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Hydrological Hazard Modeling Associated with Maximum Runoff in the Firiza River Basin

PHD THESIS SUMMARY

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Abstract

In recent decades, climate change and human interventions in the environment have led to an increase in extreme weather events, contributing to an alarming increase in the frequency and magnitude of natural disasters. In particular, floods have stood out as among the most frequent and devastating natural phenomena, generating significant damage globally. These phenomena are exacerbated by changes in the climate regime, which have directly influenced the behavior and dynamics of river basins, modifying the frequency, magnitude and duration of floods.

According to recent studies, the impact of climate change on hydrological systems has proven unprecedented, being characterized by the intensification of extreme processes, the increase in the spatial extent of the affected areas and the modification of seasonal precipitation regimes. In addition, anthropogenic factors, such as uncontrolled urban development, land use change and the degradation of hydrotechnical infrastructure, have contributed to the increase in socio-economic vulnerability and risks associated with floods.

Global statistics, such as those reported by the EM-DAT database, show that climate hazards have increased by over 300% in the last half century, with floods ranking second in frequency and severity after storms. The main causes of this phenomenon include climate change and inappropriate anthropogenic activities, such as uncontrolled interventions on floodplains and poor management of hydrotechnical infrastructure. In particular, ineffective planning and maintenance policies, as well as the lack of proactive risk reduction measures, have increased the vulnerability of local communities. Romania, like other European Union (EU) Member States, faces major challenges in flood risk management. Flood mitigation strategies along major watercourses are marked by significant deficiencies, determined by the use of outdated hydrotechnical infrastructure and inadequate anthropogenic interventions. Most flood protection works were carried out during the communist period (1960s–1970s) and have not been adapted to modern requirements. Urban expansion in high-risk areas, deforestation in the Carpathian Mountains and excessive regularization of watercourses have contributed to increasing the impact of floods on local communities.

A significant example of these challenges is the Firiza river basin, where the Firiza River, one of the most modified watercourses in the Someș River Basin, illustrates the

effects of anthropogenic interventions on a natural system. In this area, hydrotechnical works, including the Strâmtori-Firiza reservoir and other secondary structures (dams, collecting channels, protection works), were initially built to reduce the risk of floods and to support hydroelectric power production. However, these measures are no longer sufficient to cope with recent changes in hydrological regimes, precipitation and sedimentation, generated by climate change and anthropogenic interventions.

In addition, the Strâmtori-Firiza dam, located 10 km north of Baia Mare, built in 1964, represents a significant potential risk. The reservoir does not yet have an updated Action Plan for dam failure, as required by the Floods Directive 2007/60/EC and national legislation. This situation may amplify the impact of a potential disaster, especially in the context of population growth and urban development in the surrounding area.

To address these challenges, this paper proposes an innovative methodology for determining the hazard associated with maximum discharge, as well as for generating more detailed and accurate flood risk maps. By using a digital elevation model derived from LiDAR (Light Detection and Ranging) data, in combination with two-dimensional hydraulic modeling using the HEC-RAS (Hydrologic Engineering Center – River Analysis System) hydraulic modeling program and advanced radar scanning (RS) techniques, this study aims to provide a comprehensive assessment of the flood hazard in the Firiza basin. In addition, the proposed methodology will allow the simulation of risk scenarios, corresponding to return periods of 100, 500 and 1000 years, for the downstream sector of the Strâmtori – Firiza reservoir up to the confluence with the Săsar River.

This work is distinguished by the application of an advanced and integrated methodology, based on the combination of real hydrological data, mathematical simulations and LiDAR technologies, to develop personalized flood risk reduction solutions in a local context. Unlike other studies, which use calibrated hydrological data at the basin scale, this approach focuses on focuses on adapting to the specific physical-geographical conditions of the study area, thus providing a significant contribution to the field of hydrological risk management.

The results of this study will contribute to improving flood risk management strategies in Romania, aligning with European Union requirements and providing a replicable model for other areas with similar characteristics. At the same time, by updating the Action Plan for the Strâmtori-Firiza dam failure and generating adapted risk maps, this project aims to reduce the vulnerability of local communities and improve their response capacity to extreme events.

Taking into account the above, the following sections present the data used and the techniques developed and discuss the further implications of the study.

Following the activity carried out since 2015, within the Baia Mare Hydrology Office belonging to the Someș - Tisa Water Basin Administration, the Maramureș Water Management System within the National Romanian Waters Administration, we have identified a series of possibilities for improving the hydrometeorological warning system.

The working hypotheses from which we started the development of the paper assume the improvement of flood hazard assessment techniques, including the possibility of overcoming some deficiencies in the current hydrological forecasting system:

1. In the assessment of flood hazard, the use of data provided by weather radars contributes to shortening the response time in the event of a flood and, implicitly, to the safe exploitation of reservoirs.

2. Hydrological and hydraulic models can be correlated, especially in the case of the existence of reservoirs.

3. The detailed assessment of flood hazard contributes to the clearer identification of some components of the vulnerability of the population in areas exposed to this type of risk.

