MULTI-PARAMETER FLOOD RISK ASSESSMENT AND MANAGEMENT PLANNING AT HIGH SPATIAL RESOLUTION IN THE REGION OF ATTICA, GREECE

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ABSTRACT

Floods are disastrous events as they induce fatalities, damages to the environment, properties and infrastructure, at a global level. The Region of Attica, that hosts Athens (capital of Greece), has suffered various floods, including the severe flood in Mandra (2017) with 24 fatalities. In 2021, a Programming Agreement was signed between the Prefecture of Attica and the National Observatory of Athens to conduct the research study «Earthquake, fire and flood risk assessment in the Region of Attica» (Part A) in selected and most vulnerable areas. In the framework of this research and technical work, state-of-the-art methodologies were developed and implemented that support multi-parameter flood risk assessment and management planning at high spatial resolution (building block level). This work integrates different data sources, including remote sensing, in-situ measurements, field visits, and simulations, and is characterized by considerable added value, as it supports public actors and stakeholders in decision-making and management of disastrous events.

***Index Terms*—** flood risk assessment, flood management, flood risk mitigation; refuge areas; escape routes

1. INTRODUCTION

Floods can cause grave disasters, both in terms of deaths and material damages. Indicatively, in 2022, 176 floods were recorded worldwide, killing 7954 people, affecting 57.1 million people, and resulting to economic losses of 44.9 billion USD respectively, according to the latest available data for 2022, published by the Centre for Research on the Epidemiology of Disasters [1].

In order to prevent the new and reduce the existing risks from natural hazards, the Sendai Framework for Disaster Risk Reduction 2015–2030 was adopted in March 2015 coordinated by the United Nations Office for Disaster Risk Reduction (UNDRR) [2]. The Framework's basic priority for action is the understanding of the disaster risks, from pre-disaster, prevention and mitigation to preparedness and effective response to disasters [3].

Thus, to increase disaster resilience that is a core aim of sustainable development according to the Global Assessment Special Report 2023 on Disaster Risk Reduction [4], special attention should be given to assessing risks in a reliable way. Risk assessment is derived as a combination of the following factors: hazard, vulnerability, and exposure [5].

The efficient disaster risk management includes mitigation measures such as the design of civil protection measures, and the implementation of studies with proper interventions (both structural and non-structural). This is even more crucial in highly dense urban areas, with large populations, critical infrastructure, and important socioeconomic activities.

2. RESEARCH STUDY

In the framework of a Programming Agreement signed in March 2021 between the Prefecture of Attica (Greece) and the National Observatory of Athens (NOA) (Part A), a research study funded by the Region of Attica is conducted entitled «Earthquake, fire and flood risk assessment in the Region of Attica» in selected and most vulnerable areas. Within this project, a holistic multi-parameter risk assessment methodology has been developed and implemented at high spatial resolution.

The research study on flood risk assessment is implemented by the National Observatory of Athens (NOA), Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing (IAASARS), Operational Unit "BEYOND Center of Earth Observation Research and Satellite Remote Sensing" in cooperation with the National Technical University of Athens (NTUA), School of Civil Engineering, Department of Water Resources and Environmental Engineering, Research Group ITIA.

3. STUDY AREA

The study area is the Region of Attica, the most highly dense area in Greece that includes its capital, Athens. It constitutes a region with significant characteristics, such as long coastline, large inland area, and nine islands, various geoenvironmental units, high population density (i.e., 3.792.469 residents, and 36,4% of the country's population according to the Hellenic Statistical Authority (2021) [6]), crucial infrastructures, and social economic activities.

The Mandra river basin (Figure 1) is presented for the purpose of this manuscript, which is in the southwest part of Attica Region. It includes the streams Agia-Ekaterini and Soures that cross the city of Mandra, as well as mikro-Katerini stream that crosses Magoula city, while all of them join Sarantapotamos river. There is a partial diversion of Agia-Ekaterini stream to Soures stream, upstream of the city of Madra, while the rest of the flow passes through the city of Mandra. Then, there is a full diversion of these three streams to Sarantapotamos river, upstream of the city of Elefsina.

