National and Kapodistrian University of Athens

Newsletter of
Environmental, Disaster, and Crises Management Strategies

ISSN 2653-9454

Post Graduate Program
Environmental, Disaster, and Crises Management Strategies

Issue No.28 | October 2022

The October 15, 2022 Flash Flood in Agia Pelagia (Crete, southern Greece)

Prof. Dr. Efthymios **Lekkas**

Dr. Michalis **Diakakis**

Dr. Spyridon **Mavroulis**

PhD c. Katerina-Nafsika **Katsetsiadou**

PhD c. Marilia **Gogou**

PhD c. Nafsika-Ioanna **Spyrou**

Dr. Maria **Mavrouli**

MSc. Kostas **Antoniadis**

PhD c. Eleftheria **Stamati**

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About

Non-periodic publication of the Post-graduate Studies Program "Environmental Disasters & Crises Management Strategies" of the National & Kapodistrian University of Athens, issued after significant events for the immediate information of the scientific community and the general public. The publication includes also scientific data from various research teams from universities, organizations and research institutes.

Publishers:
Dr. Efthymis Lekkas
Dr. Nikolaos Voulgaris
Dr. Stylianos Lozios

Technical Editing:
Dr. Spyridon Mavroulis

Communication:
Dr. Spyridon Mavroulis (smavroulis@geol.uoa.gr)
MSc Alexia Grambas (agram@geol.uoa.gr)
MSc Katerina-Nafsika Katsetsiadou (knavsika@geol.uoa.gr)

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Scientific Mission

Of the National and Kapodistrian University of Athens, Faculty of Geology and Geoenvironment, Department of Dynamic Tectonic Applied Geology

Cited as

Lekkas, E., Diakakis, M., Mavroulis, S., Katsetsiadou, K-N., Gogou, M., Spyrou, N-I., Mavrouli, M., Antoniadis, K., Stamati, E. (2022). **The October 15, 2022 Flash Flood in Agia Pelagia (Crete, southern Greece)**. Newsletter of Environmental, Disaster and Crisis Management Strategies, 28, ISSN 2653-9454.

This study was funded by the Environmental, Disaster and Crises Management Strategies Post graduate Program of the Department of Geology and Geoenvironment of the National and Kapodistrian University of Athens.

Contributors

NATIONAL AND KAPODISTIAN UNIVERSITY OF ATHENS
Prof. Dr. E. Lekkas, Dr. M. Diakakis, Dr. S. Mavroulis, PhD c K.-N. Katsetsiadou, PhD c M. Gogou, PhD c. N.-I. Spyrou, PhD c K.-N. Katsetsiadou, Dr. M. Mavrouli, MSc. Kostas Antoniadis, PhD c E. Stamati

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INTRODUCTION OF THE 28st ISSUE OF THE EDCMS NEWSLETTER

The 28th issue of the Newsletter of Environmental, Disaster, and Crises Management Strategies refers to the October 15, 2022 flash flood in Agia Pelagia (Crete island, southern Greece). It includes the:

- evolution of the phenomenon and meteorological data in Crete,
- Agia Pelagia basin drainage network along with its current land use,
- Agia Pelagia basin geomorphology (elevation and slope),
- geology and the active tectonics of the Agia Pelagia basin,
- conduit of the main channel,
- evolution of the built environment in the area,
- estimated floodplain boundaries,
- maximum water level after the event,
- impact of the flash flood on the:
    - natural environment,
    - built – urban environment,
    - infrastructure (road network, communications and electricity supply networks),
    - mobile objects (vehicles and lighter objects),

  Based on post-flood in-situ field survey in the affected area and mass media sources there is an estimate on the
- potential impact of flooding on public health
- post - flood proposed measures for preventing infectious diseases

Finally conclusions and proposals are recommended for mitigation of the adverse effects, environmental protection & sustainable development of the area.

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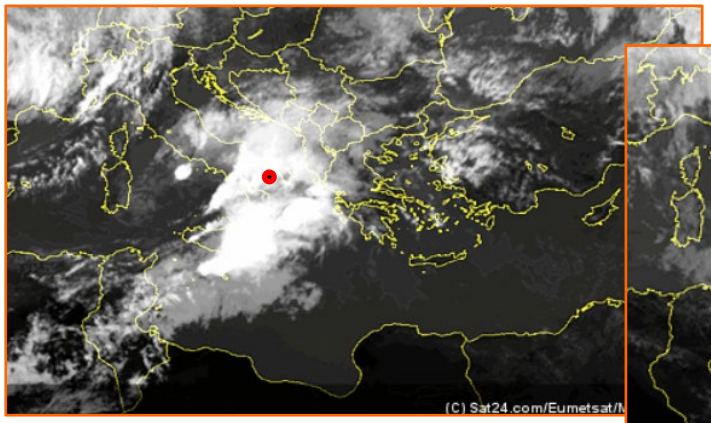
METEOROLOGICAL DATA
EVOLUTION OF THE BAROMETRIC LOW

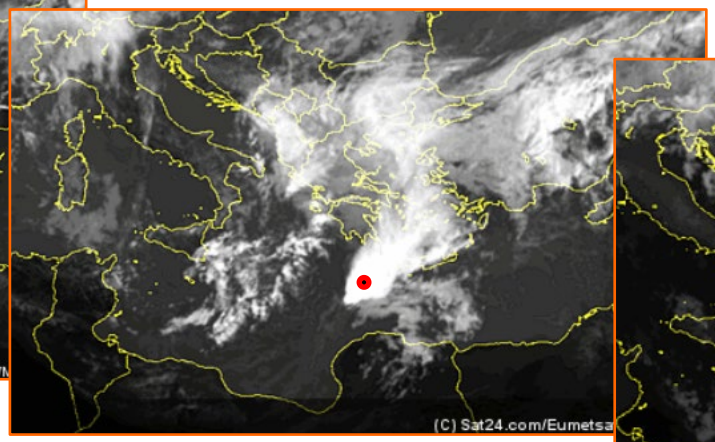
A barometric low, which reached Greece from the west, and specifically from the area of southern Italy (13/10), was intensified further from the warm Ionian Sea. It made landfall with significant amounts of rain on 14/10 in Western Greece, the Ionian Islands and the Peloponnese, before reaching Crete on 15/10 and then the Dodecanese islands.

Crete recorded the highest amounts of rain with intense storms in large parts of the island. It is estimated in the scale of between 100 to 150mm in certain locations characterized by high intensity and short duration.

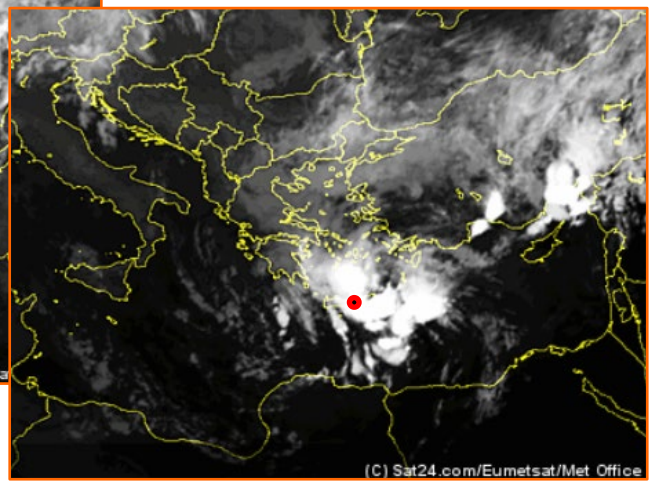
13/10



14/10



15/10



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IMPACT ON SOUTHERN GREECE
THE ISLAND OF CRETE

Significant impacts were observed in different locations around the island of Crete, mainly along the coast. Particular intensity occurred in Agia Pelagia and Lygaria villages in the Heraklion Region, as well as the towns of Sitia and Ierapetra, Agios Ioannis village and other locations to a lesser extent.

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IMPACT ON CRETE
THE AGIA PELAGIA AREA

Agia Pelagia was hit with particular intensity, recording severe impacts on buildings and infrastructure.

Two individuals were killed in the village as a result of the flood. A 50-year-old man was swept away by the torrent while in his vehicle and a 49-year-old woman who was reportedly in the same car was also found dead.

Roads were turned into rivers, while flood waters carried off towards the sea numerous vehicles, house appliances and other objects. The Greek Fire Service's Operations Center stated that it received 453 calls within an hour of the incident.

Agia Pelagia has a history of floods. The most important event, in the recent past, took place in 1994.

