the Kato Souli area. In 1980 (October 27th) Rapentosa inundated its banks, leading to one casualty, two injured people, many damaged cars, houses and crops in Vranas village. Unfortunately, although these two events were covered extensively by the press at the time and are very well known to the local community there are no official government documents survive today. However, numerous detailed reports can be found in 1979 and 1980 newspapers articles database (Nea 1979, Apogevmatini 1980).

Ψηφιακή Βιβλιοθήκη Θεόφραστος - Τμήμα Γεωλογίας. Α.Π.Θ.

After 1987 the data and the descriptions become more detailed. The archive of the Prefectural Administration of East Attica (2007) contained ten floods events accompanied by detailed descriptions of damages and locations. The database of the Hellenic National Agricultural Insurance Organization (2007) for the study area, contained eight flood events that damaged agricultural land or equipment and detailed information on extent, location, cost and time of damages recorded. The events

Table 1. Flood events in the area of study based on the records of the Prefectural Administration of East Attica (2007) and the Hellenic National Agricultural Insurance Organization (2007).

Recorded flood events			
Event Date	***Locations that suffered damages (shown in fig. 1)***	***Damages in buildings and infrastructure***	***Damages in agriculture***
12th Nov. 1987	Patitiria, Tsepi, Vranas, Tymvos, Valaria and Paralia	No detailed record	No record
26t Feb. 1988	Vranas, Patitiria, Tsepi, Valaria, Paralia and Tymvos	No detailed record. Approximately 30 houses, 20 vehicles	No record
27th Jan. 1996	Paralia. Valaria and Patitira	2 businesses, fencing in some houses, road network, public utilities	No record
12th Nov. 1998	Patitira, Tsepi and Valaria	10 buildings and the road network	No record
20th Nov. 1998	Patitiria, Tsepi, Tymvos and Valaria	2 buildings and the road network	No detailed record
27th Mar. 1999	Patitiria, Vreksiza, Tymvos and Valaria	No record	11 businesses, truck farms
14th Jan. 2001	Patitiria, Vranas, Tsepi, Paralia, Bei, Kato Souli, Rizari, Tymvos	9 buildings (household utensils and parts of the structure), many vehicles	42 businesses greenhouses, olive groves, truck farms
3rd Nov. 2001	Vranas, Tsepi, Valaria, Bei, Paralia, Marathonas and Tymvos	18 buildings, some vehicles and the road network	33 businesses, greenhouses, olive groves, truck farms
14th Dec. 2002	Valaria, Tsepi and Patitiria	No record	9 businesses, mainly greenhouses
26th Jan. 2003	Vranas, Tsepi, Rizari, Bei, Patitiria, Agios Georgios	6 buildings, road network and the sewerage system	21 businesses, mainly truck farms
16 Sep. 2005	Kato Souli, Agios Georgios, Marathonas village, Patitiria, Tsepi, Paralia, Rizari and Bei	Only minor damages to some buildings and fencing	21 businesses, mainly greenhouses
23 Nov. 2005	Patitiria, Tymvos, Tsepi, Valaria, Marathonas village, Plasi, Paralia, Kato Souli and Agios Georgios	10 buildings (houses and businesses), road network, public utilities	29 businesses, greenhouses and fields, truck farms

Ψηφιακή Βιβλιοθήκη Θεόφραστος - Τμήμα Γεωλογίας. Α.Π.Θ.

from these two sources are summarized in table 1.

These twelve flood events in total were confirmed by cross-referencing with the record of the Greek Fire Department (2007), the archive of the General Secretariat of Civil Protection (GSCP 2006), the record of Earthquake Rehabilitation Service (2006), articles from the Greek Parliament Newspaper Archive and television broadcasts obtained from the archive of national television stations. In some cases complementary information was collected from these sources.

4. Methods

4.1 Data analysis

Initially , upon collection exploitable and good quality information was selected from raw data and stored in a database, based on categorizing different types of evidence like water stage, extent, speed, severity and type of damage, time and duration of flooding. This step was followed by the compilation of an overall list of past flood events in the area. In a second phase, damages on structures and agriculture were plotted in a GIS environment along with evidence provided from pictures and videos to form an accurate reconstruction of every flood event between 1979 and 2008. Each one of these polygon shapes symbolizing reconstructed inundated areas, were converted to raster data with cell value of 1 for inundated locations and 0 for non-inundated locations. These raster data were subsequently mathematically added with the use of Weighted Sum tool of computer software ArcMAP 9.2 (ESRI 2008). Thus, raster cells were added with same-location cells of each flood event. In this way, the resulting raster symbolized the spatial extent of all the flood events and each cell contained information on how many times it was inundated. This very attribute provided a clear view of the flood recurrence rate for each location for the last 30 years, which was the time period with adequate data. It also allowed interesting observations on the evolution of flooding. Finally descriptions, reports and other evidence were examined to determine the main causes of the flooding problem in the area.

