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INVESTIGATION OF THE CAUSES OF THE FLOODING IN THE KARST AREAS OF THE MUNICIPALITY OF HALKIDA, PREFECTURE OF EVIA (GREECE)

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Abstract

In karst areas floods as a natural response to rapidly increasing amounts of water, represent one of the most dramatic interactions between humans and the environment and particularly in areas with icreasing urbanization. Floods in karst areas often accompanied by damage to property (property, business and infrastructure), landslides, rockfalls and groundwater contamination. The purpose of this work is to describe geologically, geomorphologically and hydrologically the karstic floods that occurred in the areas of Liani Ammos, Agia Eleousa and the Beam of the Municipality of Halkida during the period February-March 2019. The areas mentioned above have been heavily flooded, with groundwater levels rising, reaching even into areas within the urban fabric, resulting in floods of entire building blocks. As result of that, the inhabitants of the region experienced extensive

problems for a long time and the General Secretary of Civil Protection has declared the municipality of Halkida in an emergency until June 3, 2019.

Keywords: karst areas, karstic floods, urban area

1. INTRODUCTION

Throughout history, floods have remained an inalienable part of human fate and nature (Smith-Ward, 1998). Moreover, in recent decades there has been an increase in flooding in karst areas around the world with catastrophic consequences to humans and the environment, although they are an integral part of it.

Floods are related to the water level in the underground karstic water table. The water level in karstic groundwater systems can increase dramatically during periods of heavy or prolonged rainfall. Consequently, as underground storage and drainage reach capacities, increased aquifers can reach the topographic surface and cause flooding (Gutiérrez et al., 2014; Naughton et al., 2017).

In karst areas, floods as a natural response of the system to rapidly increasing amounts of water represent one of the most dramatic interactions between humans and the environment, and especially in the karst areas that became increasingly populated. They cause damage to properties, businesses and roads. They can lead to the formation of collapsed sinks and contamination of groundwater.

The purpose of this work is to describe the karstic flood event that occurred in the Municipality of Chalkida, in the areas of Liani Ammos, Agia Eleousa and Dokou in the period February-March 2019 (Figure 1). Similar floods but with smaller extend and intensity are well known in the study area over the past decades. However, during this flood event, the aforementioned areas have suffered of severe flooding as groundwater levels have risen to ground levels even in areas within the city plan, resulting in entire building blocks being at risk forcing their owners to evacuate them. In the fields, the water reached near Dokos the height of three meters blocking the surrounded road network, while within the temporarily formed "lake". Many businesses have been flooded and commodities have been destroyed. Thus, the Municipality of Chalkida declared a state of emergency by a decision of the Secretary General of Civil Protection for a period of three months, until June 3, 2019.

Figure 1. Study area

2. DATA COLLECTION

The data used in the present investigation is based on:

I. chartographic material:
   i. Chartographic map scale 1: 50.000, sheet: CHALKIS produced by Hellenic Military Geographical Service (H.M.G.S.)
   ii. Topographic diagrams, scale 1: 5.000, sheets: 6404/1, 6404/2, 6404/ and 6404/4 produced by Hellenic Military Geographical Service (H.M.G.S.)
   iii. Geological map, scale: 1:50.000 sheet: Halkis produced by Institute of Geology & Mineral Exploration (IGME)

II. collection of climatic - meteorological data from the National Meteorological Service

III. four consecutive visits (9.3.2019, 23.3.2019, 31.3.2019, 15.4.2019) In the flooded suburban area of the study that extends to the areas of Liani Ammou, Ag. Eleusa, Doko for multiple on-site observations related to the extend of the flood event, the identification of temperararily karst springs; thgese visits spanning to 5 weeks period covered the peak period of the flood event.

IV. the collection of all the available bibliography (mapers, reports, etc.) for the study area and its surropunding region (cientral Euboea) (e.g. *Katsetsiadou, E. N.,*2010 – 2011; Zorapa, M., Sampatakaki, P., Nikolaou N.,2019)

V. spanning for to determine the causes that led to the extensive flooding of the study area.

VI. comprehensive analysis of all collected data. In the study area we identified three areas of interest.

As a result of the above we have obtained definite scientific opinions, conclusions and suggestions for immediate corrective actions, as well as future flood response as follows:

i. Central flood zone, about 10km^2. During these four visits, biopsies were carried out on site of all major floodplains, observing various natural / anthropogenic factors and their interactions. Also monitoring the key factor such as the change in flood capacity and extent.
ii. Inner zone, on the second visit (23.3.2019) was received with anointing aerial drone (administrator drone: V. Kotinas).
iii. Outer zone or surface water table zone, requiring future environmental karst geomorphological study at a scale of 1: 5,000 with special reference to karstic soil specificity.

