Environmental Economics in Flood Mitigation for River Basins and Cities

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Abstract

Due to the increasing impacts of climate change on flood management, it is vital to implement effective flood mitigation measures. Economic factors significantly influence the feasibility and speed of these implementations. Evaluations must go beyond just the implementation costs. This paper introduces tools and methods for incorporating environmental economics into flood risk management at various scales, from urban areas to entire river basins. Comprehensive analysis should include social, environmental, direct, and indirect factors. Despite the variability in flood mitigation costs across different economies, the methods discussed are highly adaptable. Data limitations for appraisal tools like Multicriteria Analysis (MCA) and Cost-Benefit Analysis (CBA) can be addressed through expert judgment, qualitative assessment, or using GDP-proportional data for cost estimation. This approach utilizes databases from experienced countries, making the methods adaptable to different contexts.

Key words: environmental economics, flood mitigation, cost-benefit analysis, river basins, cities
J.E.L. classification: Q54

1. Introduction

Flood mitigation is a critical issue for many river basins and cities around the world, where increasing urbanization and climate change are escalating the frequency and severity of floods (Popescu and Bărbulescu, 2022). Environmental economics plays a vital role in developing and implementing effective flood mitigation measures by evaluating the economic implications of various strategies, ensuring efficient use of resources, and balancing ecological sustainability with economic development (De Bruin and Ansink, 2011).

Environmental economics helps policymakers and planners understand the costs and benefits associated with different flood mitigation measures. By applying economic principles, we can prioritize interventions that provide the greatest benefits relative to their costs, ensuring that limited resources are used effectively to protect communities and ecosystems.

Key concepts in environmental economics applied to flood mitigation can be summarized as following (Aven, 2016, MacNeil, 2024, Markandya, 2019, Salonen, 2021, Hudson and Wouter, Botzen, 2011).

a. *Cost-Benefit Analysis*: This technique involves comparing the costs of flood mitigation projects (such as levees, reservoirs, and wetland restoration) with the expected benefits, which include reduced flood damage, avoided economic losses, and improved public safety.

b. *Valuation of Ecosystem Services*: Wetlands, forests, and other natural areas provide valuable services such as water infiltration and flood regulation. Environmental economics assigns monetary values to these services, highlighting the economic benefits of preserving and restoring natural flood buffers.

c. *Externalities*: Flooding often results from external factors such as upstream land use changes, which can increase runoff and downstream flood risks. Environmental economics addresses these externalities by encouraging practices that mitigate upstream impacts, such as sustainable land use and watershed management.

d. *Risk Assessment and Management*: Environmental economists evaluate the probability and potential impacts of flooding events to inform risk management strategies. This includes developing insurance schemes and financial instruments that can distribute the economic risks of flooding more effectively.

To implement effective flood mitigation measures, various economic policy instruments are employed:

- *Investment in Infrastructure*: Funding for flood control infrastructure, such as dams, levees, and drainage systems, is assessed for its economic efficiency in reducing flood risks.
- *Natural Infrastructure Solutions*: Investments in green infrastructure, like wetlands restoration and urban green spaces, are evaluated for their cost-effectiveness and multiple benefits beyond flood control, such as biodiversity conservation and recreation.
- *Market-Based Instruments*: Tools like flood insurance and incentives for flood-resilient construction can motivate individuals and businesses to adopt practices that reduce flood risk.
- *Regulatory Measures*: Zoning laws and building codes can be designed to minimize flood damage by restricting development in high-risk areas and ensuring that new buildings are flood-resistant.

2. Theoretical background

Multicriteria Analysis (MCA) is a decision-making tool to evaluate and prioritize multiple options when addressing complex problems involving diverse and often conflicting criteria (Gamper et al., 2006). In flood risk mitigation, MCA helps policymakers and planners assess various mitigation measures by considering various factors beyond just economic costs and benefits. This holistic approach ensures that all relevant aspects of flood risk management are considered, leading to more balanced and effective decision-making.

The key components of the multicriteria analysis are criteria selection, weighting criteria, evaluation of alternatives, aggregation of scores, ranking, and selection.

The first step in MCA involves identifying the essential criteria for evaluating the flood risk mitigation measures. These criteria can be broadly categorized into economic, social, environmental, and technical factors. The economic criteria are represented by the costs of implementation, maintenance costs, and potential economic losses avoided. Social criteria refer to the impact on local communities, public safety, and social equity. The environmental criteria consider the effects on ecosystems, biodiversity, and sustainability of natural resources, while the technical criteria relate to the mitigation measures' feasibility, reliability, and effectiveness.

Once the scores for each criterion are combined, using the assigned weights, an overall score is produced for each mitigation option. This step often involves mathematical modeling and may use techniques such as weighted sum models, analytic hierarchy process (AHP), or other aggregation methods. The outcome of the MCA process is the ranking of the mitigation options based on their overall scores. The highest-ranking options are considered the most favorable for implementation. Decision-makers can then select the best option or a combination of options that meet the desired balance of effectiveness, cost-efficiency, and sustainability.

Afterwards, the scores for each criterion are combined, using the assigned weights, to produce an overall score for each mitigation option. This step often involves mathematical modeling and may use techniques such as weighted sum models, analytic hierarchy process (AHP), or other aggregation methods. Finally, the mitigation options are ranked based on their overall scores. The highest-ranking options are considered the most favorable for implementation (Popescu and

Bărbulescu, 2023, Costache et al. 2021). Decision-makers can then select the best option or a combination of options that meet the desired balance of effectiveness, cost-efficiency, and sustainability.

