Damage, Loss, and Risk Modelling in Flood Events: A Case Study of the Dâmbu River, Romania

Maria Ilinca Chevereșan
Technical University of Civil Engineering Bucharest, Romania
maria.cheveresan@utcb.ro
Mihai Valentin Stancu
DHI SW Project
mvs@dhigroup.com

Abstract

Flood events are among the most devastating natural disasters, causing significant direct and indirect damages across various socio-economic sectors. Accurate damage, loss, and risk modeling are essential for implementing effective flood risk management strategies, particularly in regions prone to recurrent flooding. This article explores a structured methodology for flood damage and loss modeling in Romania, focusing on the Dâmbu River basin as a case study. By employing damage functions, classifying damages, and identifying typologies of vulnerable elements, this study provides insights into risk quantification and mitigation strategies. The findings underscore the necessity of localized, high-resolution data for accurate flood risk mapping to inform policy and community resilience.

Key words: flood damage modeling, risk assessment, damage functions, typologies of vulnerable elements, EU Flood Directive, flood resilience
J.E.L. classification: Q54

1. Introduction

Floods represent a major challenge to sustainable development, particularly in areas where climate and hydrological conditions amplify their frequency and intensity. Romania, characterized by a diverse landscape and significant flood-prone zones, has historically experienced substantial damage from floods. These events have impacted infrastructure, housing, and agriculture, leading to direct physical destruction and cascading economic disruptions.

Developing effective flood damage and risk models is vital for managing these impacts. Such models are mandated under the European Union (EU) Flood Directive, which requires member states to generate comprehensive flood risk maps and implement targeted management plans. These efforts emphasize a scientific approach to quantifying damages and evaluating exposure.

This article delves into the methodologies employed for modeling flood risks in Romania, focusing on localized tools such as damage functions, typologies of vulnerable elements, and high-resolution risk maps. The Dâmbu River case study serves as an example of how these tools can be applied to real-world flood challenges, illustrating both their potential and limitations in guiding effective flood management strategies.

2. Theoretical background

Flood damage and risk modeling involve an integrative framework that connects hazard analysis, exposure evaluation, and vulnerability assessment. In Romania, this methodology aligns with EU standards but is also adapted to address local geographic and socio-economic characteristics. It utilizes exposure data, vulnerability curves, and typological classifications to produce actionable insights for decision-makers (World Bank, 2021).

Flood hazards are defined by their spatial extent, depth, and velocity, which determine the physical characteristics of flood events (HR Wallingford, 2020). These hazards are further analyzed to assess their potential interactions with the environment and human systems. Vulnerability refers to the predisposition of certain assets or populations to suffer harm when exposed to flood hazards. This involves evaluating factors such as the physical robustness of infrastructure, the resilience of communities, and the socio-economic conditions that may exacerbate or mitigate the impacts of flooding.

Exposure quantifies the elements within a flood-prone area that are at risk, including infrastructure, residential and commercial buildings, agricultural lands, and population centers. Together, hazard, vulnerability, and exposure form the foundation for calculating flood risk (UNDRR, 2004). The integration of these components allows for a nuanced understanding of how different areas and assets are likely to be affected under various flood scenarios.

A critical aspect of flood damage and risk modeling is the identification and classification of vulnerable elements within the flood-prone area. This process involves mapping the diverse range of assets and populations that may be impacted, allowing for targeted risk assessments and mitigation strategies. In Romania, the classification process is tailored to reflect local land-use patterns, building practices, and socio-economic dynamics.

Buildings are categorized by their type and use, such as residential houses, apartment complexes, commercial establishments, and industrial facilities. Infrastructure elements, including roads, bridges, power stations, and water supply systems, are also mapped and assessed for their vulnerability to flood hazards. Agricultural lands, a significant component of Romania's economy, are evaluated based on crop types, expected yields, and susceptibility to waterlogging or erosion. Lastly, population centers are examined to identify vulnerable groups, such as elderly residents, children, or low-income households, who may require special attention during flood events (Rufat, S. et all, 2015).

The integration of local land-use data, building characteristics, and socio-economic profiles ensures that the flood risk model accurately captures the unique vulnerabilities of the region. This enables the identification of high-risk areas and supports the development of targeted mitigation measures, such as the reinforcement of critical infrastructure, the establishment of evacuation routes, and the implementation of land-use zoning policies to reduce exposure (Ribas P. A., et. all, 2017).