3. STUDY AREA

3.1 Geography - Climatology

The study area covers the areas of Liani Ammou, Ag. Eleousa, of Doku as well as some sections within the city plan of Chalkida (Figure 2). The flooded area includes extensive lowland area between the slopes of low mountains and sea and in the background of the surface watershed have the two major massifs: Mount Olympus (1171m) to the east and mountain Dirfis (1743m) to the north – northeast. In terms of elevation, most of the flooded area are +1.1m ~ 5.5m above mean sea level.

The study area is located in Central Greece and can be characterized by a Mediterranean climate (or dry summer) which is expressed as dry summers and mild, wet

winters. During summer rainfalls are rare and cloud cover is minimal, while during winters rainfalls are more likely and extreme storm events are not unusual (Ulbrich et al., 2012).
Climatic data for this area were obtained from the Hellenic National Meteorological Service (HNMS).

The study area can be considered dry with a low average precipitation per year (about 390 mm), however there is a great fluctuation on an annual basis during some years total precipitation exceeds 600 mm. If we analyze precipitation per month we observe that the dry period extends from June to September while the wettest months are November and December. Between November and April the largest percentage of precipitation is observed. Storms with a daily precipitation larger than 80 mm usually happen during October November and November but intense storm events can also occur at a different time and exceed 100 mm during 24 hours.