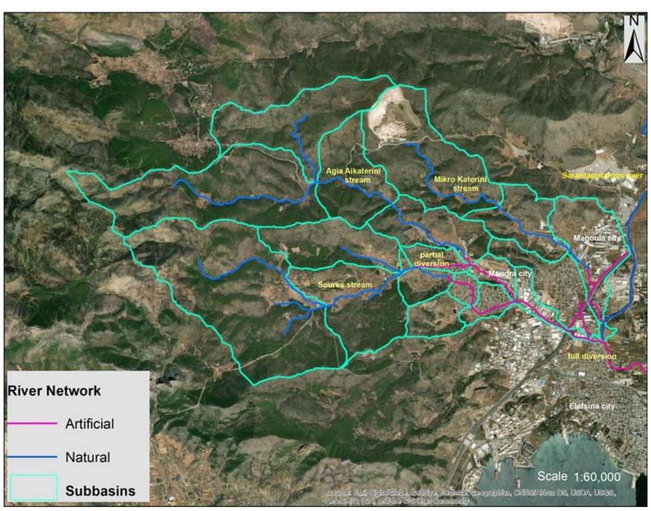

Figure 1. Sub-basin and hydrographic network layers for the catchment of the Agia-Ekaterini, Soures and mikro-Katerini streams.

4. METHODOLOGY

Flood risk is assessed by an integrated methodology that includes geo-spatial data, remote sensing, in-situ observations, and hydrologic and hydraulic simulations. This holistic multi-parameter methodology was developed by the FloodHub research group of the BEYOND/IAASARS/NOA in cooperation with the ITIA research group of NTUA.

Figure 2 presents, in a schematic way, the methodological framework for flood risk assessment. The flood risk assessment is validated using all available information on historical flood events, high risk locations indicated by the local population and the competent authorities, as well as the recorded citizens' calls for aid to the Fire Service in flooded areas.

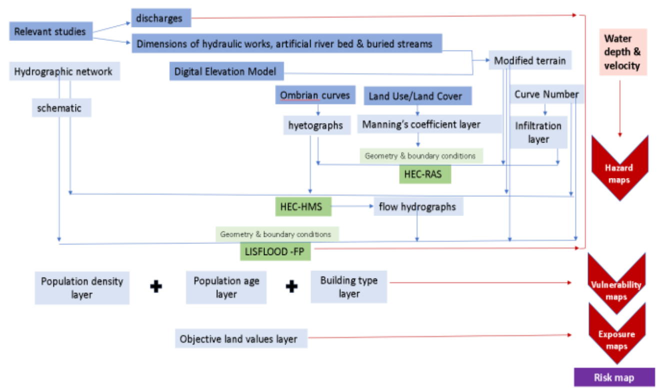

Figure 2. The methodological framework for flood risk assessment in Attica Region.

4.1. Data collection

First, all available data, including geo-spatial data and earth observation data at the highest available resolution (e.g., DEM and land cover), and relevant technical studies, are collected from the competent services, quality checked, and enriched by photo-interpretation.

Detailed field visits are conducted according to a standardized methodology and reporting template to estimate the dimensions of the technical works, identify obstacles or hydraulically sensitive points in the riverbed, critical infrastructure, and services in the area, and collect feedback from the residents.

4.2. Design hydrographs

Rainfall hydrographs are derived from updated ombrian (or else intensity-duration-frequency) curves, which are constructed and adapted to each river basin, following a new advanced methodology [7, 8]. Available data from previous studies are used, stations' data are updated where possible, and new stations are added wherever appropriate. The final sample consists of 29 stations at 18 sites managed by 4 public institutions, which jointly cover the period from 1860 to 2020.

Then, by applying the ombrian curves, hyetographs are compiled in each sub-basin for the three standard return periods (50, 100, 1000 years) according to the EU Flood Directive [9].

4.3. Hydrological analysis and modeling

Sub-basins are designed for a more accurate estimation of runoff in each sub-basin, based on the river network (both natural and artificial) and the characteristics of the terrain and land cover.