By combining hazard characterization, damage functions, damage classification, and typological analysis, Romania's flood damage and risk modeling methodology provides a robust framework for understanding and addressing the multifaceted impacts of flooding. This integrated approach not only aligns with EU standards but also ensures that local contexts and vulnerabilities are appropriately accounted for in flood risk management plans (World Bank, 2021).

Flood damages are classified into four distinct categories – direct tangible, intangible, and indirect tangible and intangible damages, each addressing a different dimension of impact. Direct tangible damages represent the physical destruction of assets, such as residential and commercial buildings, roads, bridges, and agricultural fields. These damages are typically the most immediate and visible effects of flooding. In contrast, indirect tangible damages encompass economic losses that arise from disruptions in activity, such as halted business operations, increased transportation costs, and supply chain interruptions.

Direct intangible damages are more challenging to quantify but equally significant. These include the loss of human lives, injuries, and the degradation of cultural or natural heritage. Indirect intangible damages focus on the less tangible, long-term societal effects of flooding, such as psychological trauma, loss of trust in institutions, and migration due to recurrent disasters. Each of these categories requires different methodologies for quantification. Direct tangible damages often rely on spatial data and economic appraisals, while indirect damages may involve the use of economic multipliers and scenario-based modeling to estimate broader impacts on regional and national economies (Penning-Rowsell, et. all, 2020).

3. Research methodology

Damage functions, also referred to as vulnerability curves, are mathematical relationships that link flood parameters—such as water depth, duration, and velocity—to the percentage of damage sustained by various assets (Scawthorn, C., et. all, 2006) These functions are critical in quantifying the direct and indirect impacts of flooding. In Romania, damage functions are developed and adapted to reflect local conditions, incorporating detailed exposure data and typologies of buildings and infrastructure specific to the Romanian context.

These functions are derived from a combination of national and international data sources such as MCM (UK), HAZUS (USA), SSM (NL), including architectural datasets, construction cost records, and empirical observations from past flood events. These curves are designed to reflect the incremental increase in damage as water levels rise, enabling precise calculations of direct tangible damages. This localized approach ensures that the damage assessment is accurate and relevant to the socio-economic characteristics of Romania.

A critical metric in flood risk modeling is the *Expected Annual Damage* (EAD), which quantifies the average annual economic losses due to flooding. The EAD is calculated by integrating damage estimates over all potential flood scenarios, considering their respective probabilities of occurrence. This metric is vital for comparing flood risks across different areas and evaluating the cost-effectiveness of proposed mitigation measures. The expected annual damage is computed using the following formula:

$$EAD = \sum_{i=1}^{N} \Delta P_i \times D_i$$

where: ΔP_i is the exceedance Probability increment and D_i is the average damage of the two events with exceedance probabilities P_i and P_{i+1} (World Bank, 2021).

In Romania, the EAD is determined using a combination of hazard maps, exposure data, and damage functions. Hazard maps provide details on flood extents and depths for various return periods, while damage functions estimate the potential losses for different asset types at each flood depth. By summing the expected damages for all return periods, weighted by their likelihood, the EAD offers a comprehensive view of annual flood risks. This approach helps prioritize interventions, such as flood defenses, land-use planning, and emergency preparedness strategies, ensuring that resources are allocated efficiently. Furthermore, the EAD serves as a key input for cost-benefit analyses, enabling decision-makers to justify investments in flood risk reduction based on their long-term economic impact. This metric thus bridges the gap between technical flood assessments and actionable policy development.

4. Findings

The Dâmbu River basin has experienced frequent flooding, with significant impacts on local communities (Aquaproiect, EPMC, DHI, 2020, Options Analysis). Using the outlined methodology, the flood risk assessment for this area involved:

- Data Collection: Hydrological data on historical flood events, exposure data from land-use maps, and vulnerability data specific to Romanian settings.
- Damage Modeling: Applying damage functions to categorize and quantify potential damages across the basin. The model identified hotspots, including densely populated urban areas and critical infrastructure corridors.
- Risk Mapping: Generating flood risk maps highlighting zones with the highest expected annual damage (EAD). These maps are instrumental in prioritizing flood mitigation measures, such as dike construction or river channel improvements.

