Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering. Vol. XIV, 2025
Print ISSN 2285-6064, CD-ROM ISSN 2285-6072, Online ISSN 2393-5138, ISSN-L 2285-6064

FLOOD IMPACT ASSESSMENT ON RAILWAY INFRASTRUCTURE USING NUMERICAL MODELLING: CASE STUDY OF NĂDAB, ROMANIA

Dorian HAUSLER COZMA, Teodor Eugen MAN,
Robert Florin BEILICCI, Erika BEILICCI

Politehnica University of Timișoara,
1A Splaiul Spiru Haret, 300022, Timișoara, Romania

Corresponding author email: robert.beilicci@upt.ro

Abstract

Railway infrastructure is constantly undergoing processes of change and development, it is becoming an important means of transportation. At European level, railways are going through a period of transformations aimed at increasing the transportation capacity for both goods and passengers, as well as increasing travel speeds. Railway infrastructure is constantly exposed to the action of rainwater, groundwater or extreme weather events such as floods. The problem arises when the water is not quickly drained, it remains for a longer period in the embankments leading to wetting or even saturation of the ground. Soil saturation leads to a decrease in bearing capacity and contributes to soil degradation, compromising infrastructure stability. This paper presents advanced numerical modelling with MIKE11 software of real flood situations in the Nădab area, as well as to assess mitigation scenarios through works on railway infrastructure and land improvement

***Key words**: flooding, hazard maps, MIKE11, railway infrastructure, soil saturation.*

INTRODUCTION

Floods are among the most frequent and destructive natural phenomena globally, with significant impacts on the environment, population, and critical infrastructure. In recent decades, Central and Eastern Europe have experienced an increase in both the frequency and intensity of flood events, a trend amplified by climate change. These climatic changes directly affect infrastructure vulnerability, particularly in the transport sector, such as railway networks.

Floods rank among the most widespread natural disasters and are third in terms of global impact. These disasters impact both the natural environment, where they take place, and the socio-economic sphere, causing loss of human lives, damage to transportation infrastructure, destruction of agricultural land, the spread of diseases, and interruptions in drinking water supply systems, among other consequences.

Climate change is one of the greatest challenges of the 21st century, having a significant impact on both natural and human systems. In particular, hydro-geomorphological risk events, such as floods, landslides, and erosion, have become more frequent and more intense as a result of climate changes. Floods, in particular, are complex events with significant impact at both global and regional levels, driven by a combination of natural and anthropogenic mechanisms. Their geographical distribution is influenced by climatic, topographic, and hydrological factors specific to each region. Modern risk assessments increasingly rely on geomatic tools and hydrological modeling to better predict and manage these events.

In Romania, the Crișul Alb River Basin, located in the western part of the country, is an area exposed to flood risks due to both geomorphological conditions and extreme weather events. In this context, railway infrastructure in the region is becoming increasingly vulnerable, frequently affected by flash floods and terrain erosion.

The Crișul Alb Basin (Figure 1) largely overlaps with Arad County, and in the southeastern part, with Hunedoara County; in the east, it extends slightly into Alba County, and in the north, it also partially overlaps with a small area of Bihor County.

The hydrographic basin features varied climate, influenced by differences in altitude and the shape of the terrain through which it flows. It covers several geographical units, such as the

Bihor Mountains, the Metaliferi Mountains, the Codru-Moma Mountains, the Zărand Mountains, and the associated hills and plains. The distribution of precipitation in the Crișul Alb Basin varies significantly from east to west (Figure 2).

The mountainous areas in the east are characterized by the highest amounts of precipitation, while in the western area, the amounts are lower. The diversity of soil types (Figure 3) reflects the geological, geomorphological, and climatic variability of the region. Fertile soils such as chernozems and alluvial soils predominate in the plains, while less fertile soils or those with special characteristics (such as lithosols and dystric cambisols) are found in the mountainous areas (NARW, 2024).