Subsequently, the watershed schematic is developed and the simulation is run in the open-source HEC-HMS 4.10 rainfall-runoff model [10]. The different scenarios are simulated based on the flood return period T (50, 100, 1000 years).

4.4. Hydraulic modeling and hazard assessment

The open-source hydraulic model HEC-RAS 6.3 2D is used for the hazard assessment [11], by applying the spatially distributed rainfall (rain-on-grid) method. The total hyetograph for each return period is entered without subtracting losses, which are estimated internally following the SCS method of CN III. The land cover data are obtained from the European Urban Atlas of the Copernicus Land Monitoring Service for the period 2012-2018 [[15] [15] [15]], and they are updated through photo-interpretation. Also, burnt areas for the period 1985-2021, derived from the FireHub service of BEYOND/IAASARS/NOA, are added. Then the updated land cover layer polygons are also entered, and for each land cover class a value of the Manning roughness coefficient is assigned in the floodplain and riverbed based on the land-use maps, the sensitivity analysis, and the field measurements. The hydraulic solution is performed with a variable computational step, and it is carried out at high spatial resolution (from 10-25 m depending on the area of the catchment), and becomes even more detailed (from 1-10 m) in areas of high interest (such as near the stream and road network) and intense topographic relief variations.

This hydraulic model is used to produce the water depth and velocity maps for the flood hazard assessment for different flood scenarios.

4.5. Vulnerability, exposure and flood risk assessment

Vulnerability is considered as a weighted estimation of population density and population age (socio-economic parameters), as well as building type (disaster resilience parameters), based on the most recent published data of the Population and Housing Census by the Hellenic Statistical Authority [12].

Exposure is based on the land value, according to the objective land values (€/m^2), as obtained from the Ministry of Finance [14] 14] 14]].

Finally, hazard, total vulnerability and exposure are combined to estimate flood risk. The resulting layer is combined with the exposure layer (objective land values).

Based on the flood risk assessment and the in-situ observations from the field visits, critical points are identified and classified in three risk priority levels according to a series of criteria, such as the flood depth, their proximity to the simulated flood extent and the recorded locations of citizens' calls for aid to the Fire Service, the threat they pose for human lives and critical infrastructures, etc.

4.6. Mitigation planning

Mitigation measures are proposed for the worst-case scenario, including definition of refuge areas and design of escape routes. For this purpose, a multi-criteria analysis is performed considering the following criteria: the refuge areas should be public buildings in good condition with roof (not open-air) and be well-distributed spatially to cover all the population in risk, the escape routes should respect the traffic directions, avoid crossing the river network, and follow the optimum ways possible (shortest and safest).

5. RESULTS

The flood risk assessment is presented in Figure 3 along with the critical points, which are classified into 3 priorities. The critical points of first priority are mostly buildings and infrastructure inside the flood extent, and they pose a severe danger to the local population and the passers-by, both the pedestrians and those in vehicles.

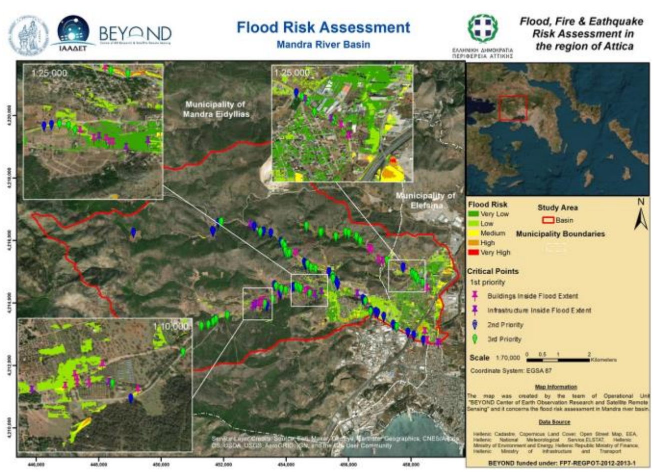

Figure 3. Map of flood risk assessment and critical points of first, second and third priority.