Image source: Crete TV (2022) - YouTube
October 1994 [left photo] – October 2022: 28 years after [right photo]

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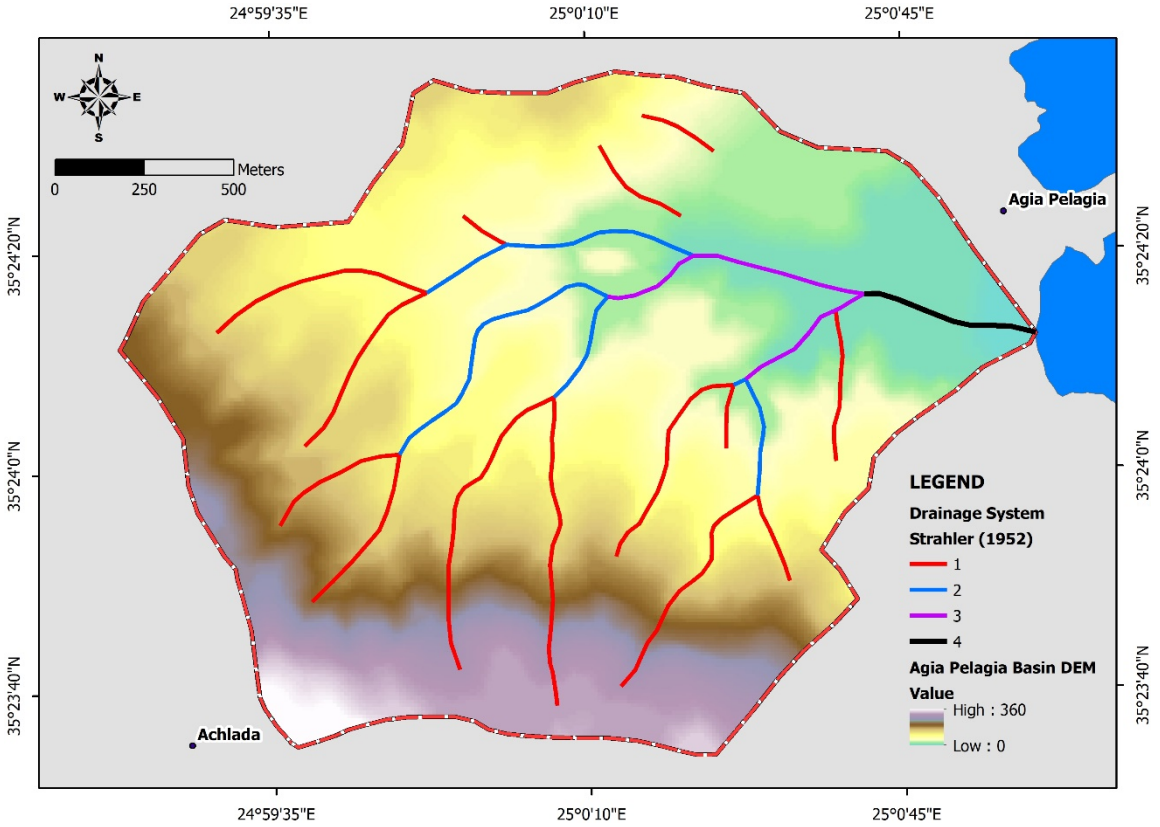
DRAINAGE SYSTEM OF AGIA PELAGIA BASIN



The classification of Strahler (1952) distinguishes and numbers the streams of the drainage system according to the way they develop and contribute, as shown by the topographic maps of the study area. Watercourses which do not receive water from other streams are numbered as 1st order streams. When two first order streams are joined, the formed stream shall be numbered as a second order one. The same is done for the larger streams of higher order.

According to the Strahler (1952) classification, the drainage system of Agia Pelagia basin consists of a main stream of 4th order (main branch of the drainage system), 2 streams of 3rd order, 5 streams of 2nd order and 14 streams of 1st order (smaller streams in the higher parts of the basin).

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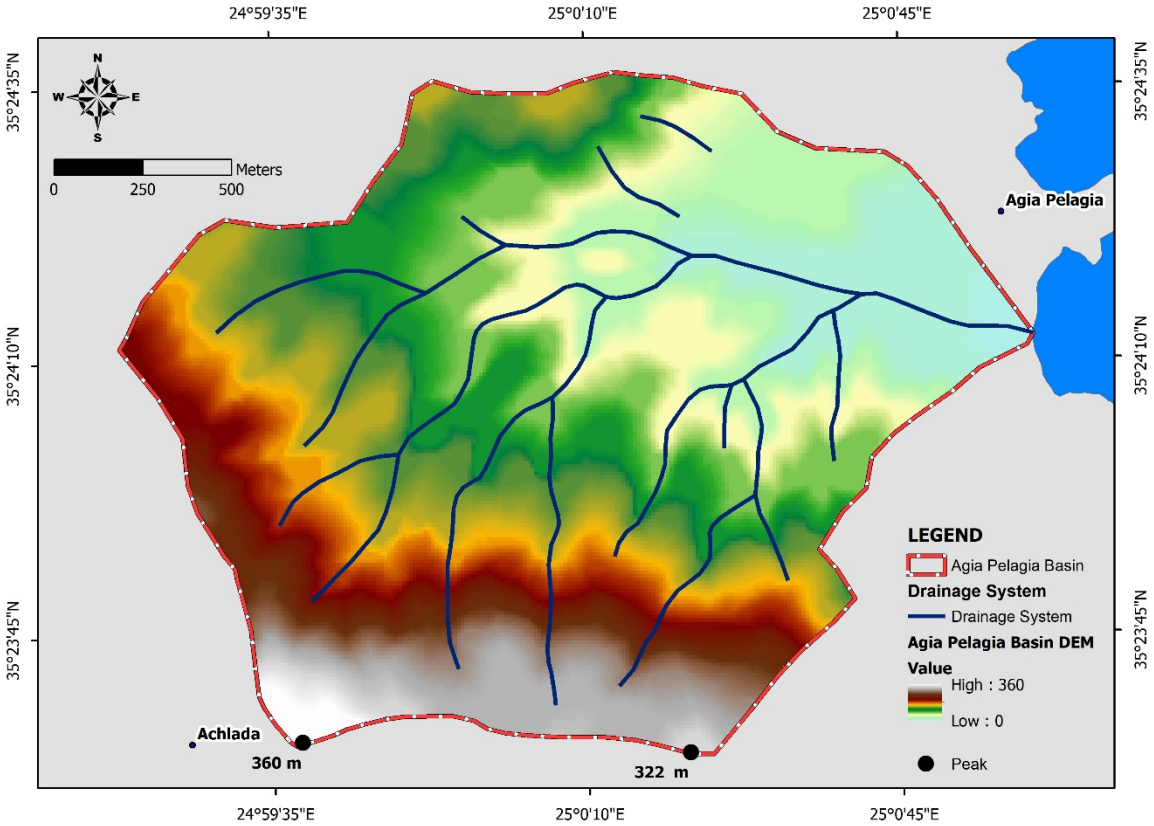
MORPHOLOGY OF AGIA PELAGIA BASIN
ELEVATION



The highest elevation of the Agia Pelagia basin occurs in the southern part of the basin. It reaches a peak of 360 m east of the Achlada settlement. Along with the Agios Nikolaos peak (322 m) further east, they define the southern watershed with the highest elevation in the basin. The elevations decrease towards the north and northeast, reaching their lowest values in the coastal zone of the northeastern part of the basin, where the Agia Pelagia settlement occurs.