4.2 Geologic and geomorphologic observations

Assessment of the influence of geologic and geomorphologic features in extreme hydrological events was considered important. Therefore, factors of geology and geomorphology of the three basins were calculated in an effort to estimate in what extent they are linked to flooding phenomena. Namely mean slope and basin elongation ratio were computed due to their influence on the hydrograph form (Sith & Ward 1998), whereas basin area and geologic formations permeability due to their importance in water volume drained. In this work, geologic formations were classified in three groups based on their hydrogeological behaviour. The first group consisted of higher permeability carbonate rocks, the second of impermeable formations, like schist, and the third from post alpine porous sediments of intermediate permeability. Additionally, the channel morphometry of the three torrents was studied in order to examine the degree to which the flooding phenomena are enhanced by parameters of the drainage network like channel's morphomology and dimensions. This was carried out by field observations and by studying geologic, topographic and historical maps of the area.

5. Results

5.1 Flood history summary

Examination of the collected evidence showed a rich history of flooding in the plain of Marathonas. From ancient years until modern days the area suffered numerous incidents. Apart from the one known

Ψηφιακή Βιβλιοθήκη Θεόφραστος - Τμήμα Γεωλογίας. Α.Π.Θ.

Table 2. Table showing recorded flood events in the study area

Flood events in Marathonas area									
Year	***Date***	***Basin***			***Year***	***Date***	***Basin***		
		Charadros	Rapentosa	Myrtia			Charadros	Rapentosa	Myrtia
1805	Autumn	×	×		1998	November 12th		×	
1879	Autumn	×			1998	November 20th		×	
1926	Unknown	×			1999	March 27th		×	
1959	July 3rd		×		2001	January 14th	×	×	×
1979	October 21st			×	2001	November 4th	×	×	
1980	October 27th		×		2002	December 14th		×	×
1987	November 12th	×	×		2003	January 29th	×	×	×
1988	February 26th		×		2005	September 16th	×	×	×
1996	January 26th	×	×		2005	November 23rd	×	×	×

casualty and some injuries, damages included buildings (houses and businesses), agricultural land and equipment, vehicles, the road network and important infrastructure. Flooding continued through the years even though significant flood defenses were developed. Based on the compiled data, one can identify 18 distinct flood events (shown in table 2) extending back to 1805. The record is considered to be complete only after 1979, in contrast with period before this year when data coverage was not adequate. Table 2 shows all the recorded flooding incidents separately for each torrent.

5.2 Characteristics and evolution of flooding

Careful study of the events' descriptions showed a series of common characteristics like the abrupt rise of flood waters and the relatively short duration of inundation. It also showed higher water velocities around Rapentosa torrent (Vranas and Patitiria) than at Charadros (Bei and Paralia) and even lower speeds at Vreksiza, Valaria, Agios Georgios and Kato Souli. In some cases, vegetation debris and sediment content was abundant in floodwaters (Prefectural Administration of East Attica 2007), a phenomenon that can be attributed to the forest fires of 1995 and 1998 in the area. Concerning the evolution of affected areas, it is evident that before the construction of Marathonas Dam, flooding in Charadros was more frequent. Thus, after 1929 flood areas around Charadros were considerably reduced along with associated damages. It is also apparent that flooding problems in Myrtia torrent have been intensified in the last six years in the record, most probably due to the recent development of housing, road networks and other public works without appropriate sewerage.

Ψηφιακή Βιβλιοθήκη Θεόφραστος - Τμήμα Γεωλογίας. Α.Π.Θ.

