FLOOD HAZARD ASSESSMENT AND VULNERABILITY ANALYSIS IN GARYLLIS RIVER BASIN, CYPRUS

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ABSTRACT

Flood is defined as one of the most devastating natural hazards that lead to immeasurable damages in terms of human settlements and economic losses. As part of the Mediterranean region, Cyprus suffers from this disaster, being subjected to extreme events, land use changes and economic development. In this study, flood hazard is estimated and its extent on residential areas, villages, and agricultural areas located within the Garyllis basin is mapped and analyzed with the integration of remote sensing techniques, GIS, in-situ data, field visits and hydraulic modeling. Open-source HEC-RAS software has been used to estimate the spatial pattern of water surface depths during a 24-hour event for a 1000-year return period. Preliminary results indicate that the areas most susceptible to flooding are observed at the southern part of the basin. The intent is to assist policy makers and planners in the development of flood mitigation measures.

Keywords: Garyllis river, Flood risk assessment, flood extent, vulnerability, mitigation measures

1.INTRODUCTION

Floods are one of the most significant types of natural disasters caused by hydrometeorological and anthropogenic factors, such as heavy rainfall, urbanization, deforestation, and poor drainage systems [1], resulting in adverse consequences concerning health and socio-economic conditions [2]. Many studies suggest an increasing trend of the flood intensity and occurrences as a consequence of the rapid climatic and land use changes [3], urging the European authorities to establish a generic framework on the assessment and management of flood risks (Directive 2007/60/EC) that aims at the development of efficient strategies for mitigating the damages, identifying the regions most prone to floods, and support emergency planning and infrastructure design [4]. Due to the complexity of this phenomenon, datasets from multiple sources, including earth observation, in-situ measurements, numerical solution of physical models etc [5] [6], are considered to accurately map and assess flood risk [6],[7]. Integration of geographical information systems (GIS) and physical models are often used to simulate the spatiotemporal extent of flood events, assess the influence of climatic and anthropogenic factors, identify the most vulnerable areas, and estimate the damage levels, enabling the authorities to adopt well-informed policies [8], [9]. HEC-RAS is a widely used open-source software for hydraulic modeling and analysis of river systems [10]. In particular, HEC-RAS provides estimations of the water surface profiles for steady and unsteady flows, while taking into account the effects of various technical works such as culverts, bridges, elevated structures, and weirs [11]. Many studies report the integration of HEC-RAS with other GIS software tools, such as ArcGIS and HEC-GeoRAS extension. For example, Khalil and Khan [12] considered HEC-RAS, ArcGIS, and HEC-GeoRAS extension to determine the depth of feeding zones and identify regions of flooded areas around the Indus River in Pakistan, while estimating the maximum flow rate and the time delay between water inlet and outlet. Similarly, Khattak et al. [13] utilized HEC-GeoRAS to assess flood occurrences under different return-periods in the Mejerda Basin of North Africa in 2015, enabling the national authorities to design efficient mitigation strategies. Salajegheh et al. [14] combined HEC-RAS and ArcGIS to map the floodplain in the Polasjan River Basin, located in Iran central plateau. The authors proposed an automatic approach for analyzing the outputs of HECRAS in ArcView GIS, enabling the frequent update of floodplain maps with respect to hydrologic and hydraulic conditions.

This study aims to identify the areas that are most prone to flood events within the Garyllis River basin. HEC-RAS has been used to simulate the spatio-temporal patterns of the water surface during a 24-hour event, which is characterized by a 1000-year return period.

2. STUDY AREA AND DATA

The Garyllis river basin, covering about 104 square kilometers in the southern and southwestern parts of Cyprus, comprises a river network with a total length of about 9.68 km (Figure 1). Its northern part is characterized as hilly to semi-mountainous. According to Urban Atlas Land Cover/Land Use 2018, Europe, Copernicus Land Monitoring Service, the northern part of the basin mainly consists of arable land, herbaceous vegetation associations and forests, whereas the southern part of the catchment is mainly characterized by continuous urban fabric along with various industrial, commercial, public, military, and private units.

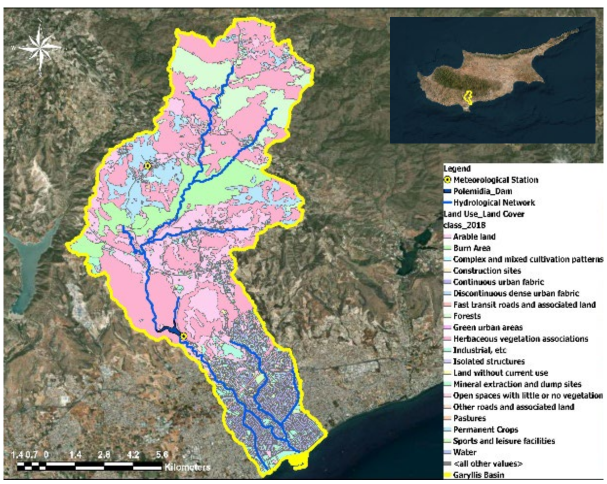

Figure 1:Land use and land cover map of Garyllis river basin, along with the river network (blue lines).

