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HYDROLOGICAL HAZARD MODELING USING GEOINFORMATICS AND HYDROINFORMATICS: A CASE STUDY OF THE BAȘEU WATERSHED WITH 1D AND 2D APPLICATIONS

PHD THESIS SUMMARY

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Abstract

The addressed problem is a current one and is based on the intensification of extreme hydrological phenomena associated with peak discharge. By approaching the concept of hazard, a quantitative assessment of it was desired, followed by an evaluation of the potential damages caused by an exceptional hydrological event.

This study provides support to national, regional, and local authorities in the process of developing flood management plans. The flood hazard assessment was carried out based on the application of two distinct methodologies: one methodology generated inundation maps using 1D hydraulic models (models that were also used in developing the Flood Risk Management Plan) for different return periods (0.1%, 1%, and 3%), and another methodology simulated the dam break of a permanent reservoir (Cal Alb reservoir) on the Bașeu river, also for three return periods (0.1%, 0.5%, and 1%).

The Bașeu river basin, with an area of 981 km², was chosen as the study area. It almost entirely overlaps with the Moldavian Hilly Plain (90%) and the Suceava Plateau (10%). Its characteristics, typical of lowland basins, make the study area suitable for applying modern methodologies for assessing hydrological hazard and establishing a best practice model that can be transferred to other basins with the same characteristics.

This doctoral thesis aims to evaluate the hydrological hazard associated with peak discharge and to determine the exposure of settlements along the Bașeu river. The exposure analysis is conducted at the level of built-up areas.

To achieve this goal, three hypotheses were formulated. Each hypothesis is associated with one or more objectives.

Hypothesis 1:The integration of up-to-date data and information (digital terrain model based on Light Detection and Ranging (LiDAR) technology, roughness coefficient values based on land use categories, building footprint, historical discharges) can significantly improve the accuracy of HEC-RAS hydraulic forecasting models.

Hypothesis 2:The strategic placement of reservoirs along the Bașeu river reduces the volume of water released downstream and protects settlements.

Hypothesis 3:Simulating multiple scenarios of hypothetical dam break allows for a more comprehensive assessment of hydrological hazard compared to a single scenario.

For Hypotheses 1 and 2 (Objectives 1 – 4):

Scenario 1 (S1): A complex 1D hydraulic model was developed. Based on the recorded discharges at three stations along the Bașeu River (Havârna, Știubieni, Ștefãnești), inundation zones were generated for return periods of 0.1% (1000 years), 1% (100 years), and 3% (33 years). The model utilized a Digital Elevation Model (DEM) with a spatial resolution of 1 m/pixel, generated using LiDAR technology, bathymetric models for the Cal Alb and Negreni reservoirs, and volumes of both permanent and temporary reservoirs along the Bașeu River.

Scenario 2 (S2): A simplified 1D hydraulic model was created, excluding the volumes of reservoirs along the Bașeu River. This was done to highlight the importance of reservoirs and for comparison purposes, generating only the inundation zone corresponding to a 1% return period.

Scenario 3 (S3): The 1% probability inundation limit was extracted from the county's flood defense plan against hazardous meteorological phenomena, accidents at hydraulic structures, and accidental pollution. This was done to highlight the crude manner in which potentially flooded areas were delineated.

Scenario 4 (S4): The 1% return period inundation zone provided by the Basin Water Administration (BWA) was used for comparison with S1 (with a 1% probability of occurrence) and S3 (with a 1% probability of occurrence).

Objective O1 was achieved by comparing the results of S1[1%], S3[1%], and S4[1%]. It was concluded that S1[1%] and S4[1%] present the actual situation of potentially inundated areas, while S3[1%] underestimates the potentially inundated areas due to the crude manner in which the inundation limit was delineated. This objective assessed the accuracy of different inundation maps. The results showed that the models considering detailed information (S1 and S4) provided more accurate results compared to the simplified model (S3).

Objective O2 was achieved by generating three inundation zones with return periods of 0.1%, 1%, and 3%, and extracting the potentially inundated areas for each land use category corresponding to the settlements located along the Bașeu River. The results indicate that in the event of a flood with a 1000-year return period, 196.5 hectares would be below the danger level; in the case of a 100-year return period, 136.4 hectares would be affected; and in the case of a 33-year return period, 111.8 hectares would be vulnerable to hydrological hazards. This objective aimed to quantify the extent of flooding for different return periods and land use categories. The results showed a significant increase in the inundated area for higher return periods.

Objective O3 was achieved by calculating geomorphological parameters and extracting land use categories based on orthophotomaps.