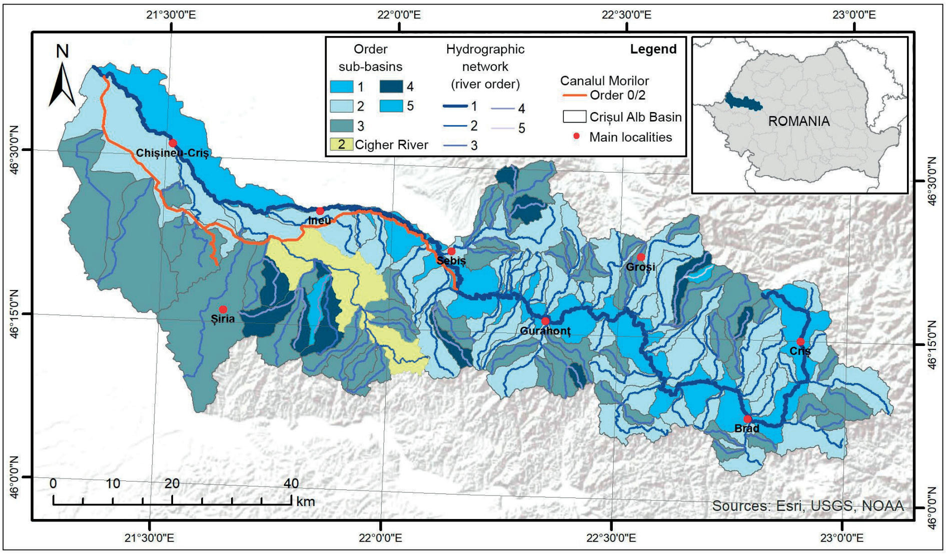

Figure 1. Overview map of the Crișul Alb River Basin, showing administrative boundaries and main hydrographic features

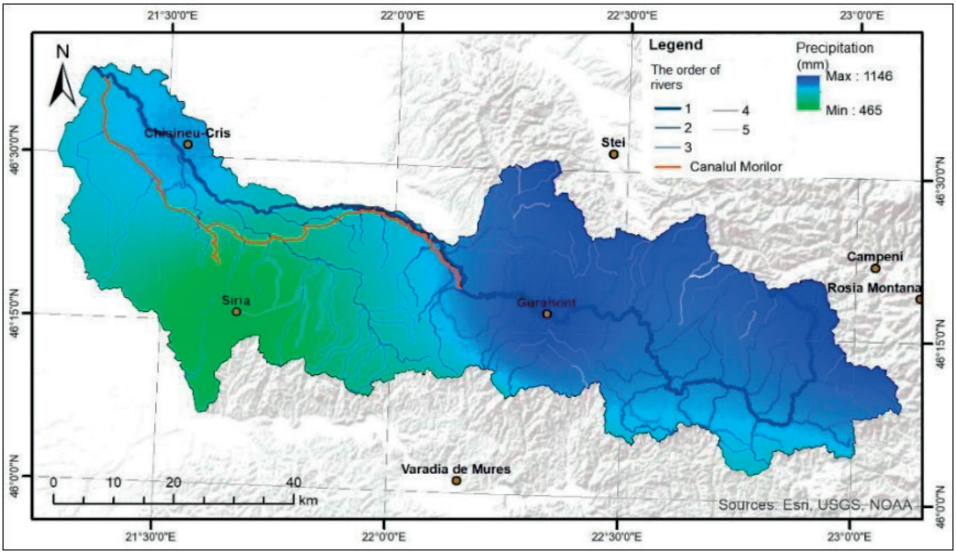

Figure 2. Annual precipitation distribution in the Crișul Alb Basin (mm/year), highlighting east-west variation