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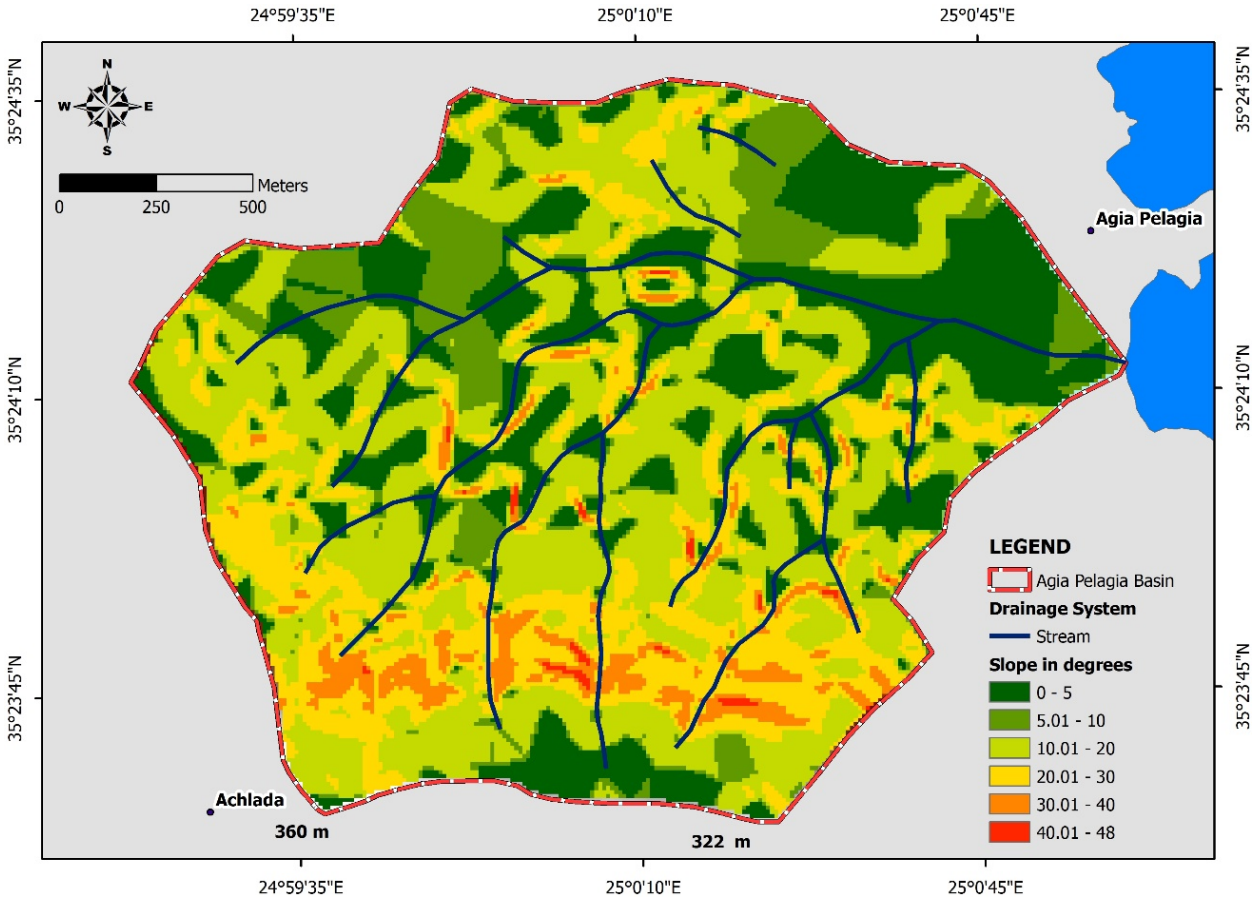
MORPHOLOGY OF AGIA PELAGIA BASIN
SLOPE



The steepest slopes within the Agia Pelagia basin are observed in the southern part of the basin and are greater than 25°. Large slope values are also observed in stream valleys in the central part of the basin. The main stream of the basin is located in its northeastern part, which is gently sloping.

Higher erosion rates, are expected to appear in the southern part of the basin, where steeper slopes are located.

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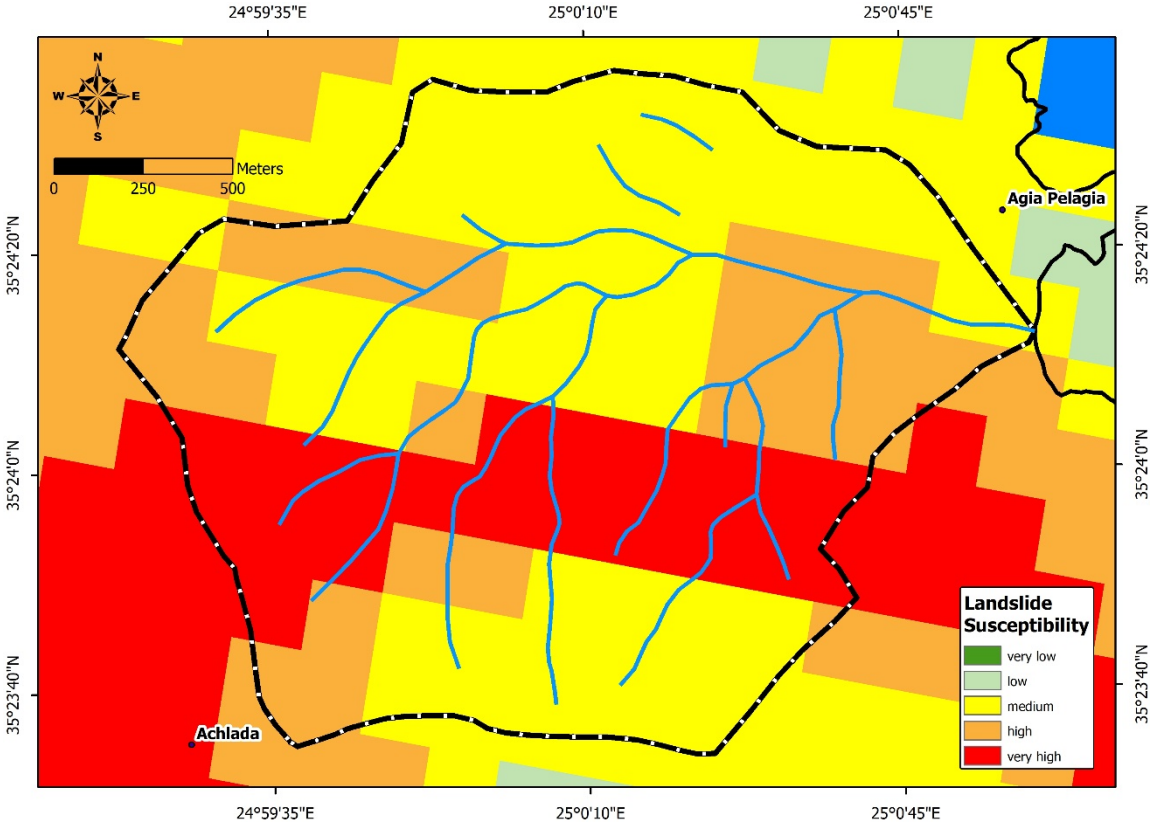
LANDSLIDE SUSCEPTIBILITY IN AGIA PELAGIA BASIN

based on the European Landslide Susceptibility Map Version 2 (ELSUS V2)



ELSUS v2 shows levels of spatial probability of generic landslide occurrence at continental scale. It covers all European Union member states except Malta, and several neighboring countries. ELSUS v2 has been produced by regionalizing the study area based on elevation and climatic conditions, followed by spatial multi-criteria evaluation modelling using pan-European slope angle, shallow sub-surface lithology, and land cover spatial datasets as the main landslide conditioning factors. In addition the location of over 149,000 landslides across Europe, provided by various national organizations or collected by the authors, has been used for model calibration and map validation [Günther et al. (2014) in *Geomorphology*; Wilde et al. (2018) in *J. Maps*).

The Agia Pelagia basin is characterized by medium to very high landslide susceptibility. The high to very high landslide susceptibility is found in the southern part of the basin and is mainly associated with its steep morphological slopes.

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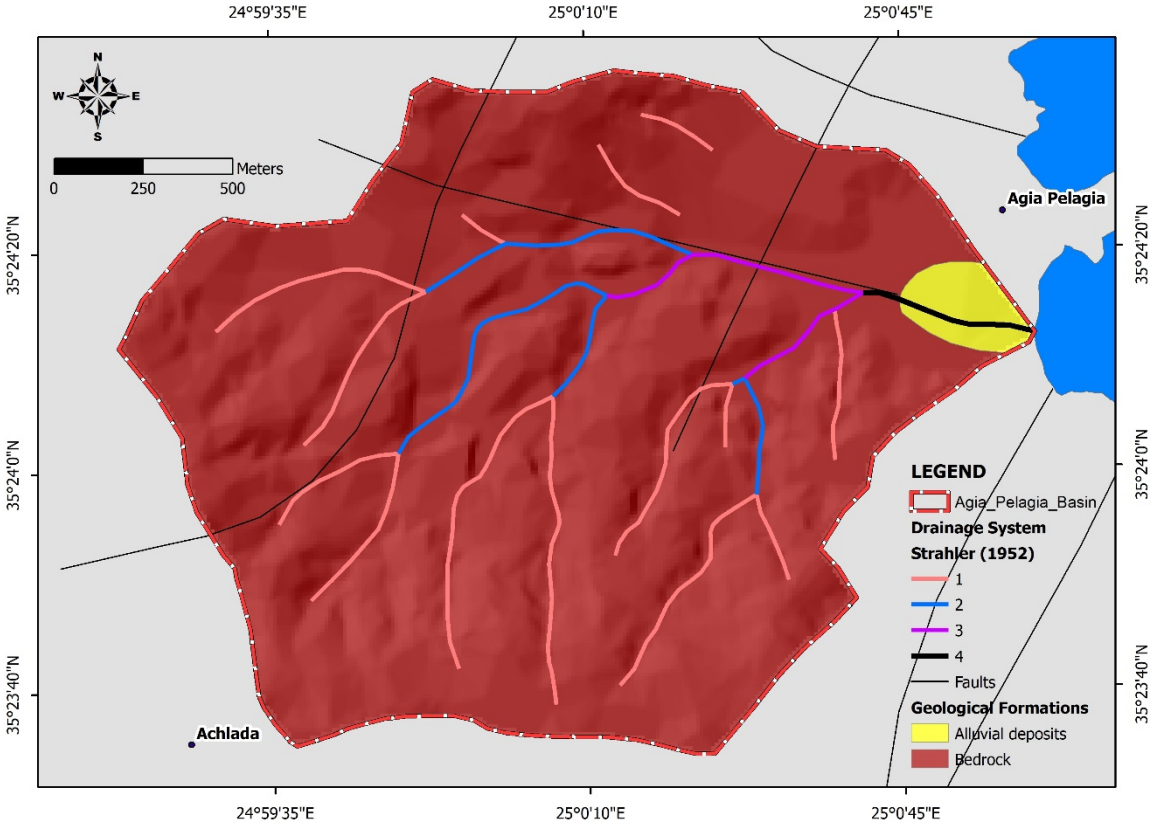
GEOLOGY
ALPINE FORMATIONS AND POST-ALPINE DEPOSITS



The affected Agia Pelagia basin is located at the northwestern edge of the Heraklion Regional Unit (Region of Crete), a seismic active area with strong historical and recent seismicity. The geological structure of the basin includes alpine formations and post-alpine deposits. The alpine formations belong to the Arna geotectonic unit.