The main objectives we pursue:

- O1: Flood hazard assessment based on radar data and hydrological and hydraulic modeling

- O2: Improving the operational management of the Strâmtori – Firiza Dam during flood periods

- O3: Carrying out a flood hazard analysis for the Ferneziu district of Baia Mare, a district located on the lower course of the Firiza River, downstream of the Strâmtori – Firiza reservoir to the confluence with the Săsar River

The existence of a reservoir within the Firiza River basin makes it difficult for water from precipitation to flow in the flood wave. Thus, the possibility of using 3 different models arises: one for the distribution of the amount of precipitation (generated in the case of the Firiza basin by the Igniș radar), a hydrological basin model for determining the flow at the entrance to the Strîmtori-Firiza accumulation and a hydraulic (hydrodynamic) model for determining the distribution of water depth and speed on the sector located downstream of the Strîmtori - Firiza accumulation for three probability scenarios corresponding to the assurances of 1%, 0.2% and 0.1%.

Chapter 1 presents the Firiza river basin in terms of physical-geographical characteristics in accordance with Directive 2000/60/EC, which aims at the integrated management of river basins for Europe. Thus, emphasis was placed on the characterization of the river basin in terms of its unity but also of its differentiation from the surrounding regions. Thus, the characterization of all elements regarding the genesis, geology, relief characteristics, climate, hydrography and hydrological characteristics, vegetation and fauna, pedological characteristics, protected natural areas, population and settlements, are treated unitarily at the level of the river basin unit. We paid special attention to the characterization of the exploitation mode of the Strîmtori – Firiza accumulation, which plays a central role in water management at the level of the river basin.

Chapter 2 describes the main materials and methods used in carrying out this study. We chose to present in this chapter both the European and national legislation in the field of water management, as well as the history of the use of radars in weather forecasts both at the global and national level. The main materials used are described both in terms of topographic mapping equipment and that of determining runoff conditions and pluviometric and nivometric ones. We note that the data collection took place in 2019 - 2020. From a digital point of view, the main materials used refer to GIS databases, both open source and those developed during the doctoral training period. As for the methods used, they differ depending on the characteristics analyzed. Thus, for the interpretation and analysis of radar data, GIS vectorization and rasterization methods were used in order to obtain maps usable in the hydrological basin modeling process. To carry out the hydrological modeling, a series of maps were created representing the distribution of the various indices required at the level of the hydrographic basin. The input data for the hydraulic modeling were also created in GIS software in order to obtain detailed topographic models for the minor and major riverbeds. The results of the hydraulic model were exported from the modeling software and imported into GIS for the spatial representation of flood wave depths and speeds.

Chapter 3 presents the hydrological modeling of the basin upstream of the Strîmtori-Firiza reservoir and the hydraulic modeling downstream of the Strîmtori-Firiza reservoir, as well as the interpretation of the results obtained. In the first subchapter, the flow parameters at the level of the hydrographic basin were analyzed, so that in the second subchapter, the focus is on the analysis of the hydrological event produced between 20 and 26 May 2019. In the third subchapter, the hydrological model of the basin was created, in which the data produced by the Igniș radar were used, as well as the information collected during the hydrological event. The purpose of the analysis of this event was strictly related to the calibration of the hydrological model with the measurements carried out by Apele R omane. In the fourth subchapter, the hydraulic modeling of the Firiza River course from the Strîmtori – Firiza accumulation downstream to the confluence with the Săsar River was carried out.

In this framework, we aimed to develop a complex methodology for assessing flood hazards in the context of real hydrological data (average flows) and mathematical (flows with different return periods) by combining LiDAR-derived digital elevation models, HEC-RAS 2D modeling and remote sensing techniques. Unlike other studies in which flood hazard maps are provided based on hydrological data calibrated at the river basin scale, the model provided the first accurate flood hazard maps for the study area developed based on the calculated discharge for Strîmtori - Firiza and adapted to the local geomorphology by using the LiDAR-derived DEM. Therefore, three 2D HEC-RAS scenarios with recurrence intervals of 1% (100 years), 0.2% (500 years) and 0.1% (1000 years) were calculated to test the flood mitigation capacity of the Firizei Valley downstream of the Strâmtori - Firiza dam. All scenarios were based on the average discharge and the discharge calculated at the spillway gate of the Strâmtori - Firiza dam and correlated with the official dam operating regulations. The results provided a more realistic perspective on the possible flood threats in the urban environment of Baia Mare municipality and contribute to the update of the Strâmtori - Firiza Dam Failure Plan. Considering the above, the following sections present the data used and the techniques developed and discuss the further implications of the study.

Chapter 4 is dedicated to the analyses and discussions derived from the interpretation of the obtained results. At the same time, a brief assessment of the flood hazard was carried out for each of the three scenarios analyzed.

At the end of the paper, the conclusions summarize the effort to obtain the results and their analysis from the aspect of water management at the river basin level.