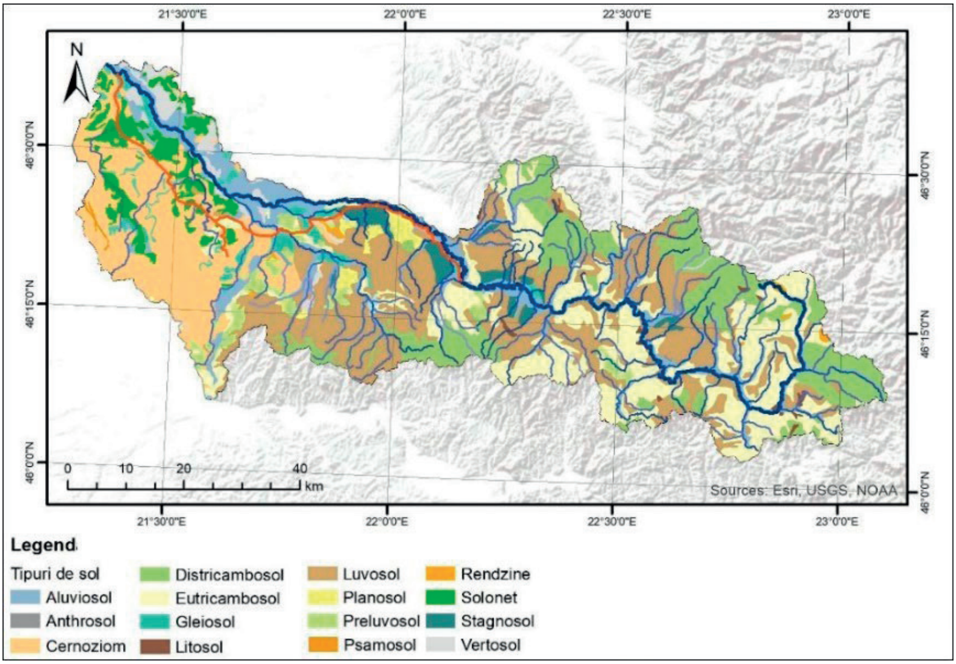

Figure 3. Spatial distribution of soil types in the study area, based on NARW classification

The Crișul Alb River originates in the Apuseni Mountains, in the northern area of the Bihor Mountains, at an altitude of approximately 1,250 meters. It flows through the counties of Hunedoara, Arad, and Bihor, covering a distance of about 234 km before discharging into the Tisza River on the territory of Hungary.

In the Crișul Alb Basin, the hydrographic network is composed of 103 rivers, with a total length of 1,667 km.

The Crișuri hydrographic area has a complex system of hydraulic works for the quantitative management of water resources, containing several water diversion structures that transfer water volumes from one river course to another. To supply water for various uses (drinking water, irrigation, fish farming), as well as for collecting high waters from interfluves, 27 water intakes and diversions have been constructed.

The existing flood protection works in the Crișuri hydrographic area include river regulation, embankments, bank reinforcements, as well as permanent and temporary reservoirs or polders.

This study aims to assess the impact of floods on railway infrastructure using numerical modelling, with a case study focused on the locality of Nădab. The main objective is to gain understand hydraulic behaviour in critical flood-prone areas and to propose solutions to reduce risks to railway transport.

MATERIALS AND METHODS

The analyzed area is located in the western part of Romania, in the Crișul Alb River Basin, with a focus on the sector corresponding to the locality of Nădab. This region is characterized by a predominantly low-plain relief and the presence of critical infrastructure, including the Arad-Oradea railway line, which is vulnerable to recurrent flooding.

In the last two decades, Europe has experienced over 100 major floods, resulting in more than 700 casualties, displacing over half a million people, and causing damages exceeding 25 billion EUR.

The extreme hydrological phenomena occurring in recent decades, both globally and in Romania, highlight the fact that society is affected not only by slow floods, caused by rivers with medium and large catchment areas, but also, to the same extent, by fast floods, typical of small basins, generally less than 200-300 km². There is a growing trend in the frequency of severe flash floods, which have caused significant material damage and, in many cases, loss of human lives (Biali et al., 2022).

Global practice has shown that the occurrence of floods cannot be avoided, but they can be managed their effects on the social, economic, environmental, and cultural heritage sectors can be reduced through a process involving complex analyses and targeted prevention and mitigation measures at the local, regional, and national levels, designed to contribute to reducing the risk associated with these phenomena (Hausler et al., 2020).