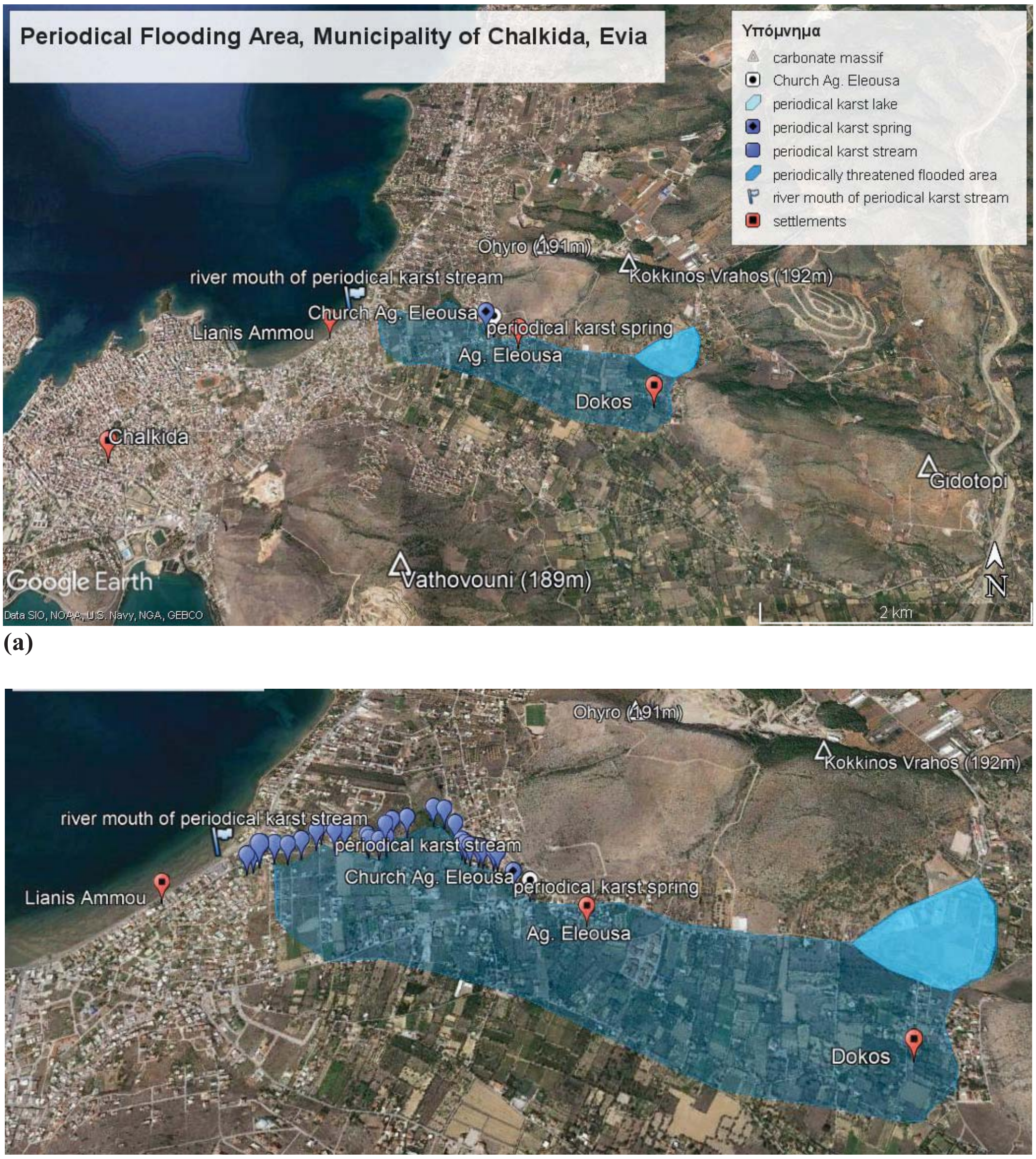

Figure 2. Periodical flooding research area, Municipality Chalkida, Evia (a,b) (Source: Google Earth, 2018©Google)

Mean annual air temperature for the study area is 18ºC and the distribution of monthly values of air temperature is normal during the year. We can observe that the warmest months are during summer and more specifically between June and September (>25 ºC), while during January and February average monthly temperature is about 9.5 ºC. During the summer period max air temperatures can exceed 35 ºC, while during the cold period temperatures rarely drop lower than 0 ºC (Figure 3).