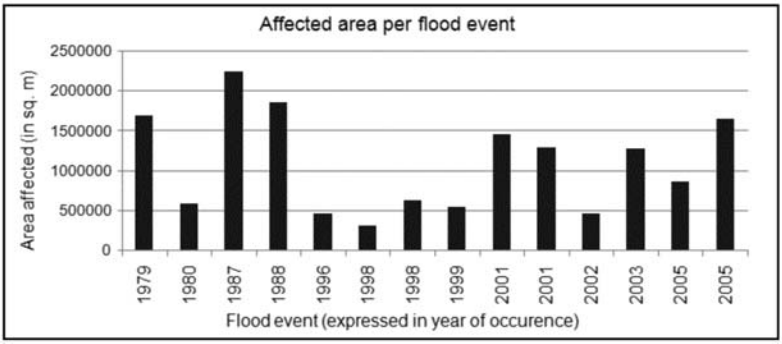

Fig. 2: Chart showing the fluctuation of affected areas in square metres through the years, for each flood event. In horizontal axis, events are expressed in year of occurrence.

Table 3. Recorded damages for compensation purposes (Prefectural Administration of East Attica 2007, Hellenic National Agricultural Insurance Organization 2007).

Officially recorded damages	*Rapentosa*	*Charadros*	*Myrtia*
Buildings damaged (1996-2009)	38	9	10
Damaged agricultural land (1999-2009)	802.000 m^2	78.000 m^2	287.000 m^2

Human interference with hydrologic processes is considered to have intensified flooding phenomena through blocking drainage routes towards the sea and reducing the flow capacity of channels. Such effects are evident at Patitiria and Tymvos, Paralia and Agios Georgios. Changes due to the recent development of flood defenses have to be evaluated in the long term.

5.3. Damage type and distribution

Analysis of the spatial distribution of damages, illustrates that Rapentosa (mainly Tsepi and Patitiria) are the most affected areas. In most cases damages included agricultural land and equipment, greenhouses, vehicles, buildings fencing and masonry, household utensils and loss of some domestic and livestock animals.

5.4 Flood recurrence rate

Flooding has a higher repetition rate in Rapentosa torrent (13 events in 30 years) than in Charadros (7 events in 30 years) and Myrtia catchment (6 events in 30 years). Data analysis, as described in 4.1, showed explicitly the areas with higher recurrence rate. Figure 3 illustrates these areas with a ranking based on the number of events suffered in 30 years. Thus, high recurrence rate represents areas that flooded 10 to 14 times during this period, whereas medium recurrence rate locations that flooded 5 to 9 times and low recurrence rate areas 1 to 4 times. According to this process high recurrence rate locations can be identified at Patitiria and Tymvos and medium rate areas at Valaria and Agios Georgios.

5.5 Correlation with geologic and geomorphologic data

Examination of calculated basin properties showed that higher recurrence flood rate in Rapentosa in comparison with the other two torrents is partly connected to its increased percentage of imper-

Ψηφιακή Βιβλιοθήκη Θεόφραστος - Τμήμα Γεωλογίας. Α.Π.Θ.

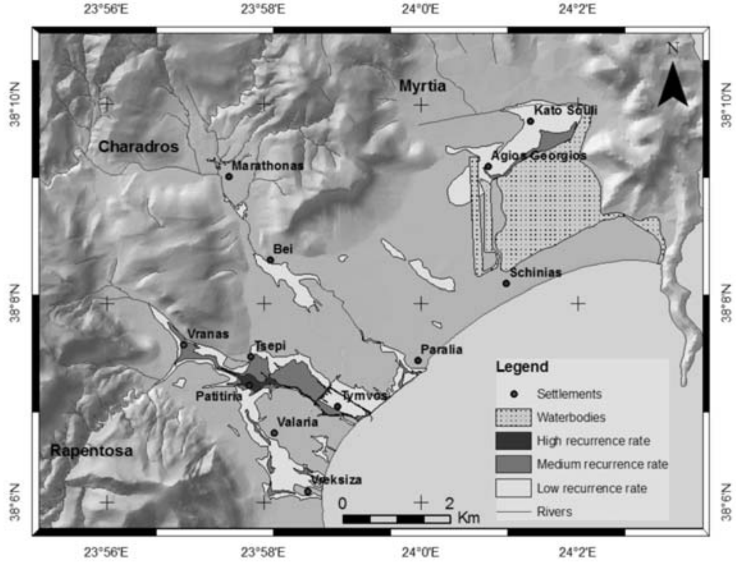

Fig. 3: Map showing the areas that flooded during last 30 years. High recurrence rate represents areas that flooded 10 to 14 times in 30 years. Medium recurrence rate stand for locations that flooded 5 to 9 times and low recurrence rate areas that flooded 1 to 4 times in the same period.