The National Flood Risk Management Strategy for the medium and long term encourages the construction of communication routes (roads, railways) with embankments reinforced to appropriate levels whitch serve as flood localization lines, and must include properly dimensioned bridges.

Additionally, it encourages the construction embankments for national roads and railways in such a way that they can serve as flood protection lines in areas identified with a high flood risk particularly where geographic conditions require such measures to be the only viable option for protecting settlements. These specific cases will be included in the River Basin Master Plan and, later, in the Flood Risk Management Plan, and will be carried out in accordance with the approved budgets.

The history of risk phenomena in the Crișul Alb basin highlights the need for proactive management of hydrographic resources and flood protection measures. Repeated flooding and landslide events underscore the region's vulnerability and the importance of risk prevention and management interventions.

Floods are natural phenomena, and of the 20 types of hazards considered natural disasters, they are ranked highest terms of geographic spread, number of events, and number of people affected.

In determining areas at risk of flooding, both river overflow floods (medium/large basins) and flash floods (small catchments) are considered.

Flash floods are floods that occur in a short period of time and are characterized by sudden increases in water levels and flow rates. The main characteristic of flash floods is that they have a maximum growth time of 4 to 6 hours, occurring in small catchment areas ranging from a few to several hundred km². The main cause of these flash floods is torrential rainfall, with exceptionally high intensities. However, there are also other physical and geographical factors that contribute to or trigger flash flood events, factors that will be detailed in the section dedicated to hazard analysis.

Historical flood events with significant impacts on health, the environment, cultural heritage, and economic activity were included in the assessment, including those that could occur in areas with hydraulic infrastructure, such as embanked zones. (Gabor et al., 2019).

To carry out hydraulic simulations and assess the potential impact of floods on railway infrastructure, the MIKE21 and MIKE FLOOD applications developed by DHI were used.

MIKE 11 is a software developed by DHI (Danish Hydraulic Institute) and is designed to perform one-dimensional hydraulic and hydrodynamic calculations, with integrated storage zones to represent networks of natural and engineered channels (Armas et al., 2016).

In essence, the calculation procedure is based on a numerical solution of the one-dimensional energy and mass conservation equations (the Barre-de-Saint-Venant system of equations). Energy losses are primarily evaluated through friction (Manning's equation) and contraction/expansion (via a dynamic head loss coefficient) (Marossy et al., 2016).

The hydraulic modeling of river sections identified as potentially flood-prone, using specialized software, consisted of one-dimensional (1D) and two-dimensional (2D) simulations of flow on the analyzed river courses. For 1D hydraulic modeling, the dependence of water level on flow rate was determined using the MIKE 11 (DHI) application, while for areas requiring more detailed analysis, the MIKE 21 (DHI) application was used. The 1D and 2D hydrodynamic modeling was applied with calibration and verification for significant historical floods (DHI, 2021).

MIKE21 allows for the two-dimensional modeling of surface runoff, which is useful for assessing the spatial extent of water in flood-prone areas.

MIKE FLOOD integrates 1D and 2D models, enabling complex analysis of the interaction between watercourses and surrounding land, including transport infrastructure.

Flood hazard maps were obtained using the MIKE Flood (DHI) mathematical model, a model that allowed the coupling of 2D and 1D models into a single calculation system. These maps indicate, for different analyzed scenarios (Qp%), the extent of flooded areas and water depth.

The model was fed with data obtained from multiple sources:

- Topography: High-resolution digital terrain model (DTM) obtained using LiDAR technology;
- Hydrographic Network: Cross-sections and hydraulic parameters of the Crișul Alb River;
- Climatic and Hydrological Data: Historical records of precipitation and discharge, obtained from ANAR;
- Railway Infrastructure: Positioning and physical characteristics of the Nădab railway line, including embankment levels and existing flood defense works.

The railway infrastructure is constantly exposed to the action of water.