According to the national authorities, Garyllis river basin is considered to be highly prone to flash floods and urban flooding. Historical flood records, dating back to 1880, have documented significant damages. For example, flood events that occurred in November 1880 and 1894 were triggered by the overflow of the Garyllis River due to heavy rainfalls. During the event in 1894, more than one hundred houses, including St. Anthony's Church and a nearby mosque, were subjected to structural failures and casualties. Particularly, more than 20 human deaths were reported, including children, whereas 250 animals drowned. The most recent floods occurred at the beginning of 2019 and 2020, causing significant damages of buildings in the center of Limassol urban area due to the combined effect of extreme precipitation and overflow of the Polemidia dam. These historical events urged the authorities to redirect the flow pathway of Garyllis river by constructing a river diversion. The construction of the Polemidia Dam, with a capacity of about 3.4 million cubic meters, combined with the river diversion, have significantly reduced the levels of flood damages, except in cases of dam overflow. Given the proximity of the river systems to residential and commercial areas, the absence of designated protection zones, and the land use changes (e.g., the development of public units such as park and playgrounds), proper flood management is essential.

In this study, multiple datasets (Table 1) are collected from various sources of information. Precipitation data are provided by the Meteorological Department of Cyprus, whereas discharge and water level data are collected from the Water Development Department of Cyprus. The intensity-duration-frequency (IDF) curve for the most upstream meteorological station in the river basin, installed nearby Kalo Horio village, is used for the extraction of the hyetograph for 24-h rainfall duration. Terrain's characteristics, namely slope, flow accumulation, flow direction, and the extraction of the river basin, are derived from a Digital Elevation Model (DEM) with 5-m spatial resolution provided by the Department of Lands and Surveys Cyprus.

Land cover data of the study area are extracted from Urban Atlas Land Cover/Land Use 2018, Europe, 6-yearly — Copernicus Land Monitoring Service [15], enriched with the burnt areas for the wildfire events in September of 2022 and in August of 2023 derived by European Forest Fire Information System (EFFIS)[16]. The spatial distribution of the runoff Curve Number is used as well to estimate the hydrological losses and the precipitation excess. These datasets, alongside the hydrographic network of the river basin, are used as inputs for the development of a two-dimensional hydraulic model. Additional information, such as population data, has been also collected from the Cypriot Statistical Service to quantify the vulnerability of the exposed elements, such as humans and buildings, to flood events.

Table 1: Information and data collected about the Garyllis river basin.

Data	Information	Resources
DEM	5-m resolution	Department of Lands and Surveys Cyprus DLS Portal (moi.gov.cy)
Road Network	2016	Department of Lands and Surveys Cyprus DLS Portal (moi.gov.cy)
Rainfall timeseries	2011-2023	Meteorological Department of Cyprus Home Page | Department of Meteorology (moa.gov.cy)
Intensity-duration-frequency (IDF) curve	Kalo-horio station	Meteorological Department of Cyprus Home Page | Department of Meteorology (moa.gov.cy)

Discharge and water level timeseris	1980-2023	Water Development Department of Cyprus Water Development Department | Home Page (moa.gov.cy)
hydrological network	-	Water Development Department of Cyprus Water Development Department | Home Page (moa.gov.cy)
land use/ land Cover	2018	Copernicus Land Monitoring Service (CLMS), Urban Atlas Land Cover/Land Use 2018 (vector), Europe, 6-yearly — Copernicus Land Monitoring Service
Population	2011	Statistical Service Στατιστική Υπηρεσία - Αρχική (cystat.gov.cy)
Runoff Curve Number (CN)	2009	Water Development Department of Cyprus Water Development Department | Home Page (moa.gov.cy)

3. METHODOLOGY

A two-dimensional (2D) simulation of the unsteady flow within the study area is carried out with the use of HECRAS 6.4.1, estimating the surface water depths and the inundated areas for 24-h rainfall duration and 1000-year return period scenario. The overall flowchart of the adopted methodology is shown in Figure 2. DEM is imported in the hydraulic model to estimate terrain properties, whereas the hydrographic network is included as 2D breaklines, used to enforce the cell faces along linear features, such as high ground, to direct the movement of water through the 2D. The geometry of the model is generated using ArcGIS. The grid discretization is generated in HEC-RAS by choosing the appropriate spatial resolution for the 2D-mesh and the 2D-breaklines. Flood hazard assessment for the study area is performed using the spatially distributed rainfall method (rain-on-grid). Specifically, the hyetograph inserted in HEC-RAS is derived by the IDF curve of the meteorological station located nearby Kalo Horio village for 24-h rainfall duration via alternative block method. CN polygons for medium antecedent soil moisture conditions are utilized to assess the rainfall excess based on the SCS method, whereas the abstraction ratio is corresponded for each CN class. Also, the Manning's roughness coefficient values, required for the estimation of energy friction losses of surface flow, ,are associated with land cover polygons and used as input for the model as well. The outcomes of the hydraulic simulations are consequently used to compile the spatial representation of flood hazards in ArcGIS. Particularly, five hazard classes have been determined based on the statistical characteristics of the depth levels: very low (depths less than 1 m), low (1–2 m) moderate (2-3 m), high (3-5 m) and very high (greater than 5 m) [17].