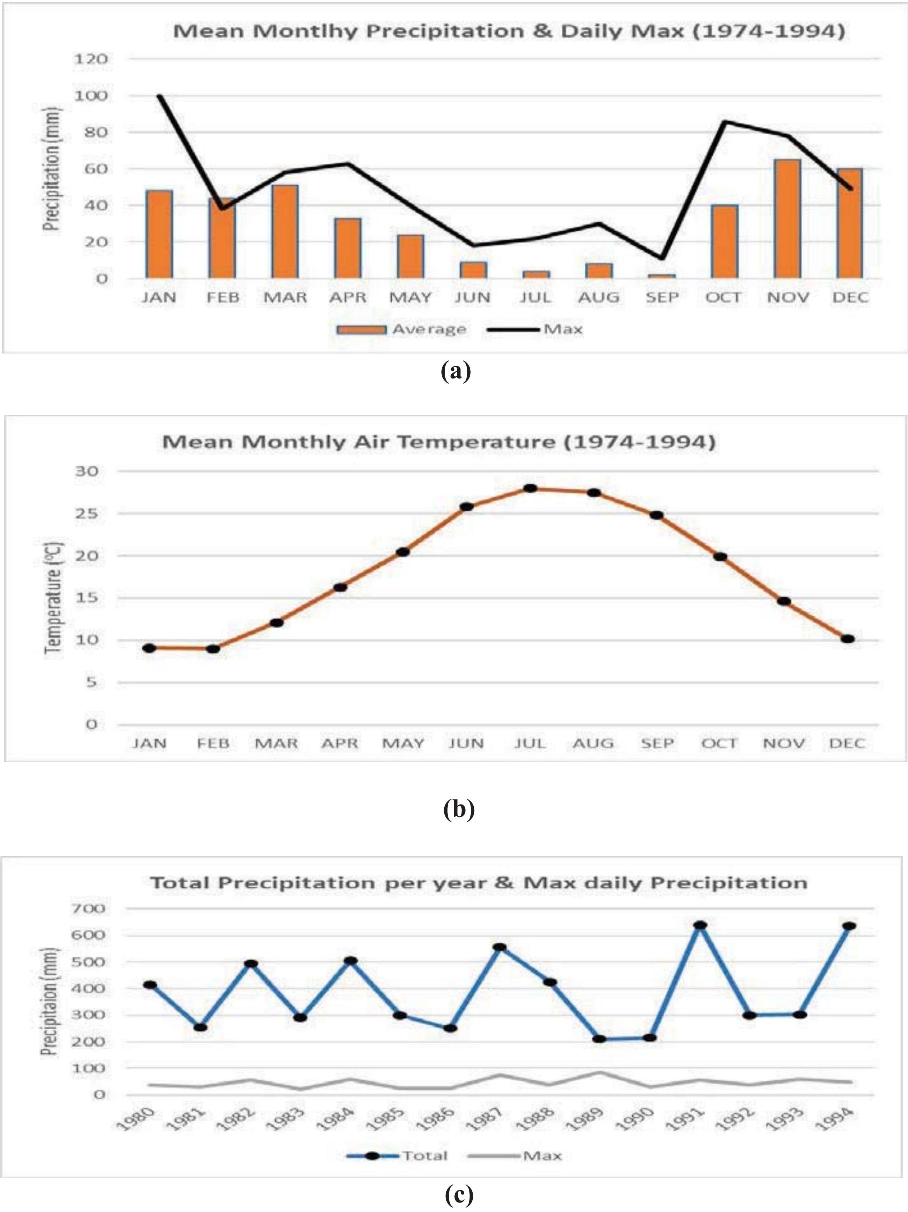

Figure 3. Climate charts of the municipality of Chalkida (period 1974-1994)

3.2 Geology - Tectonics

The geological structure of the lowland flooded area is constructed of low-thickness sandy-walled sandstones (<8 m) that have been deposited on a background consisting of Peridotites and volcanic-sedimentary "Melanze" (IGME, 1988).

The flooded area of Liani Ammou - Ag, Eleousa - Dokos superimposed on surface horizon of alluvial deposits with thickness varying from position to position. The geological formation is limited water permeability and does not allow easy movement of underground or surface water infiltration broth permeability coefficient is k <10-5 m/s. The geological structure of the massifs is composed of limestone age A. Triadic - M. Jurassic. Limestone formation has high water permeability due to karstification whose permeability coefficient is k≥10-3 m/s (Ref). The faults of the study area have a general orientation East - West. The specific direction of the faults determines the conditions of the direction of the karstic groundwater supply. This phenomenon creates favorable geological-tectonic conditions within the limestone geological formations surrounding the lowland area of interest and which has a decisive influence on the flood phenomenon. (IGME, 2019)

4. RESULTS AND DISCUSSION

4.1. Karst Geomorphology

The study area, belongs to the final stages of karst evolution in Triassic limestones and characterized a type of Holokarst, including karst forms such as poljes, dolines, and sinkholes. There are three denudes carbonate massifs belonging to the type of exposed karst (i.e., no cover on their surface); this is the final evolutionary stage of an initial Denude karst, after removing (eroded) its cover. The flow of water is lower and quite unstable in the Exposed / Denuded karst, while the underground karstic channels largely inherited from the early stages. Limited water circulation "release" the flow of water during the transition from deeply entrenched and exposed karst evolutionary stages, resulting in the development of the watershed and the vadose zone. Heavy rainfall leads to surges of diffuse autogenic recharge and to pulses of percolation through the vadose zone (Williams, 1993). The rising volume of water within the epikarst aquifer during storm events increases hydraulic head and so produces a pressure pulse that stimulates a transfer of water trough karst underground channel system. This type of karst can present a wide exposition of the different forms of caves, inherited from the earlier stages, which used in various areas of the active systems.

The karst (carbonate formations) overlay to volcano-sedimentary sequence that are generally characterized by limited water permeability; this prevents the so-called karst drainage downwards, acting as impermeable (or slightly permeable) floor.