The Arna unit is represented by a formation of schists, prasinites - greenschists and metabasites, which occur in the largest part of the basin. The post-alpine formations are of Quaternary age and have been uncomformably deposited over the basement of the alpine rocks. More specifically, they are Holocene alluvial deposits along the stream beds and coastal deposits along the Agia Pelagia beach. As regards the tectonic setting of the basin, NE-SW and E-W striking faults are observed in the study area.

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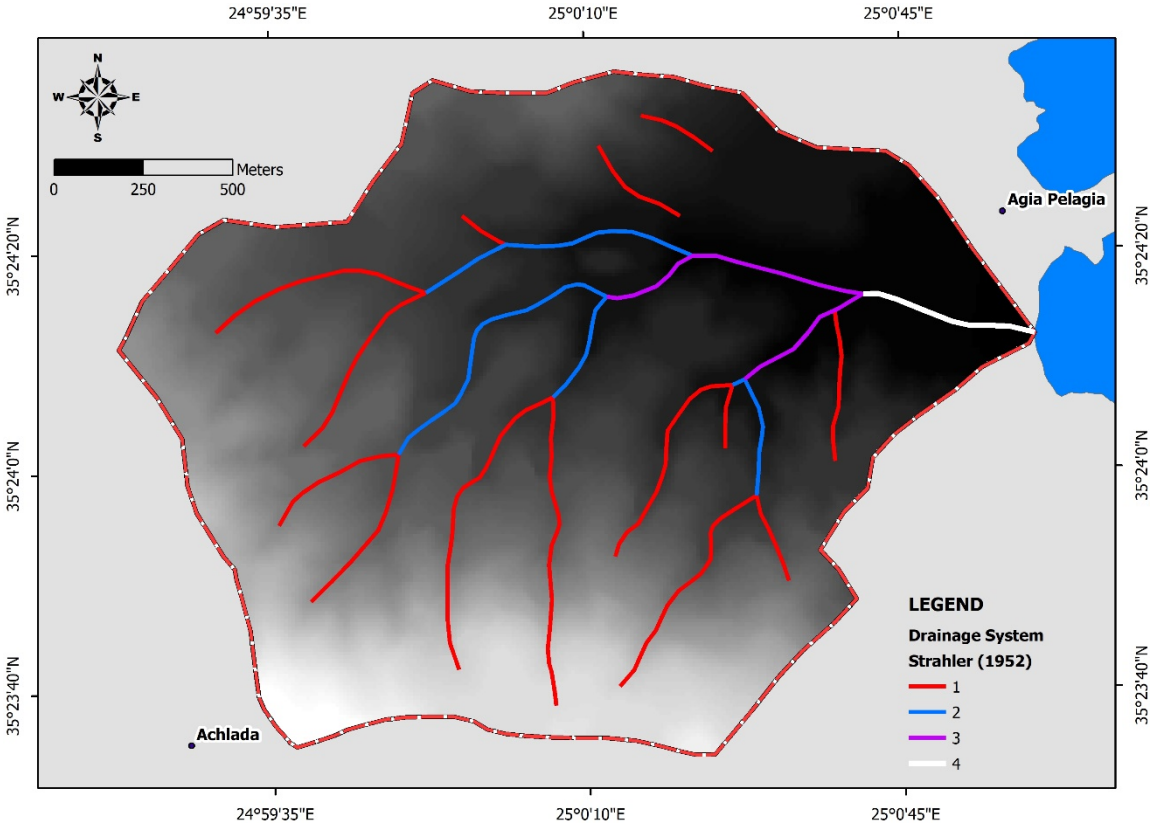
ACTIVE TECTONICS IMPACT ON DRAINAGE SYSTEM
DRAINAGE BASIN ASYMMETRY



The arrangement of the Agia Pelagia basin streams reveal that its development is asymmetrical. The majority of the streams are observed south of the main stream of the basin, while only two first order streams are observed in the area north of it.

This asymmetry of the basin reveals that the drainage system was developed under the influence of active tectonics and in particular under the influence of active faults that has caused the basin to tilt northwards resulting in the migration of the main stream from the basin midline (ideal symmetrical development) to the north.

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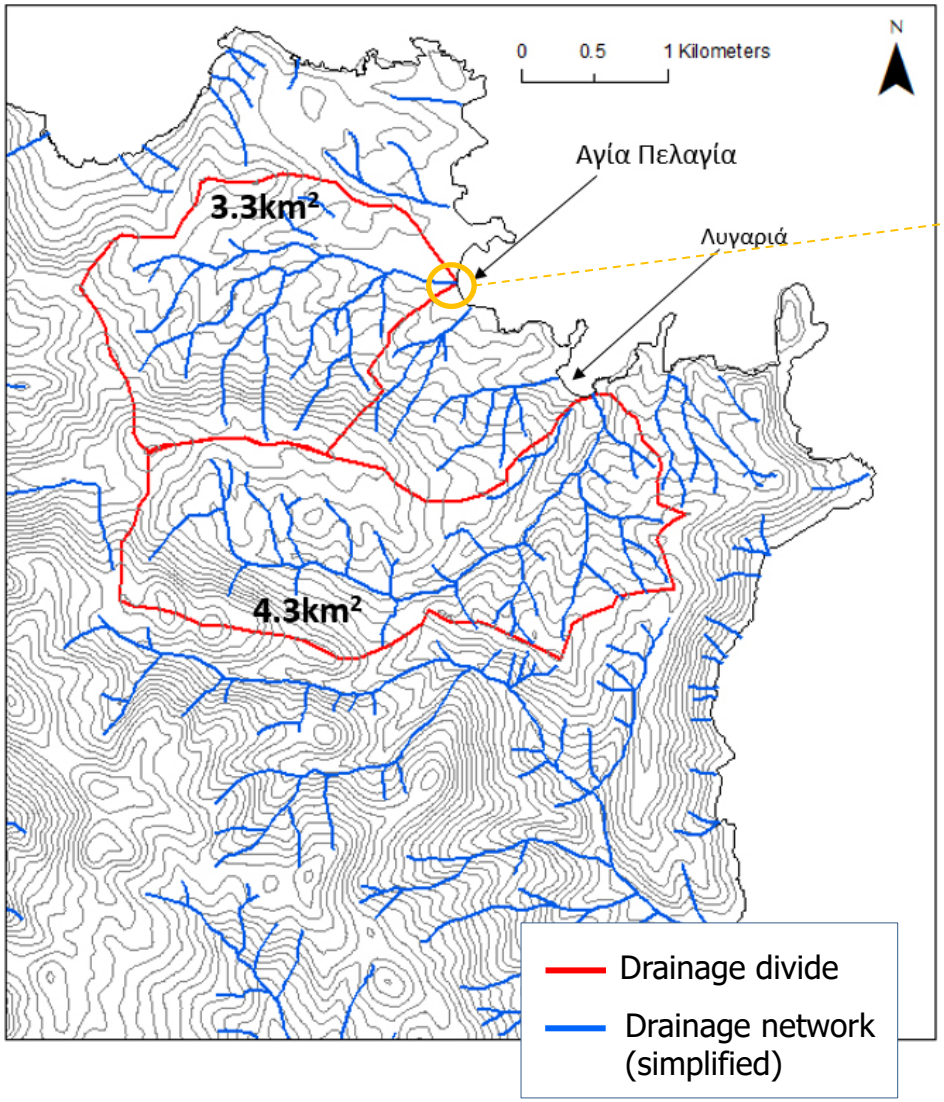
LOCAL DRAINAGE NETWORK IN AGIA PELAGIA TOWN



The local drainage network consists of small-sized catchments, with relatively high slopes especially in their upstream parts. These catchments due to their size and characteristics are particularly vulnerable to short duration high-intensity storms. In lower elevations, the torrents are heavily affected by development, with various obstructions situated within the floodplain. A portion of the drainage network has been converted into roads. At the outlet of the Agia Pelagia catchment, a rectangular concrete conduit has been constructed before a few years, to drain the basin and guide/lead storm waters to the sea.