Types of water that affect railway infrastructure:

- Surface water comes from atmospheric precipitation that falls directly on the railway embankment or on the adjacent land (berms, slopes);
- Groundwater is found in aquifer layers located beneath the ground level;
- Extreme weather events: Floods result from flash floods, heavy rains, storms, or river flooding. Although the railway infrastructure is not designed within riverbeds, there are situations where high waters affect the embankments. The embankments serve as dikes against high waters, which leads to soil erosion and landslides, consequently damaging the railway infrastructure (Vara et al., 2024).

The problem arises when water is not quickly evacuated, remaining for a longer period of time in the embankments, which leads to the dampening or even saturation of the soil. (Kellermann et al., 2016). Dampening or saturation of the soil with water leads to a decrease in load-bearing capacity and soil degradation (Hausler et al., 2020). The MIKE11 program was used for numerical modeling. At the beginning, the existing situation of the Crișul Alb River was modeled. The model plan is shown in Figure 4.

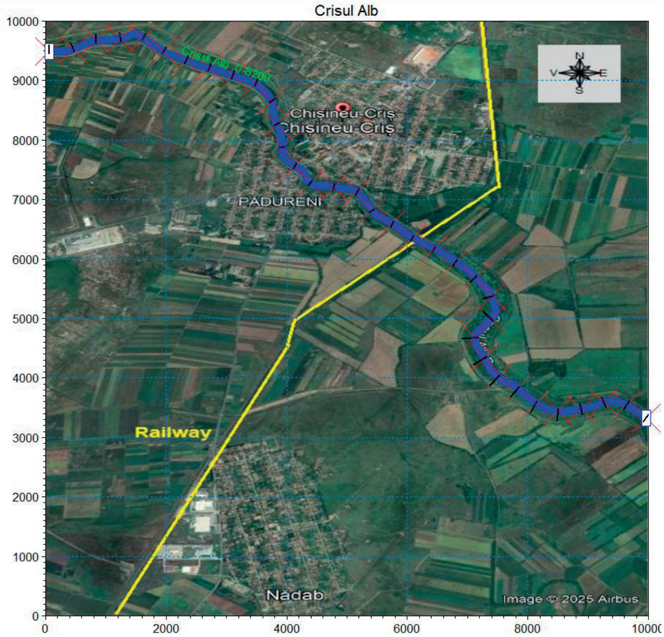

Figure 4. MIKE11 model plan view for the Crișul Alb River, showing simulation domain in the Nădab sector

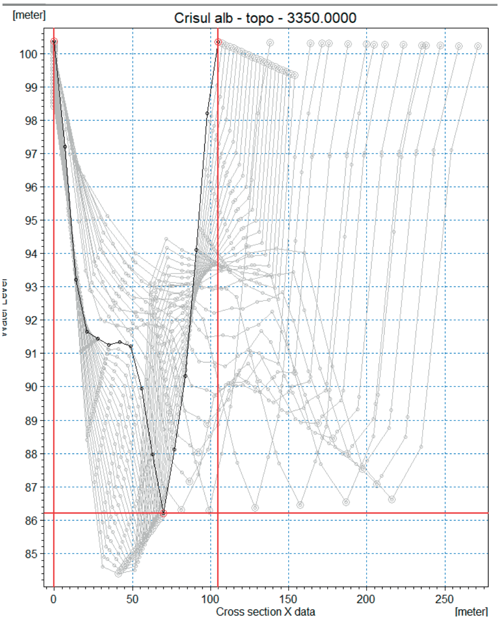

Figure 5. Topographic cross-sections of the canal used in MIKE11 hydraulic modeling