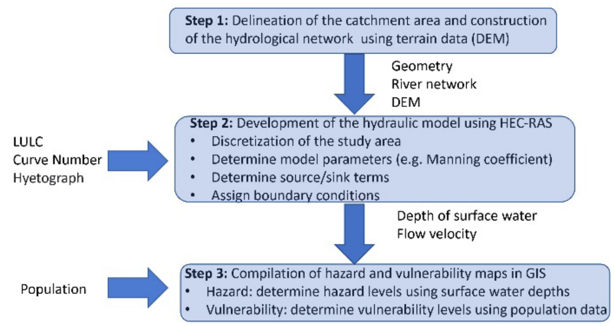

Figure 2: Overview of the current methodology

Regarding the spatial representation of flood vulnerability, additional data have been provided by the national authorities to estimate the density of the human population that is directly affected by flood events. The population density is used to represent the vulnerability levels and is calculated by dividing the total number of humans that reside along each major road within the study area with the total length of this road.

4. PRELIMINARY RESULTS

Preliminary results for the spatial distribution of vulnerability for the study area as well as the flood hazard assessment for 24 h rainfall duration and 1000-year return period scenario are shown in Figures 3 and 4, respectively.

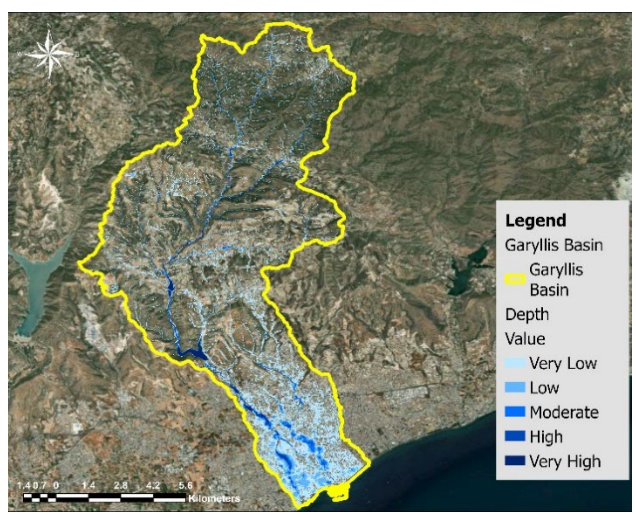

Figure 3: Flood Hazard Map of Garyllis Basin for 24-h rainfall duration and 1000-year return period scenario.

High flood depths are observed in the southern and southwestern parts of the basin, indicating significant flood hazards. This analysis demonstrates that the danger is not confined to the close vicinity of the hydrological network but also extends to areas up to 500 meters away.

In addition, the results suggest that the most vulnerable regions are located in the southern part of the basin, in the vicinity of the urban centers and major roads, attributed to the simultaneous presence of high population densities and water depths.

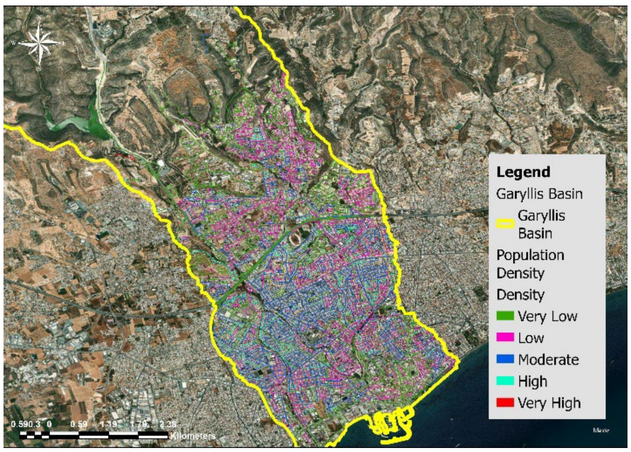

Figure 4: Vulnerability Map of Garyllis river basin for 1000-year return period.

5. CONCLUSIONS

This study presents preliminary results for the flood vulnerability and hazard assessment of Garyllis river basin for the extreme scenario of 1000-years return period. Two-dimensional simulations are performed with the use of HEC-RAS hydraulic model, whereas ArcGIS processes are deployed to edit the corresponding data and analyze the simulated output from the model. The result shows that a significant portion of the urban area, associated with high population densities, is expected to be affected in the presence of a flood event which is characterized by a 1000-year return period. The flood hazard assessment reveals the presence of very-high hazard classes in the vicinity of the river, located in the south and central part of the catchment area. Since IDF curves of 2009 are used in this study, it is suggested that more recent IDF curves could be constructed to represent the present situation in a more reliable way.

As expected, the vulnerability map shows that the most vulnerable areas are clustered in the southern section of the basin, which is dominated by urban units. The update of the vulnerability assessment is crucial since more recent population data would give an up-to-date assessment for the study area.

6.ACKNOWLEDGMENTS

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