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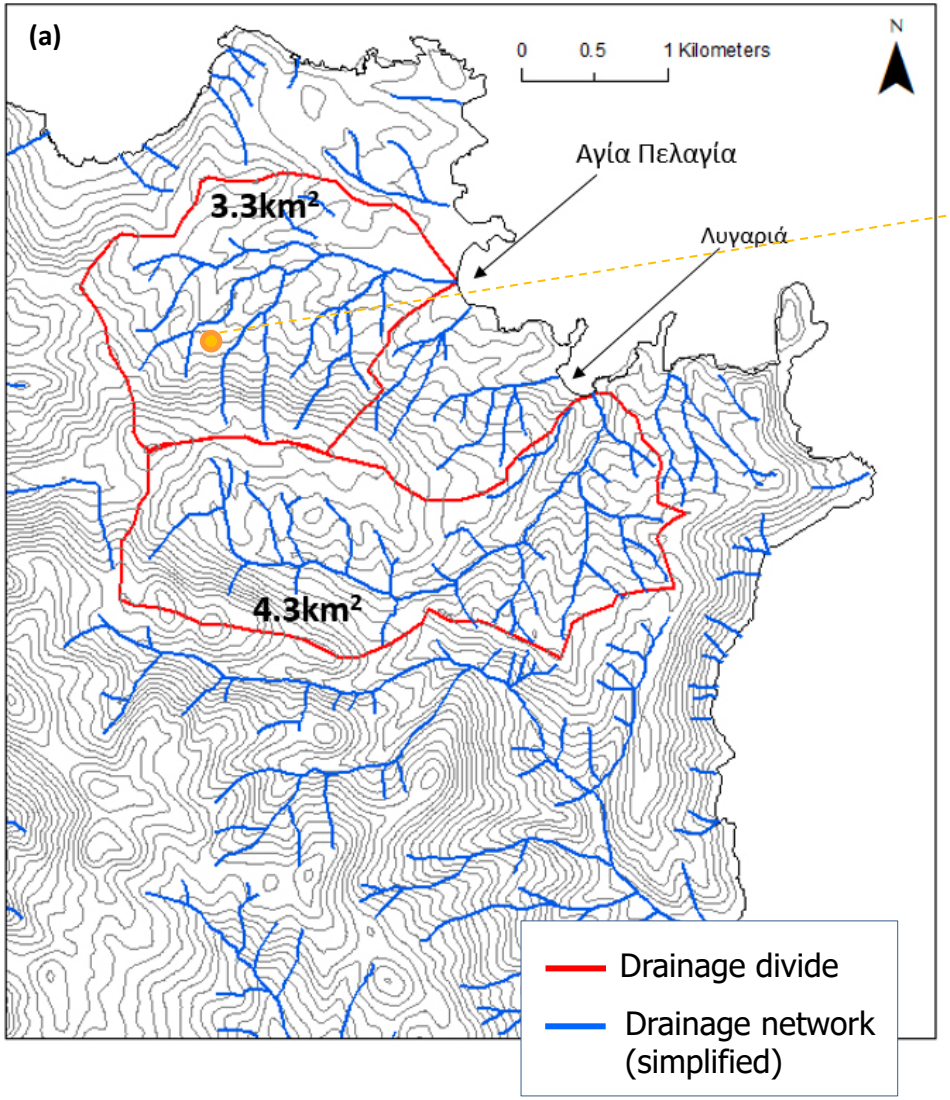
LOCAL DRAINAGE NETWORK IN AGIA PELAGIA TOWN



The upper parts of the small basin shown in map (a) present a relatively high inclination (b), (especially regarding the south slopes of the catchment).

The main two streams of the drainage network converge at lower elevations forming a narrow flood plain surrounding the main torrent of Agia Pelagia. A large part of the floodplain is nowadays converted into the urban fabric of the Agia Pelagia town.

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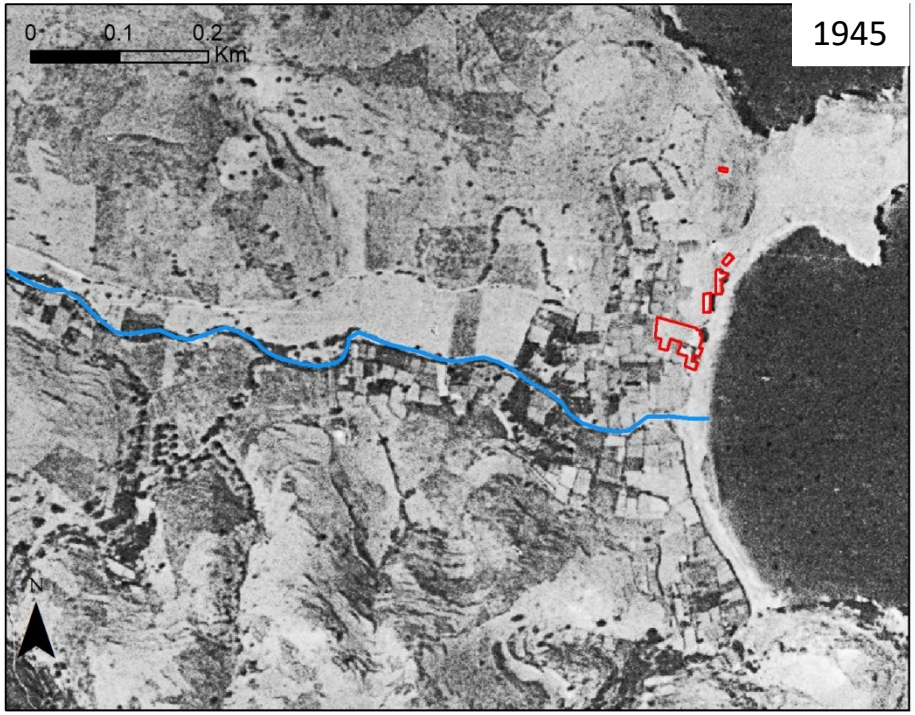
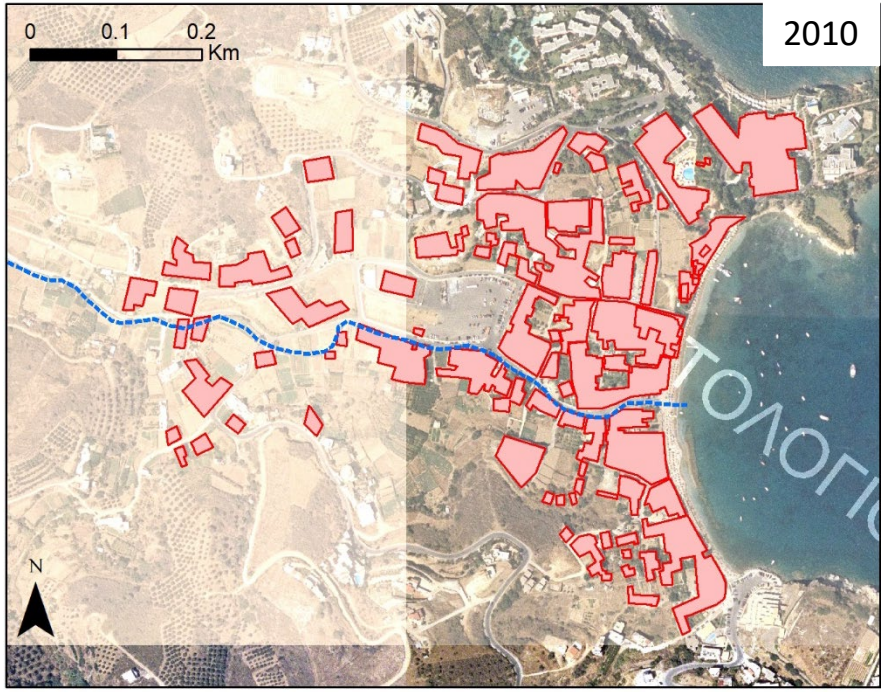
BUILT-UP OF THE AREA



The gradual built-up of the area between 1940s and today is a major human-induced intervention on natural runoff, erosion and sedimentation processes of Agia Pelagia, creating significant obstructions within the floodplain of the local torrent.