To be able to compute and map the flood risk, a set of hazard information is required. The hazard data available for the pilot studies is obtained from the hydrological/ hydrodynamic modelling activity for each pilot area, consisting of water depth and water velocity maps. The expected Annual Damage (EAD) was computed based on 5 return periods (10, 50, 100, 200, 500 years).

Results from the Dâmbu River case study revealed that residential buildings accounted for the largest share of direct tangible damages, followed by transportation infrastructure. Indirect damages were significant, especially in agricultural areas, where prolonged inundation disrupted planting and harvesting cycles (World Bank , 2020).

The study underscores the importance of localized damage functions in enhancing the accuracy of flood damage estimates.

Table no. 1 Risk assessment results for Dambu pilot area – EAD and 5 hazard scenarios (Mi euro)

	EAD	**0.20%**	**0.50%**	**1%**	**5%**	**10%**
Direct Tangible	13.7	286	230	181	129	77
Indirect Tangible	2.5	50	41	32	24	15
Direct Intangible	0.5	16	9	8	4	2
Indirect Intangible	0.1	1.3	1.2	1	0.7	0.3
Total Damage	16.8	253	281	222	158	95

Source: (World Bank, 2020)

By tailoring damage curves to specific local contexts (World Bank, 2020), such as incorporating unique building materials and structural designs observed in the Dâmbu River basin, the modeling process achieved a higher level of reliability. This adaptation ensures that results are reflective of the actual vulnerabilities within the region.

Additionally, the use of comprehensive vulnerability typologies that account for land use, infrastructure (World Bank, 2021), and population distribution proved crucial in producing detailed and nuanced risk assessments. This methodology enabled the identification of critical vulnerabilities in the Dâmbu River basin, highlighting areas most susceptible to flood impacts and requiring focused attention.

The integration of risk maps, derived from the damage and loss models, provided policymakers with actionable insights. These maps effectively highlighted priority areas for flood mitigation interventions, such as floodplain restoration or the enhancement of drainage systems, ensuring that resources were directed to where they could yield the greatest benefits.

However, several challenges remain. The limited availability of high-resolution exposure and vulnerability data poses a significant constraint. Expanding national databases and utilizing advanced remote sensing technologies can help overcome this limitation, improving the comprehensiveness of future assessments. Additionally, the inherent uncertainties in flood damage modeling, particularly concerning indirect damage estimation, necessitate improvements in data quality and the adoption of probabilistic approaches to better manage these uncertainties.

Finally, the success of flood risk management depends heavily on collaboration among stakeholders, including government agencies, local communities, and international organizations. Transparent communication of risk assessments and mitigation plans is essential to foster stakeholder engagement and ensure the effective implementation of flood resilience strategies.

5. Conclusions

The Dâmbu River case study demonstrates the practical effectiveness of damage, loss, and risk modeling in addressing the complex challenges posed by flooding in vulnerable areas. By leveraging localized data, tailored damage functions, and detailed typologies of vulnerable elements, the methodology produces highly specific risk assessments that reflect the unique socio-economic and geographic characteristics of the region. This localized approach ensures that the outcomes are not only accurate but also actionable, allowing policymakers to prioritize mitigation strategies in high-risk areas effectively.

Beyond its application in the Dâmbu River basin, the broader methodology developed for flood risk assessment in Romania provides a versatile and robust framework. The integration of hazard mapping, exposure data, and vulnerability curves tailored to local contexts enables a comprehensive understanding of flood risks. The methodology's focus on Expected Annual Damage (EAD) as a key metric further enhances its utility by facilitating comparative risk evaluations and justifying investments in flood protection through cost-benefit analyses.

Moreover, the classification of damages into direct tangible, indirect tangible, direct intangible, and indirect intangible categories ensures that the full spectrum of flood impacts is accounted for. This nuanced approach allows for a more holistic understanding of flood consequences, including physical destruction, economic disruptions, and societal effects such as psychological trauma and reduced trust.

The findings emphasize the importance of integrating such sophisticated methodologies into national and regional flood management plans. By adopting these tools, Romania can enhance its resilience to flooding, minimize socio-economic losses, and ensure that resources are allocated efficiently. This framework aligns with the requirements of the EU Flood Directive and serves as a model for other flood-prone countries aiming to improve their risk assessment and mitigation strategies. In sum, the methodology not only offers a scientific and systematic approach to flood risk assessment but also bridges the gap between technical analysis and practical policy implementation.

6. References

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