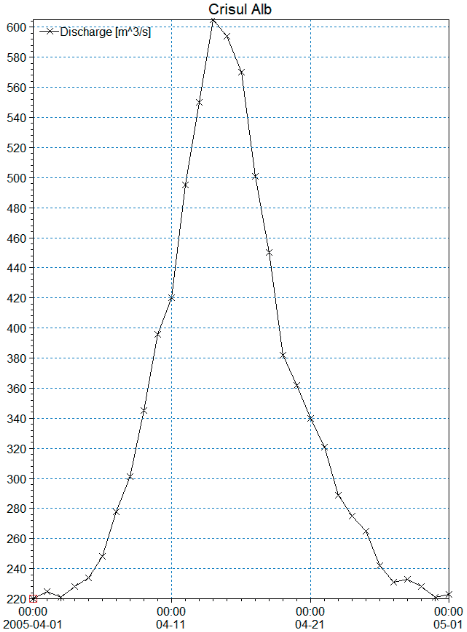

Figure 6. Inflow hydrograph (m³/s) used as upstream boundary condition for the 2005 flood event simulation

Cross-sections obtained from topographic surveys are shown in Figure 5.

Boundary conditions included an upstream flood hydrograph at chainage 0+000 and a downstream rating curve at chainage 8+200 (Damian et al., 2022).

The flow hydrograph is shown in Figure 6.

RESULTS AND DISCUSSIONS

The model was configured to simulate flood scenarios with different occurrence probabilities (1%, 2%, 10%). Hydraulic parameters, such as Manning's roughness and loss coefficients, were adapted based on local characteristics. Built-up areas and agricultural lands were treated differently to improve the accuracy of flow distribution.

The model was calibrated using data from historical events (the floods of 2000 and 2006) by adjusting hydraulic parameters the simulated values closely matched observed water extents and recorded levels. Validation was performed on a separate data set to ensure the robustness and applicability of the model for future scenarios.

The water levels from the initial results were compared with measured levels in several sections. Roughness coefficients were adjusted in specific sections until the simulated levels aligned with observed data.

By carrying out the MIKE11 program, a longitudinal profile of the canal was obtained showing water levels over the simulation period (Figure 7).

From Figures 7, it follows that for the hydrograph of the inflows introduced in 2005 on the Crisul Alb River, the maximum water transport capacity of the canal was exceeded, with the flood risk occurring for flows greater than those considered. Flood hazard maps generated with the MIKE Flood model show the spatial extent and depth of inundation under each flood scenario (Figure 8).

The results included detailed maps of the water extent and longitudinal profiles of the affected railway line, as well as estimates of water depth and flow velocity along sections of the railway line.

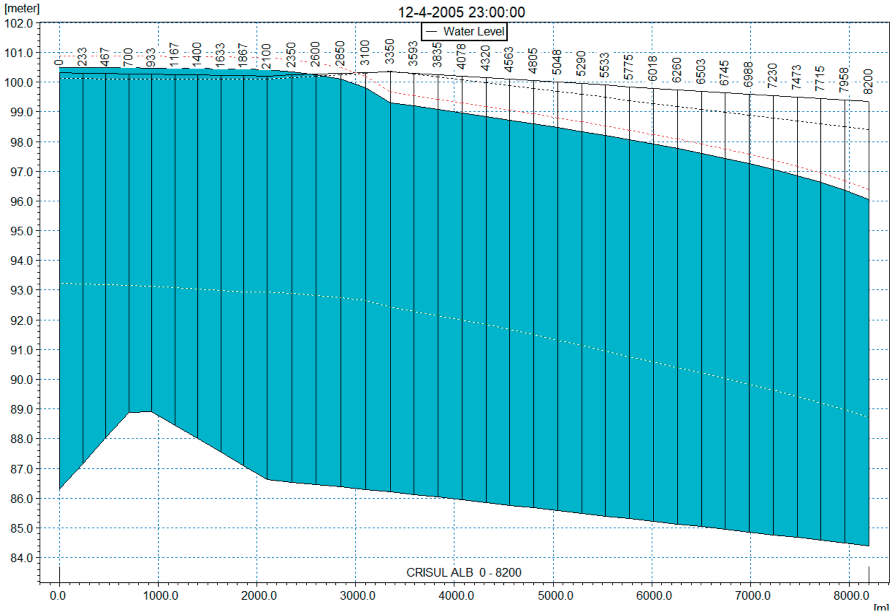

Figure 7. Longitudinal profile of the Crișul Alb Canal, showing simulated water levels during peak flow