4.2 Karst Hydrology

In the study area there is no developed surface hydrological network. Therefore, the main factors of the flood event are related to karst water table, which is associated with:

I. The massif of Ohirou on a large visible front of a periodic karstic spring in the village of Agia Eleousa, and on a non-visible front along the base of the existing estavela; the overflow of the karstic water table appears to be more pronounced along the base of limestone's massifs. Thus, in the basement of the church of Ag. Eleousa (Figure 4a) there is one spanning for to determine the causes that led to the extensive flooding of the study area, which caused flooding in the basement of the same church (Figure 4b). The waters, that flood the basement of the church, by pumping were drained to nearby field plot creating a temporarily anthropogenic dolines – water tanks, without to exclude the possibility of the existence of other estavelas operating in the that plot (Figures 4c,d). Moreover, in the urban area of Ag. Eleousa, 80-100 m northwest of the church Ag. Eleousa, there is a basic periodic karstic spring, outflowing to a technical channel (2-3 m wide, 1.5 m deep) whose discharge measured on 31.3.2019 exceeded 200 m^3/hr; this channel going through an urban area (Figures 5a,b,c) debouches to the beach of Lianis Ammos beach. About 140 m from the sea during the peak period of flooding, a pumping machine was used to prohibit water overflow from the aforementioned canal (Figure 5d).

(a) (b) (c) (d)

Figure 4. Periodical flooded area of the Church Ag. Eleousa**;** a: road in front of Church; b: pumping floodwater from church; c: pumping water from plot (d); and d: flooded plot

II. Vathivouni massif, which borders the area towards the city of Chalkida, together with other neighboring massifs being characterized by high water permeability, develop an underground water table, which laterally supply with groundwater the lowland of the study area.

III. Therefore, the low-lying part of the study area, during and after a period of intense rainfall, is saturated causing major discharge at surface of the underground karstic water table, causing a flood whose spatial extension and time lasting depends on the amount of water encompassing in the karstic formations and in the absence of a nature hydrographic network, the ability of the surface draining artificial network.


(a) (b)
(c) (d)

Figure 5. Technical channel through an urban area (a, b, c). Pumping machine transferee water from the canal through soft pipes (d).

IV. Within the flooded exist more than 100 estaveles (Figure 6). There are more than 100 estavelas on the flooded area. They are located on fenced plots (Figure 6) some of which are cultivated and some are built and inhabited (Figure 7).

V. Also, at Dokos area was formed a small karstic lake (with depth of 2m) (Figure 8) which in the past used to be formed periodically following rainy periods.

VI. In addition, the possible involvement in the karstic water overflow may also have contributed to the non-use of old springs / drillings for irrigation of the city of Chalkida.

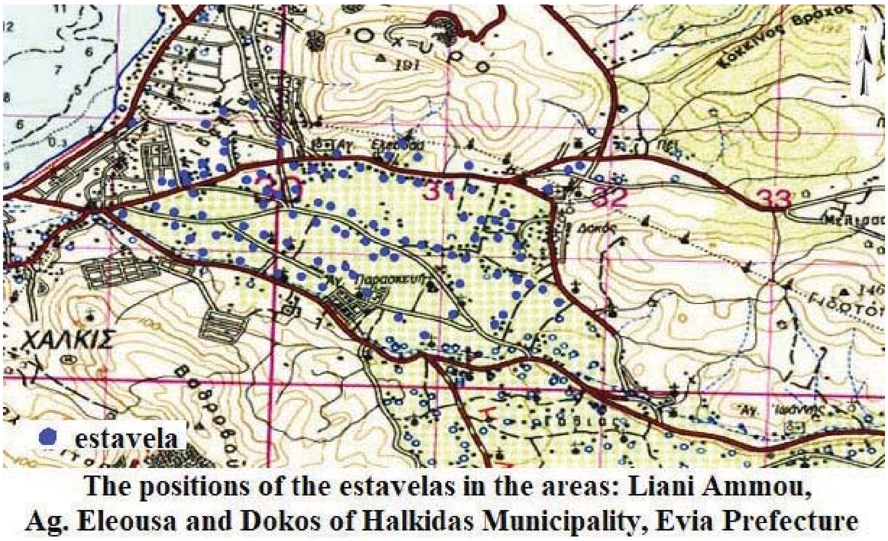

Figure 6. The position of estavelas in the study area (Chartographic map 1: 50.000, sheet: CHALKIS H.M.G.S)

(a) **(b)** **(c)**

Figure 7. Periodical flooded urban area; a, b: flooded inhabited fenced plot and c: flooded road in urban area

(a)

(b)

(c)

Figure 8. The area of periodical flooded karst lake (a: the road from Ag Eleousa to Dokos); b: the north side of kast lake and c: panoramic view taken with drown)