Red polygons in the two orthophotos denote building footprints
Orthophotos by Ktimatologio

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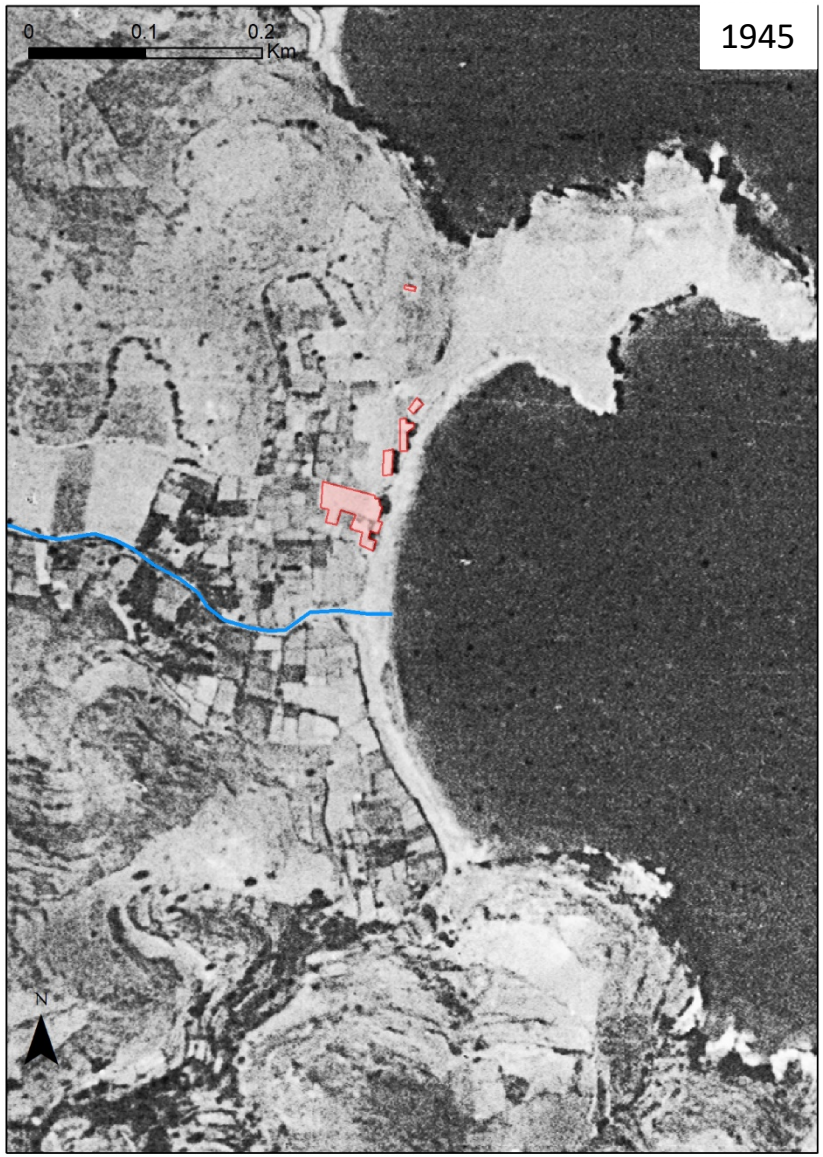
BUILT-UP OF THE AREA



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BUILT-UP OF THE AREA

Photo credit by Mike Naletakis (https://maleviziotis.gr/)

Images show quite a different landscape in Agia Pelagia bay in previous decades

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CONDUIT IN AGIA PELAGIA

The outlet of local drainage network uses a rectangular conduit under Agia Pelagia street that follows the course of the main channel. Evidence from the entrance and exit of the conduit indicate that, at locations, the debris deposited by the flood had reduced its capacity by blocking part of its cross sectional area.

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TILE-ROOFED CONDUIT AT THE DRAINAGE NETWORK OUTLET

The tile-roofed conduit was constructed during 2019. Until then, the stream followed its natural flow without any restriction, crossing the main road of the settlement.

Source: Google Earth Pro, https://ypodomes.com/kriti-se-pliri-ekseliksi-antiplimmyrika-kai-apoxeteftika-erga-stin-agia-pelagia-maleviziou/

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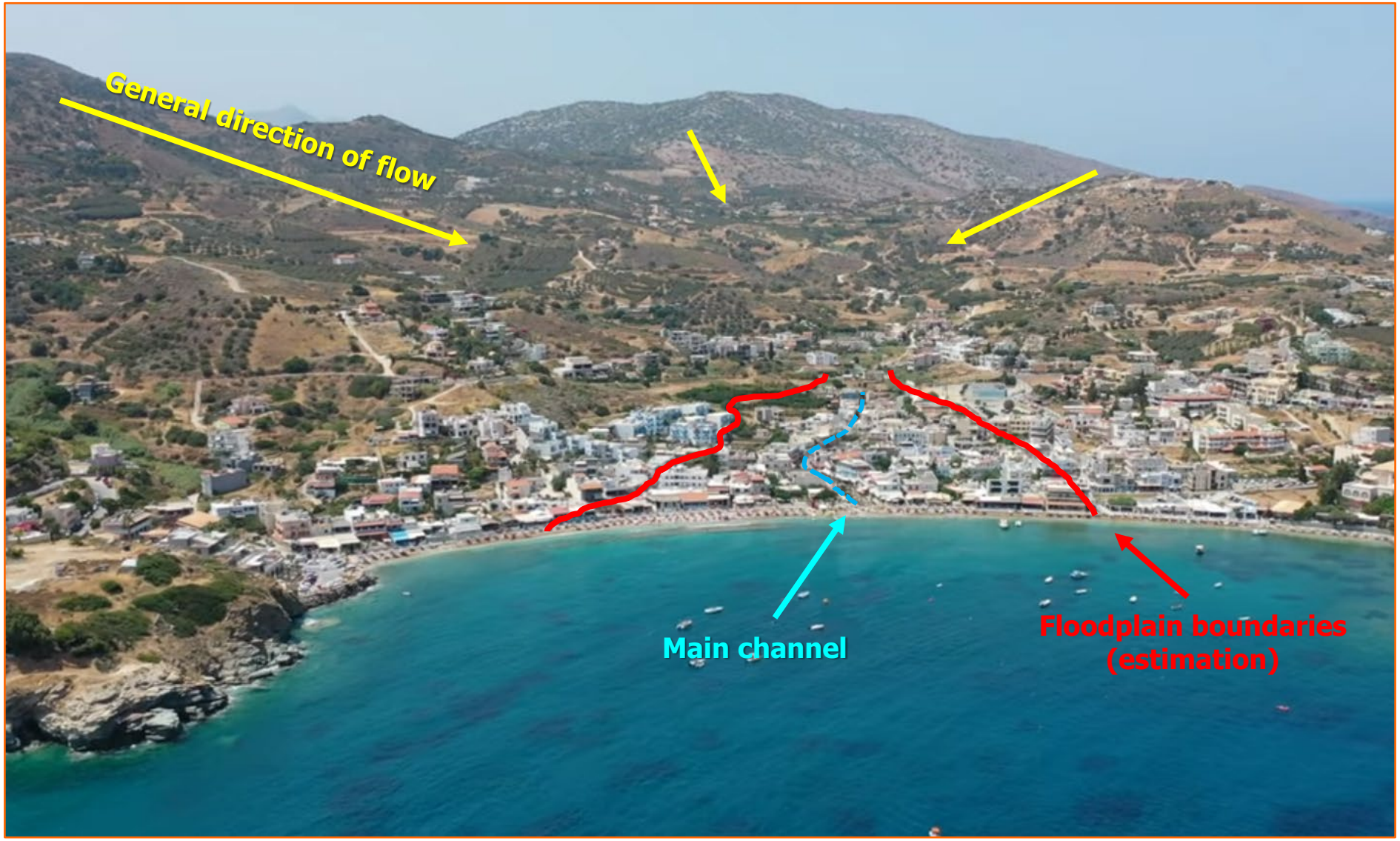
MAIN CHANNEL AND FLOODPLAIN BOUNDARIES IN AGIA PELAGIA COASTAL AREA



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MAXIMUM WATER LEVEL FINDINGS

Water stage recorded at multiple locations around Agia Pelagia at 0,80m to 1,80m
(Photo credit by Prof. Dr. E. Lekkas)

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IMPACT ON HUMAN

The car in which the two flood victims tried to leave their workplace when the flood struck Agia Pelagia (Photo credit by Prof. Dr. Efthymis Lekkas)

Two fatalities (male and female) were recorded due to the flash flood. Both where passengers of the same car, which was drifted by the water.

The 50-year-old driver lost his life while trapped inside his car. The 49-year-old passenger was swept into the sea, as she tried to abandon the car washed away by the flood.

With the aid of drones, the Fire Service's Special Disaster Response Unit found her body one day after offshore Agia Pelagia.

Based on related studies on flood-induced fatalities [e.g. Diakakis And Deligiannakis, (2013) in *J. Flood Risk Manag.*], it is concluded that the majority of such fatalities are vehicle-related.