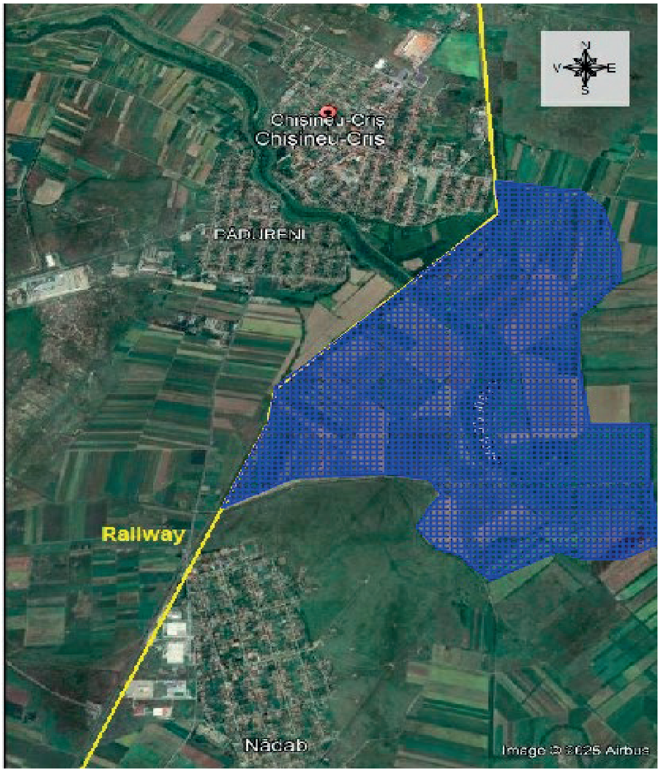

Figure 8. Flood hazard map of the Nădab area for the 1% probability scenario (Q100), showing extent and depth of inundation

In the specific context of the Nădab locality, the results suggest the need for additional protective measures, such as raising the railway embankments or constructing protective barriers to prevent flooding of the railway line during extreme events. Additionally, interventions to improve drainage systems in the area should be considered to reduce the risk of railway infrastructure blockage due to heavy precipitation.

On a broader scale, the results of this model help to improve understanding of the impact of flooding on critical infrastructure, especially in areas vulnerable to extreme weather events. This information may inform urban and infrastructure planning, considering climate change and the increased risks of flooding in the future. Furthermore, it can assist authorities in developing prevention strategies and rapid-response plans for natural disasters.

Comparisons with existing studies suggest that the vulnerability of railway infrastructure to flooding is a well-documented issue, especially in regions with low-lying terrain and nearby watercourses. While previous research has indicated similar protective measures (e.g., raising embankments and improving drainage systems), the current study highlights the specificity of the Nădab area, with its unique topographic and hydrological characteristics.

Among the limitations of the study are the simplified assumptions of the hydraulic model and the limited availability of historical flood data, which could have improved the model's calibration. In the future, it would be useful to expand studies to include long-term flood scenarios, considering climate forecasts and potential changes in the region's hydrological regime. Additionally, innovative solutions, such as green infrastructure (e.g., water retention zones), could be explored to enhance the flood resilience of railway infrastructure.

CONCLUSIONS

The study showed that the Nădab railway sector is vulnerable to flooding, especially in low-probability scenarios (1%), where water levels can exceed the capacity of the embankments. The results of the hydraulic simulations indicate significant water extent along the railway line during flood conditions, which poses a major risk infrastructure stability and operational safety.

The railway infrastructure in the Nădab area is vulnerable to recurring floods, particularly under he influence of climate change, which is expected to increase both the frequency and intensity of extreme weather events.

The greatest threat is the overload of local drainage capacity and subsequent flooding of the railway corridor, which can lead to major disruptions in train circulation and material damage.