Objective O4 was achieved by comparing the results of S1[1%] and S2[1%]. It was observed that S2[1%] overestimates the potentially inundated areas because the retention role of the reservoirs on the Bașeu River was not considered, highlighting the significant role of hydraulic structures in mitigating floods and floods. This objective highlighted the importance of reservoirs in reducing flood risk. The simplified model (S2) overestimated flood risk because it did not account for the water retention capacity of the reservoirs.

The localities most affected in the case of a 0.1% probability are: Suharău (L2–81.8 ha), Româneşti (L32–15 ha), Bădiuți (L30–13.6 ha), and Petricani (L15–12 ha). The localities with the least damage are Slobozia Hănești (L22–0.2 ha), Năstase (L27–0.2 ha), Niculcea (L10–0.1 ha), Mihălășeni (L24–0.0 ha), and Negrești (L25–0.0 ha).

In the case of a 1% probability, the ranking remains the same as for the 0.1% probability, with the exception that some areas bordering the floodplains are no longer at risk of flooding: Suharău (L2–70.7 ha), Româneşti (L32–11.4 ha), and Bădiuţi (L30–5.5 ha). The least affected localities are Păun (L26–0.3 ha), Niculcea (L10–0.1 ha), and Năstase (L27–0.1 ha), while Slobozia Hăneşti (L22–0.0 ha), Mihălăşeni (L24–0.0 ha), and Negreşti (L25–0.0 ha) have no vulnerable areas. According to the 3% probability, the most affected locality remains Suharău (L2–66.2 ha), and the localities Slobozia Hăneşti (L22–0.0 ha), Mihălăşeni (L24–0.0 ha), and Negreşti (L25–0.0 ha) remain safe from hydrological hazards.

The most affected land use category is arable land, given that the predominantly rural population is dependent on subsistence agriculture practiced in the region. Additionally, according to the inundation map with a 0.1% probability, over 300 buildings are at risk of being affected by floods. According to the 1% probability inundation map, approximately 150 buildings could be affected, and according to the 3% probability inundation map, over 60 buildings are vulnerable.

The obtained results demonstrate that the methodology applied within the Başeu river basin improves the accuracy of hydrological risk maps and can be applied to other basins with similar characteristics.

Hypothesis 3 (Objective O5):

The creation of three dam failure scenarios for the Cal Alb reservoir using 2D hydraulic modeling techniques and the evaluation of the hydrological hazard induced by dam failure was achieved by generating three scenarios in which the failure of the Cal Alb reservoir dam was simulated for three different return periods (0.1% - discharge of a volume of 17.39 million m³, 0.5% - discharge of a volume of water of 12.35 million m³, and 1% - discharge of a volume of water of 10.19 million m³). For each generated scenario, the potentially affected areas by the flood wave were extracted for each land use category. Additionally, a flood hazard assessment was conducted for all three inundation zones according to the methodology accepted and used by the Australian Institute of Resilience (AIR).

The Cal Alb reservoir is located on the upper course of the Başeu River, approximately 900 meters downstream from the confluence with the Valea Ciolac valley and has the cadastral code XIII 1.10. The Cal Alb reservoir is located in the administrative territory of Hudeşti commune, Botoşani county, at a distance of 4 meters from the locality of Hudeşti, and the reservoir's catchment area has a total surface of 183 km². The earth dam of the reservoir was constructed from local materials, predominantly yellow loamy clays, of a homogeneous type. The reservoir was built between 1971-1973 and was first put into operation on September 20, 1973.

The choice of this reservoir for simulating dam failure is due to its history, when in the first years after commissioning it was affected by some unusual events, such as infiltration or swamp formation downstream of the dam, in addition to the fact that this reservoir does not have a Dam Safety Action Plan (DSAP).

Therefore, by creating a complex hydraulic model and simulating a piping breach (infiltration through the dam body) in the body of the Cal Alb reservoir dam, the control capacity of the hydraulic system A1-A5 was analyzed at the moment of the flood wave occurrence. Depth levels, velocities, and flood extent were extracted and calculated based on the results obtained from the RAS Mapper module.

Based on the specialized literature, a series of parameters were calculated (average breach width, breach width at the base, breach formation time). As in the case of the 1D hydraulic model, for high accuracy, a DEM with a spatial resolution of 1 m/pixel was used, into which constructions and the road network, bathymetric models of the Cal Alb and Negreni reservoirs, and lake volumes were integrated.

Following the hydraulic model run, the results indicate that in the case of emptying the Cal Alb reservoir to a maximum volume of 17.39 million m³ (0.1%), 3,163 hectares would be at risk of being affected and a maximum flow rate of 957 m³/s would be recorded. In the case of the accidental release of a volume of 12.35 million m³ (0.5%), 1,229 hectares would be vulnerable, and the maximum flow rate would be 248 m³/s. Furthermore, the release of 10.19 million m³ (1%) would endanger 1,191 hectares, and the maximum flow rate would be 222 m³/s.