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IMPACT ON ENVIRONMENT
EFFECTS ON VEGETATION


Photo credit by V. Vrontakis

Photo credit by M. Tsagarakis


Photo credit by cretatv.gr


Photo credit by cretatv.gr

There are different impact severity classes on the environment. They include, mainly uprooting of riverine vegetation (reeds), small vegetation bending and uprooting, small uprooted trees [Denoting Class III & IV impacts in the Flash flood severity scale proposed by Diakakis et al. (2020) in *J. Hydrol.*]

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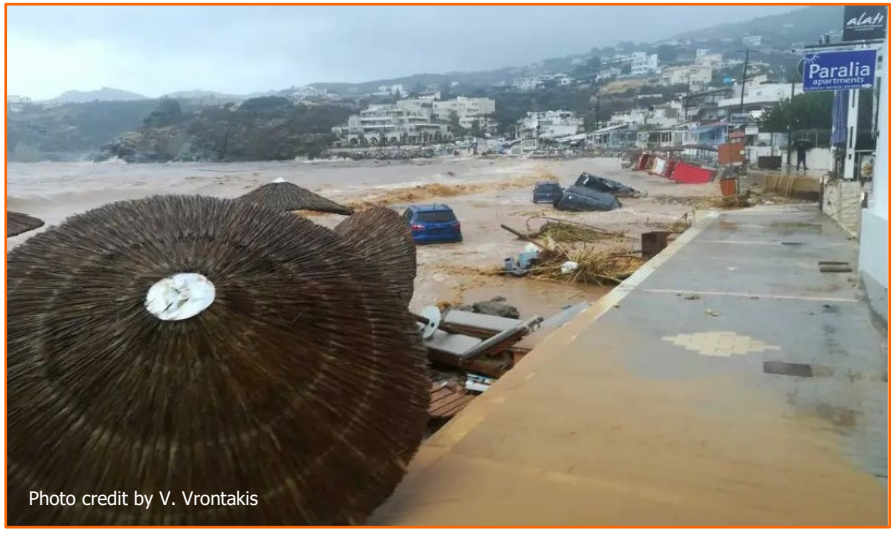
IMPACT ON ENVIRONMENT
COASTLINE CHANGES



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IMPACT ON ENVIRONMENT
EFFECTS ON COASTLINE

▲ Deposition of fine-grained material in Agia Pelagia town

▶ Changes are observed due to the deposition of material on the shoreline. These changes will be temporary as deposition and erosion are strongly affected from oceanographic conditions, the character and load of the river sediment and the morphological features of the shelf.

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IMPACT ON THE BUILT ENVIRONMENT
DAMAGE TO BUILDINGS



Non-structural damage to buildings with reinforced concrete frame with infill walls. Broken windows and destruction of window aluminum frames were recorded. Ground floor flooding affecting higher positioned equipment was also observed (Photos credit by Prof. Dr. E. Lekkas)

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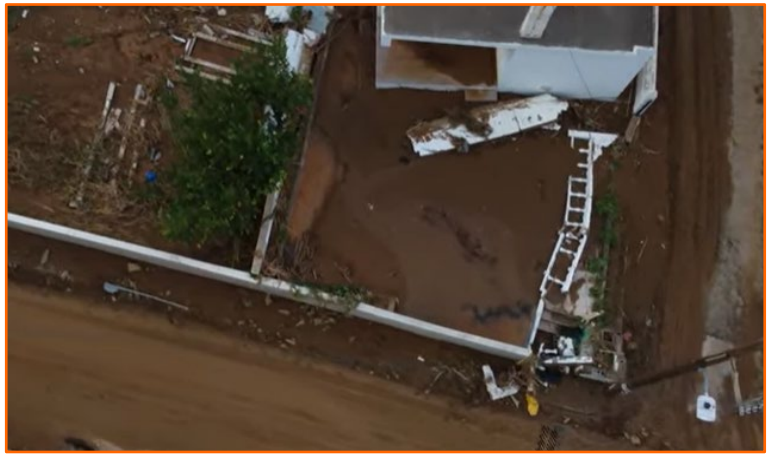
IMPACT ON THE BUILT ENVIRONMENT
DAMAGE TO BUILDINGS


Yards and gardens suffer inundation

Yard walls and fences suffer structural damage
(Photo credit by Prof. Dr. E. Lekkas and skai.gr)

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IMPACT ON BUILT ENVIRONMENT
DAMAGE TO INFRASTRUCTURE

Damage to electricity and road networks (Photo credit by Prof. Dr. E. Lekkas)

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IMPACT ON MOBILE OBJECTS
DAMAGE TO VEHICLES

Dozens of cars swept away by the water and suffered severe damage
(Photo credit by Prof. Dr. E. Lekkas)

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IMPACT ON MOBILE OBJECTS
DAMAGE TO VEHICLES

17 cars were found after the flood [have been found] either on land or on the coastline. Many other cars drifted and sank into the sea [Photo credits by Nikos Sarantos YouTube video, cretapost.gr (7), bankingnews.gr (9), Leonidas Aretakis facebook video (10)]

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IMPACT ON MOBILE OBJECTS
DAMAGE TO LIGHT OBJECTS

Lighter objects (beach umbrellas, sunbeds, light furniture and equipment, flower pots etc.) were swept away, sometimes forming debris gathered at some points (Photo credits by Prof. Dr. Efthymis Lekkas, Nikos Sarantos youtube video)

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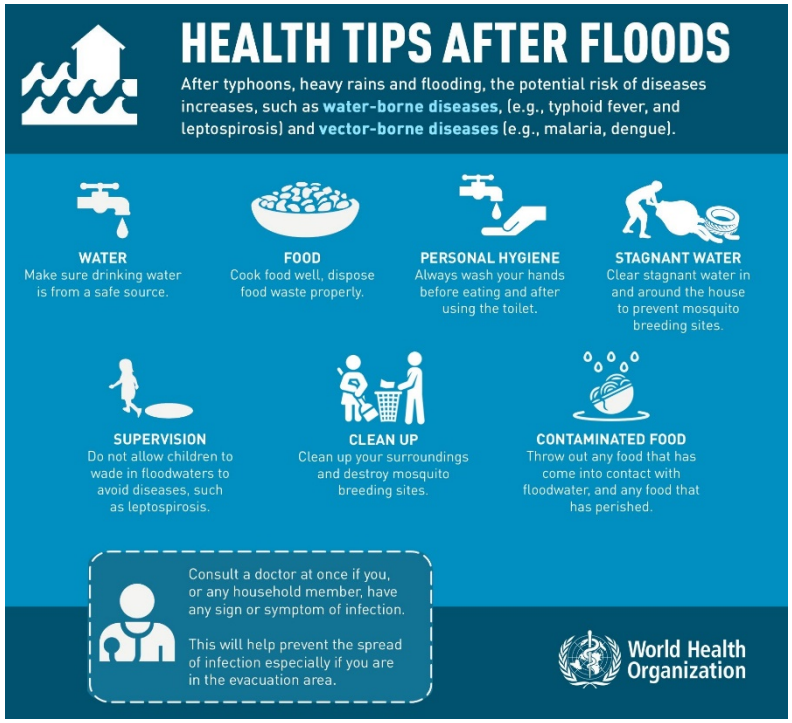
POTENTIAL IMPACT ON PUBLIC HEALTH

Flooding alters the natural balance of environment and frequently establishes a favorable habitat for pathogens and other vectors to thrive. Diseases caused by pathogens that require vehicle transmission from host to host (waterborne) or a host/vector as part of their life cycle (vector-borne) are those most likely to be affected by flooding.

Taking into account the aforementioned on the potential impact of floods on public health, post-flood measures for the prevention of infectious disease outbreaks follow in this section and are based on Mavrouli et al. (2022, in *Int. J. Environ. Res. Public Health*).



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POST-FLOOD MEASURES FOR THE PREVENTION OF INFECTIOUS DISEASE OUTBREAKS

Disinfection of the inundated buildings after cleaning-up processes in the flood-affected area

- Mechanical disinfection should include the removal of mud and dirt from surfaces such as walls, ceilings, and floors.
- Chemical disinfection should complete the process with motor-spraying surfaces with chlorine-based disinfectants.
- All household equipment, including furniture and electric appliances, as well as non-structural elements comprising wooden floors, doors, and windows that cannot be disinfected, should be removed.

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POST-FLOOD MEASURES FOR THE PREVENTION OF INFECTIOUS DISEASE OUTBREAKS

Within the first week from flooding

A rapid risk assessment should be conducted by recording information on the flood-affected area and population with special emphasis on displaced people.

Recorded information contributes to the establishment of adequate disease surveillance systems and the identification of appropriate interventions for managing and mitigating the adverse effects of infectious disease outbreaks that occur subsequently to a flood disaster.

Prioritization of the surveillance of vector- and rodent- borne diseases to minimize the related risk

The local vector and rodent species should be recognized and identified along with the environmental factors and breeding habitats that influence local disease transmission. This is important for the implementation of response activities and control measures and the improvement of preparedness activities aimed at emerging infectious diseases.