Hydraulic modeling and hazard maps provide a clear picture of flood risks and help identify critical areas that require protective measures. These tools are essential for assessing potential impacts and supporting well-informed infrastructure protection strategies, particularly in flood risk planning and management.

Protective actions such as embankment elevation and the installation of barriers should be urgently considered to prevent flooding of the railway. Moreover, authorities are encouraged to prioritize drainage system upgrades and to invest in long-term infrastructure resilience strategies in light of future flood risk escalation.

Looking ahead, it is important to continue monitoring flood risks and improving hydraulic models by incorporating reliable climate projections.

Additionally, innovative green infrastructure solutions, such as water retention areas and the use of permeable materials, should be explored to enhance the resilience of railway infrastructure and help mitigate the effects of a changing climate.

The growing recognition of climate-related risks has brought the issue of water-related impacts on railway infrastructure to the forefront of discussions at the European level.

ACKNOWLEDGEMENTS

Thanks to the project: Development of knowledge centers for lifelong learning through the involvement of specialists and decision-makers in flood risk management, this activity can be possible using advanced hydroinformatics tools, AGREEMENT NO. LLP-LdV-ToI-2011-RO-002/2011- 1-RO1-LEO05-5329, was funded with the help of the European Commission.

REFERENCES

Armas, A., Beilicci, R., Beilicci, E. (2017). Numerical limitations of 1D hydraulic models using MIKE11 or HEC-RAS software - Case study on the Baraolt River, Romania, *IOP Conference Series: Materials Science and Engineering*, *245*, DOI10.1088/1757-899X/245/7/072010.

Biali, G., Cojocaru, P. (2022), GIS Hydrological modeling in an agricultural river basin with high potential for water erosion, *Scientific Papers-Series E-Land Reclamation Earth Observation & Surveying Environmental Engineering*, *11*, 418-425, WOS:000931961700050.

Damian, G., Pricop, C., Statescu, F. (2022), The study of hydrological regime modeling using HEC-RAS model. case study river basin Bahluet, *Scientific Papers-Series E-Land Reclamation Earth Observation & Surveying Environmental Engineering*, *11*, 338-343, WOS:000931961700039.

DHI - Danish Institute of Applied Hydraulics, 2021, MIKE 11 user manual - *A modeling system for rivers and channels, Short introduction and tutorial*, DHI, Horsholm, Denmark

Gabor, E., Beilicci, E., Beilicci, R. (2019), Advanced Hydroinformatic Tools for Modelling of Reservoirs Operation", *IOP Conference Series: Materials Science and Engineering*, *471*, DOI10.1088/1757-899X/471/4/042002.

Hausler, P.C.D., Beilicci, E., Beilicci, R (2020), Modelling of Privalul Tinoasa channel, in irrigation system Borcea 2-Danube Romania, *IOP Conference Series: Materials Science and Engineering*, Volume 960, DOI10.1088/1757-899X/960/2/022023.

Kellermann, P., Schönberger, C., Thieken, A.H., (2016), Large-scale application of the flood damage model RAilway Infrastructure Loss (RAIL). *Natural hazards and earth system sciences*, *16*(11), DOI10.5194/nhess-16-2357-2016.

Marossy, Z., Beilicci, R., Beilicci, E, Visescu, M. (2016), Advanced hydraulic modeling of the Cp3 irrigation channel, in the Teba - Timiș irrigation system, Romania, Timiș County, SGEM *Water, Resources, Forest, Marine And Ocean Ecosystems Conference Proceedings, I*, 39-46, WOS:000391653400006.

NARW - National Administration "Romanian Waters", Crişuri (2024), *Flood Risk Management Plan*, 005-049.

Varra, G., Morte, R.D., Tartaglia, M., Fiduccia, A., Zammuto, A., Agostino, I., Booth, C.A., Quinn, N., Lamond, J.E., Cozzolino, L (2024), Flood Susceptibility Assessment for Improving the Resilience Capacity of Railway Infrastructure Networks, *Water, 16(18), 2592.* https://doi.org/10.3390/w16182592