According to the 0.1% probability, the most affected localities are Havârna (L1–25.02 ha) and Gârbeni (L2–14.52 ha), while 4 localities have no vulnerable areas: Slobozia Hănești (L17–0.0 ha), Mihălășeni (L19–0.0 ha), Negrești (L20–0.0 ha), and Românești (L27–0.0 ha). In the case of the 0.5% probability, the most affected localities are Havârna (L1–10.97 ha) and Balinți (L4–5.78 ha), and 14 localities have no vulnerable areas: Chișcăreni (L8–0.0 ha), Săveni (L11–0.0 ha), Bozieni (L13–0.0 ha), Sârbi (L14–0.0 ha), Slobozia Hănești (L17–0.0 ha), Mihălășeni (L19–0.0 ha), Negrești (L20–0.0 ha), Românești (L27–0.0 ha), etc. The potentially inundable areas resulting from the run of the scenario with a probability of 1% place the localities Havârna (L1–10.97 ha) and Balinți (L4–5.78 ha) as the most vulnerable, and 16 localities have no vulnerable areas: Chișcăreni (L8–0.0 ha), Săveni (L11–0.0 ha), Bozieni (L13–0.0 ha), Sârbi (L14–0.0 ha), Slobozia Hănești (L17–0.0 ha), Mihălășeni (L19–0.0 ha), Negrești (L20–0.0 ha), Românești (L27–0.0 ha), etc.

Regarding the land use categories potentially affected, the situation is as follows:

In the case of a 0.1% probability discharge (arable land - 45.10 ha; vineyards and orchards - 0.32 ha; forested areas - 8.35 ha; pasture - 12.65 ha; yards - 10.57 ha; road network - 2.36 ha; buildings - 322 houses and annexes) would be at risk of being affected by the flood wave.

According to a 0.5% probability (arable land - 13.89 ha; vineyards and orchards - less than 0.01 ha; forested areas - 2.30 ha; pasture - 2.84 ha; yards - 1.88 ha; road network - 0.34 ha; buildings - 43 houses and annexes) would be vulnerable.

According to a 1% probability (arable land - 13 ha; vineyards and orchards - less than 0.01 ha; forested areas - 2.18 ha; pasture - 2.52 ha; yards - 1.61 ha; road network - 0.29 ha; buildings - 38 houses and annexes) would be subject to the flood wave.

Based on the flood depth, it was identified that most buildings are affected by a depth not exceeding 1 meter (45.3% of the total affected buildings) in the case of a 0.1% probability, 72.1% of buildings in the case of a 0.5% probability, and 73.7% of buildings in the case of a 1% probability.

Velocities below 1 m/s affect the majority of constructions, 67.7% (218 constructions) in the case of a 0.1% probability, 86% (37 constructions) in the case of a 0.5% probability event, and 89.5% (34 constructions) in the case of a 1% probability.

The flood hazard was assessed based on the methodology developed by Cox et al., 2010 and implemented by AIR. Based on the product of flood depth and flood velocity, six hazard classes were established.

The results obtained for the 0.1% probability show that most buildings are in the H5 class ($> 2 \leq 4$ m²/s), representing 20.2% (65 constructions); in the case of a 0.5% probability, the dominant hazard class is H1 (≤ 0.3 m²/s), representing 46.5% (20 constructions); in the case of a 1% probability, the dominant class remains H1 (≤ 0.3 m²/s), representing 36.8% (14 constructions).

The efficiency of the hydraulic system A1-A5 in the present study was demonstrated by the results of both hydraulic models: (1D) in which a constant discharge was simulated on the Bașeu River course and it was observed that the localities located before the first accumulation in the hydraulic system A1-A5 (Cristinești and Suharău) have significantly larger potentially flooded areas than the localities located downstream of the mentioned hydraulic system. Immediately after A5 (Hănești pond), the potentially flooded areas dropped below 1 ha, and some localities had zero values in terms of potentially flooded areas, such as the localities Mihălășeni and Negrești; and (2D) in which the dam failure of the Cal Alb reservoir, the first accumulation in the hydraulic system A1-A5, was simulated. The results showed that there is the same behavior where, downstream of A5 (Hănești pond), the flow is carried out exclusively in the minor bed, thus protecting the localities located near the river. In both situations, the area representing the common floodplain of the Bașeu River and the Prut River and having an average altitude of less than 80 meters records significant potentially flooded areas (Ștefănești).

The HEC-RAS hydrological modeling program provides the necessary resources to create a complex scenario regarding the simulation of floods or the analysis of dam failure with the possibility of implementing a series of structures that are very important in the manifestation of a flood event (dam, reservoir, various obstacles, etc.), being at the same time a tool on the basis of which a general idea can be formed about the way a flood manifests itself depending on its mode of occurrence.