In 23rd of March, 2109 water salinity measurement revealed that the outflowing karstic water had conductivity of 1400-1500 μS/μm, that corresponds to salinity of <1 ppt (part per thousand), indicating no interference with seawater (salinities 37-38 ppt). This low salinity could also be attributed to the chemical dissolution of the carbonate rocks as groundwater passes through them. But, on the other hand, the water level (or the thickness) of the flood could be affected by the mean sea level (coast is at a distance of ~3 km) that varies in the case of the north part of the Euripus channel up to 0.8 m during spring tides. Interestingly the staff for the technical office of the Municipality of Chalkida stated that although they started to pump the water from the "lake" its level increase temporarily by 20-30 cm few day ago; this period of tome coincide with the fool moon (i.e. spring tides). On the other hand, the possible communication of the ground karstic water with seawater was inhibited by the hydraulic pressure developed between the surrounding mountains and sea-level, without seawater intrusion into karstic formations to be excluded during the summer period when karstic water table is lower and the associate hydraulic pressure reduced following period of limited rainfall.

5. CONCLUSIONS - SUGGESTIONS

In the study area, we have a combination of two types of karstic flooding: recharge-related flooding and unloading-related flooding. This phenomenon explained by the fact that the flood of the study area was subjected to a series of floods due to the increase of aquifers in

the karst water level. Once the underground canals filled with water and periodic springs/estaveles activated with water overflowing to the flat surfaces of the karst forms (dolines, poljes, uvala). The analysis of the above factors lead to two flood scenarios:
Senario 1, where groundwater exceeding normal underground water levels causes flooding by outflowing through estaveles; and,
Senario 2, where the flow of water within the wider zone of karstic massifs triggered by high groundwater levels, causes activation of periodical karst springs and, then, flooding of the adjacent karstic surface cavities.

Both scenarios are justified by wave -like of the plain surface separated by isolated areas of slightly higher terrain such as in the study area. Here, the recharge zones are located in a well-developed epikarst zone characterized by high permeability and is located just below the alluvial layers.

Raising the level of the karstic underground aquifer above the land surface causes the water to outflow. The flood occurs after a certain period of time following a period of intense rainfall that may last for weeks. Due to the small gradients of the study area, the surficial drainage network does not have high carrying capacity, which is reduced further by the fine-grainned sediment (mostly mud and fine sand) deposited. Moreover, drainage capacity depends also upon the amount of the non drained water after short-lived high-intensity storms and the "wavy" surface topography of the rather flat land-surface of the study area. The time interval between the storm (or successive storms) and the associated flood events maybe predictable on the basis of water budget justification, but is not easy to be mitigated.

The volume and evolution of the flood depends directly on the volume and intensity of the flow diffusion through limestone joints and the flow in between the karstic canals network. In the study area, the degree of threat and deterioration of the karst area, characterized by changes in between surface and underground waters, varies in space dramatically depending on the hydrological karstic system, which are related to:

i. climate change;
ii. intensive karstification process in the study area associated with the creation of the karstic periodic lake (dolina), karstic springs, estaveles, and polje;
iii. active urban activity in alluvial deposits, resulted in the formation of closed cavity forms considered anthropogenic dolines*; and ,*
iv. active urban planning activity (type and method of construction of building foundations) that blocks the natural underground and surface drainage networks towards the sea.

Understanding the type of karstic flood is essential to solving the problem. The study area is a typical karstic area and therefore prone to karstic flooding. This investigation leads to the conclusion that the karstic geomorphological character of the study area must officially recognized and restrictions and laws on the use of karstic land must applied. Discharge and erosion control plans should address the unique characteristics of karst features. Solutions to flooding problems in karst areas should also be coordinated with water quality control to prevent groundwater contamination.

Future research tackling the problem of these karst-related floods and in the concept of urban planning and environmental management could involve (in different spatial and time scales) measurements/observations/cartography by addressing:

(i) morphological / topographic characteristics;
(ii) geological structure / lithology, including boreholes;
(iii) stratigraphic investigation using geophysical methods (e.g. thickness of alluvial deposits, epikarst);

(iv) climatic conditions;
(v) karst geomorphology (mapping of karst geomorphs at a scale of 1: 5,000);
(vi) hydrographic analysis of surface karst waters;
(vii) water quality in relation to the prevention of pollution and contamination in flooded areas.

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