Monitoring of high risk areas

- Stagnant water serving as a common breeding habitat for mosquitoes should be regularly checked.
- Stagnant water should be removed where possible.
- Water storage containers should not be left unattended and become suitable aquatic breeding sites for female mosquitoes to lay their eggs.
- Residents could also use thick clothing, insect and pest repellents, insecticide vaporizers, mosquito nets, and door and window covers as personal protective measures.
- Areas and facilities, including local landfills, in which conditions may be conducive to rodent population growth, should be better monitored.
- Waste should be properly and safely stored and disposed.

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PRELIMINARY CONCLUSIONS

1. A strong barometric low reached Greece from the west, specifically from the area of southern Italy (13/10). It was intensified further from the warm Ionian Sea, and made landfall with significant amounts of rain on 14/10 in Western Greece, the Ionian Islands and the Peloponnese, before reaching Crete on 15/10 and then the Dodecanese islands.

2. The highest amounts of rain recorded in Crete, with intense storms in large parts of the island, are estimated to be in the scale of 100 to 150 mm at certain locations, characterized by high intensity and short duration, in the context of an extreme phenomenon and with a long return period (preliminary estimation).

3. Significant damages were observed in coastal areas in various parts of Crete, with particular intensity in Agia Pelagia and Lygaria of Heraklion, Sitia, Ierapetra, Agios Ioannis of Ierapetra area and other locations in a lesser extent.

4. The small size of the Agia Pelagia basin (3.3 km2) makes the settlement vulnerable to flooding after high-intensity storms - of short duration, with a quick response.

5. Steep topography and geology of the area (prone to erosion and impermeable geological formations) contributed to the rapid runoff and concentration of water downstream, but also to the large volume of transported materials that were carried downstream by the flood.

6. Over the last 60 years the floodplain experienced an extensive and poorly planned urban development through constructions and infrastructure that obstruct natural flow of water and in this case was an important factor in the occurrence of the flood, as there is limited available space from which the waters could drain towards the sea.

7. Preliminary analysis indicates that the underground conduit on the main street of Agia Pelagia settlement, constructed along the main channel of the hydrographic network, was not sufficient to transport the total volume of water to the sea. For this case, previous research reveals that pipelines of this type are not sufficient during such phenomena, as the strong presence of transported materials can significantly contribute to cause failures due to clogging or a reduction in the hydraulic capacity (a phenomenon that has been recorded multiple times in other floods in the Greek area).

8. In the general context of the climate crisis, there is concern about the increasing frequency of such extreme phenomena, and should be taken into consideration in any future risk mitigation initiatives (in terms of change in frequency of extreme events etc.).

9. In the wider area, the investigation and prioritization of risk, as well as exploring different structural and non structural measures to reduce the risk and the systematic training are considered necessary. In particular, in the basin of Agia Pelagia, it is considered necessary to investigate short-term interventions and long-term measures in order to reduce the risk.

10. A flood risk analysis and assessment throughout the Region of Crete based on modern methodologies and vulnerability assessment of various systems (urban fabric, infrastructure, tourist facilities, lifelines, etc.) in order to calculate the risk in each hydrological basin separately are strongly recommended. Based on these results, local and regional authorities will be able to prioritize the flood protection measures, initiatives and planning for the Region.

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ΠΡΟΚΑΤΑΡΚΤΙΚΑ ΣΥΜΠΕΡΑΣΜΑΤΑ (GR)

1. Πρόκειται για σύστημα ισχυρού βαρομετρικού χαμηλού το οποίο έφτασε στην Ελλάδα από τα δυτικά, ξεκινώντας από τη νότια Ιταλία (13/10), ανατροφοδοτήθηκε από το θερμό θαλάσσιο χώρο του Ιονίου, και έδωσε σημαντικά ύψη βροχής στη Δυτική Ελλάδα, τα Επτάνησα και την Πελοπόννησο (14/10) και στη συνέχεια την Κρήτη και τα Δωδεκάνησα.

2. Η Κρήτη κατέγραψε τα πιο σημαντικά ύψη βροχής με έντονες καταιγίδες σε μεγάλα τμήματα του νησιού της τάξης των 100 με 150 mm κατ' εκτίμηση και κατά τόπους με υψηλή ένταση και μικρή διάρκεια, στο πλαίσιο ενός φαινομένου ακραίου και με μεγάλη εκτιμώμενη περίοδο επαναφοράς.

3. Καταστροφές παρατηρήθηκαν σε διάφορες παραλιακές περιοχές της Κρήτης με ιδιαίτερη ένταση στην Αγία Πελαγία και Λυγαριά Ηρακλείου, τη Σητεία, την Ιεράπετρα, τον Άγιο Ιωάννη Ιεράπετρας και άλλες τοποθεσίες σε μικρότερο βαθμό.

4. Το μικρό μέγεθος της λεκάνης απορροής (3.3 km^2) της Αγίας Πελαγίας καθιστά τον οικισμό ευαίσθητο σε πλημμυρικά φαινόμενα μετά από καταιγίδες υψηλής έντασης - μικρής διάρκειας, με γρήγορη απόκριση.

5. Το έντονο ανάγλυφο και η γεωλογία της περιοχής (αδιαπέρατοι και ευδιάβρωτοι γεωλογικοί σχηματισμοί) συνετέλεσαν στην γρήγορη απορροή και συγκέντρωση του νερού στα κατάντη, αλλά και το μεγάλο όγκο φερτών υλικών που κατέβηκαν προς τα κατάντη με την πλημμύρα.

6. Η κατάληψη του πλημμυρικού πεδίου διαχρονικά τα τελευταία 60 χρόνια από κατασκευές και υποδομές αποτέλεσε σημαντικό παράγοντα για την εκδήλωση της πλημμύρας, καθώς καταγράφεται ελάχιστος διαθέσιμος χώρος από τον οποίο θα μπορούσαν τα ύδατα να αποστραγγιστούν προς τη θάλασσα.

7. Από την προκαταρκτική ανάλυση προκύπτει ότι ο πλακοσκεπής αγωγός επί της οδού Αγίας Πελαγίας, ο οποίος έχει κατασκευαστεί κατά μήκος του κύριου κλάδου του υδρογραφικού δικτύου δεν κατέστη επαρκής για να μεταφέρει το συνολικό όγκο των υδάτων στη θάλασσα. Διαπιστώθηκε ότι αυτού του τύπου οι αγωγοί δεν επαρκούν κατά τη διάρκεια τέτοιων φαινομένων καθώς η έντονη παρουσία φερτών υλικών δύναται να προκαλέσει αστοχίες λόγω απόφραξη ή μείωσης της παροχευτικής ικανότητας (οι οποίες έχουν καταγραφεί πολλαπλώς και σε άλλες πλημμύρες στον Ελληνικό χώρο).

8. Στο γενικότερο πλαίσιο της κλιματικής κρίσης καταγράφεται ανησυχία για την αύξηση της συχνότητας τέτοιων ακραίων φαινομένων, και θεωρείται σημαντικό να ληφθεί υπόψη σε οποιαδήποτε σχεδίαση μέτρων μείωσης του κινδύνου στο άμεσο μέλλον.

9. Στην ευρύτερη περιοχή η διερεύνηση και η ιεράρχηση του κινδύνου, η χαρτογράφηση και η πρόταση έξυπνων κατασκευών και η συστηματική εκπαίδευση θεωρούνται απαραίτητες για τη μείωση του κινδύνου. Στη λεκάνη Αγ. Πελαγίας, κρίνεται αναγκαία η διερεύνηση βραχυπρόθεσμων παρεμβάσεων και μακροπρόθεσμων μέτρων για τη μείωση του κινδύνου.

10. Συνιστάται έντονα η ανάλυση και η εκτίμηση του κινδύνου πλημμύρας σε ολόκληρη την Περιφέρεια Κρήτης με βάση σύγχρονες μεθοδολογίες και η εκτίμηση της τρωτότητας των συστημάτων (οικιστικός ιστός, υποδομές, τουριστικές εγκαταστάσεις, γραμμές ζωής κ.λπ.), προκειμένου να υπολογιστεί ο κίνδυνος σε κάθε υδρολογική λεκάνη ξεχωριστά. Με βάση αυτά τα αποτελέσματα, οι τοπικές και περιφερειακές αρχές θα είναι σε θέση να ιεραρχήσουν τον αντιπλημμυρικό σχεδιασμό της Περιφέρειας.

Newsletter of
Environmental, Disaster, and Crises Management Strategies

ISSN 2653-9454
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The 15 October 2022 Flash Flood in Agia Pelagia (Crete, southern Greece)

Prof. Dr. Efthymis **Lekkas**
Dr. Michalis **Diakakis**
Dr. Spyridon **Mavroulis**
PhD c. Katerina-Nafsika **Katsetsiadou**
PhD c. Marilia **Gogou**
PhD c. Nafsika-Ioanna **Spyrou**
Dr. Maria **Mavrouli**
MSc. Kostas **Antoniadis**
PhD c. Eleftheria **Stamati**