Table 4. Table showing calculated properties for the three drainage basins.

Calculated basin properties			
Properties	***Rapentosa***	***Charadros***	***Myrtia***
Mean Slope (%)	33.3	21.3	22
Area (Km^2)	37.5	60.2	11.7
Elongation Ratio	0.46	0.56	0.70
High permeability formations (% of total area)	45.4%	50.3%	58.4%
Medium permeability formations (% of total area)	13.2%	19.8%	29.3%
Impermeable formations (% of total area)	41.4%	29.9%	12.3%

meable formations and its higher mean slope value. The first attribute augments the total volume of runoff and the second increases peak flow rates, reduces the watershed's time of concentration and raises the stream power of storm runoff as it enters the plain. On the other hand, basin area and elongation ratio do not show good correlation with historical analysis results, denoting a less critical role for these parameters.

Field and map observations on the torrents' morphology suggest channel morphometry plays a very important role. As far as Rapentosa is concerned, the torrent's morphological characteristics degenerate and it eventually disappears morphologically at about 2km before reaching the sea. A careful study of older published maps and sketches shows the same regime for the last 180 years. Namely, the same setting as today appears in 1829 Leake's sketch-map (in Hammond 1968), in 1880 Kauper's map (Kauper 1889), in Hughes' sketch of 1901 (Hughes 1901), in Caspari's (1911) map, in Hellenic Military Geographical Service's (HMGS) sketch-map of 1928 (in Hammond 1968), in

Ψηφιακή Βιβλιοθήκη Θεόφραστος - Τμήμα Γεωλογίας. Α.Π.Θ.

Vanderpool's 1966 sketch-map (Vanderpool 1966), and in HMGS topographical maps of 1970's. This shows a natural diffusion of the channel in its last section. The point where the torrents characteristics disappear in all the maps, coincides with the higher flood recurrence rate areas (i.e. Patitiria). This regime together with the high percentage of impermeable formations and its high mean slope increases Rapentosa's natural potential for flooding in comparison with the other two watersheds. In relation with channel dimensions, field observations show that human activities have greatly affected the torrents' flow capacity. In case of Rapentosa in Vranas and Patitiria and in case of Charadros in Bei and along the coast.

6. Conclusions

Past flooding in Marathonas is a well known phenomenon in an anecdotal sense, but it has not been studied systematically. This analysis proves that Rapentosa is the most hazardous between the three torrents studied. It also shows that Kato Souli (Myrtia torrent) suffered more damages in the last decade compared to the past. The locations where more damages are concentrated are Patitiria, Tsepi, Tymvos and Agios Georgios. These areas show higher possibility to be also affected by flooding in the future. In the case of Rapentosa, human development in the course of the river, mainly in Patitira and Tsepi, augments exposure and vulnerability and obstructs local hydrologic processes in a degree to which the possibility of overflowing is increased. Hazard is further augmented due to natural basin characteristics and the drainage network's natural diffusion. Extensive development along the coast and around the marsh interferes also with drainage processes obstructing surface runoff in Charadros and Myrtia.

In this context and taking into account that high flow rates are part of a river's natural process, a significant step towards the problem's solution would be a long term policy of reducing intervention to hydrological processes. This involves of course gradual removal of human activities from the active floodplain. Meanwhile, developing flood defenses is valuable but in many cases, including the event of November 2005 in Marathonas is proved to be inadequate.

It should be also kept in mind that the methodology has a number of limitations. For example flooding phenomena are subject to natural and human induced change and therefore the method's results must not be perceived as stationary and have to be reviewed every time new knowledge is available. Moreover, quiet periods in the flood record, in some cases, may not correspond to periods lacking flood events.

This method can be used either as a standalone process or to verify results of other methodologies. Generally, examining high temporal extent historical records are a special benefit when studying rare natural disasters, especially when hydrological data are scarce. The use of such methods for reconstruction of flood history has a great potential in Greece due to the early and continuous habitation. In this work, past flooding is perceived as the result of an evolving natural experiment. In this context, flooding history analysis offers and in depth appreciation of the flooding problem and its evolution over time.

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Ψηφιακή Βιβλιοθήκη Θεόφραστος - Τμήμα Γεωλογίας. Α.Π.Θ.