Taking into account the flood risk and the critical points, safe population assembly points and evacuation routes are proposed (Figure 4). Public schools are identified as the most appropriate shelters, especially in the urban areas, and safe escape routes are designed so that all the areas under medium, high and very high flood risk are covered.

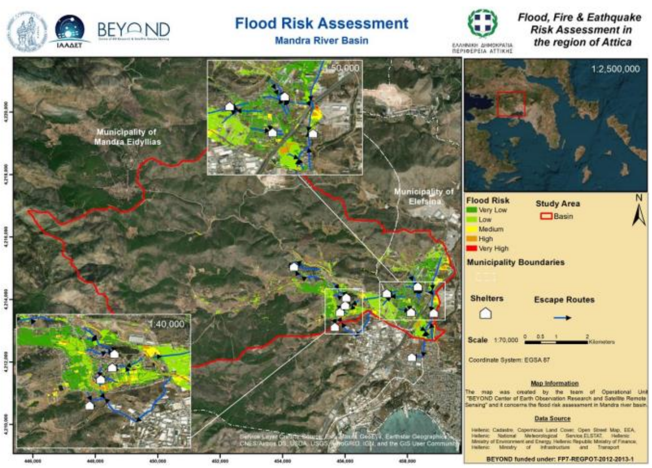

Figure 4. Map of flood risk assessment and critical points of first, second and third priority.

6. DISCUSSION

This research study analyses the flood hazard, vulnerability and exposure of selected areas, in conjunction with the actual physical and socioeconomic parameters of each study area. Taking all this into consideration, the study estimates the flood risk - in the most objective and reliable way secured by science and technology –and proposes appropriate mitigation measures. It's the first time that such a holistic approach for risk assessment is implemented on building block level in Greece.

Various challenges were encountered during the hydraulic simulation due to model instability, which are mainly caused by the complexity of the topography of the study area. For this reason, and due to the inherent uncertainty of the models [[15]], various tests were performed by varying the resolution of the computational mesh, the solution scheme and the required values of the adjusted variable time step based on Courant conditions, until the solution results were free of instabilities/errors, had acceptable computational load and were hydraulically correct.

Moreover, in the process of vulnerability and exposure estimation, additional challenges were faced due to data gaps. A multi-criteria technique was developed and applied in order to fill the data gaps, using both photo-interpretation and logical assumptions. Further challenges needed to be addressed in the proposal of mitigation measures for the worst-case scenario, including definition of refuge areas and design of escape routes, because not all requirements were always covered for a specific area. In such cases, safety was prioritized to distance.

7. CONCLUSIONS

In conclusion, the utilised methodologies in this research work consist of state-of-the-art techniques that support multi-parameter flood, fire and earthquake risk assessment and management planning at a high analysis level (building block level) using a variety of data sources. This work is characterised by considerable added value as it supports public actors and stakeholders in decision-making and management of disastrous events. Additionally, the contribution of this work is dual, both on prevention phase and on operational phase during a crisis; on prevention phase offers the prioritization and implementation of the necessary interventions according to the risk level, and on operational phase how to successfully evacuate the affected areas with safety and order.

Indeed, the prototype knowledge created through this project is currently supporting the Prefecture of Attica in the optimum implementation of the National Civil Protection Plan, and the work of Civil Protection Coordination Bodies. This can be used to serve the operational needs during a crisis, as well as the preparedness and the strategic decision making towards disaster resilience. All the above-mentioned were repeatedly confirmed and evaluated positively according to the stakeholders' feedback.

The specific project also serves the implementation of the Sendai Framework for Disaster Risk Reduction, given that it conducts comprehensive surveys on multi-hazard disaster risks and develops disaster risk assessments and maps. Moreover, the project is based on the understanding of disaster risk in all its known dimensions of vulnerability, capacity, exposure of persons and assets, hazard characteristics and the environment, as required by the Sendai Framework for Disaster Risk Reduction. This knowledge supports the relevant authorities towards adopting effective policies and practices for disaster risk management, and is used for risk assessment both for prevention and mitigation.

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