MCA is often applied in Flood Risk Mitigation, being also steered by national methodologies requirements and compliant with EU flood Directive implementation or other regulatory requirements. MCA is particularly useful in flood risk mitigation because it allows for a comprehensive evaluation of mitigation measures, incorporating diverse perspectives and criteria often overlooked in traditional cost-benefit analyses. MCA facilitates the inclusion of stakeholders in the decision-making process, ensuring that the selected measures align with the values and preferences of the affected communities. The systematic and structured approach of MCA increases the transparency of the decision-making process, making it easier to justify and communicate decisions to the public and stakeholders. At the same time, the MCA can be adapted to various scales and contexts, from local community projects to large-scale regional flood management plans.

An example of criteria in flood risk mitigation MCA can be represented by the economic impact, namely the cost of construction and maintenance, potential savings from avoided flood damage, the effectiveness - reduction in flood risk, extent of area protected, environmental impact - preservation of wetlands, impact on water quality, biodiversity, social impact - displacement of communities, impact on public health and safety, equity in risk distribution and the technical feasibility - ease of implementation, robustness under different flood scenarios, adaptability to future changes.

In practice, evaluating the MCA can be bumped by different potential obstacles related to data availability, subjectivity, and complexity. Accurate and comprehensive data is essential for reliable MCA; any data gap can lead to biased or incomplete evaluations. Also, the weighting of criteria and scoring of options can introduce subjectivity. It is crucial to use transparent and consistent methods to minimize bias. Finally, MCA can become too complex, especially when dealing with many criteria and options. Simplifying the analysis without losing essential information is a key challenge and desired for the success of the evaluation. Other challenges refer to the accuracy of predicting the economic impacts of climate change, valuing intangible benefits such as biodiversity, and integrating diverse stakeholder perspectives. Future directions may involve enhancing economic models to account for dynamic environmental changes, increasing interdisciplinary collaboration, and promoting adaptive management approaches.

Once the MCA is finalized, the next step is to perform a Cost-Benefit Analysis (CBA) for Flood Risk Mitigation. This systematic approach evaluates the economic efficiency of flood risk mitigation measures by comparing their total expected costs against their total expected benefits. The objective is to determine whether the benefits of a proposed flood mitigation project outweigh its costs and to identify the most economically advantageous option. The CBA process involves identifying and quantifying costs and benefits, considering the time horizon and discounting, and conducting a sensitivity analysis to assess the robustness of the results.

The first step in CBA is identifying all the relevant costs and benefits of the flood mitigation project. These can be categorized into direct costs - costs of constructing and maintaining flood defenses (e.g., levees, reservoirs, drainage systems), indirect costs - secondary costs such as disruption to local communities, environmental degradation, and opportunity costs of land use, direct benefits -reduction in flood damages to properties, infrastructure, and agricultural land, and indirect benefits - improved public safety, enhanced property values, ecosystem services, and economic stability. Once identified, the next step is to quantify these costs and benefits in monetary terms. It involves estimating the financial expenditure required for the project and the monetary value of the benefits achieved, such as reduced flood damage and improved quality of life. Flood mitigation projects often have long-term implications, so it is essential to consider the time horizon over which costs and benefits will occur. Future costs and benefits are discounted to present value using a discount rate, reflecting the time value of money. This allows for comparing costs and benefits that occur at different times. The NPV is calculated by subtracting the present value of costs from the present value of benefits. A positive NPV indicates that the project's benefits exceed the costs, making it economically viable. The BCR is another important metric calculated by dividing the total present value of benefits by the total present value of costs. A BCR greater than 1 indicates that the benefits outweigh the costs. Finally, a sensitivity analysis can be performed to test the robustness of the CBA results by varying key assumptions and parameters, such as the discount rate or cost estimates. Sensitivity analysis helps identify which variables have the most significant impact on the outcome and assesses the reliability of the conclusions.

CBA is widely used in flood risk mitigation to assess and prioritize different projects and strategies, ensuring that resources are allocated efficiently. Common applications include:

- comparing structural and non-structural measures: evaluating the economic viability of constructing physical barriers versus implementing early warning systems or land use planning.
- project feasibility studies: determining whether specific flood defense projects, such as levees or reservoirs, provide sufficient economic benefits to justify their costs.
- policy formulation: informing the development of flood management policies by assessing the economic impact of regulatory measures and incentive programs.
- investment decisions: guiding public and private investment in flood risk mitigation infrastructure and initiatives.

For a better explanation let’s consider the following example of CBA for flood mitigation: let's consider the following example of CBA for flood mitigation: costs are given by the construction and maintenance of flood defenses, administrative and operational expenses, environmental impacts, such as habitat disruption, and social costs, including displacement of communities. The benefits are represented by reduced flood-related property and infrastructure damage, decreased economic losses in agriculture and industry, enhanced public health and safety, increased property values and community resilience, and preservation of ecosystems and biodiversity.

The CBA’s challenges are related to data availability and accuracy, valuation of intangibles (e.g. ecosystem services or social well-being are difficult to quantify in monetary terms, potentially leading to underestimation of true benefits), and distributional effects (CBA typically focuses on aggregate costs and benefits, but it is also important to consider how these are distributed among different stakeholders and communities).

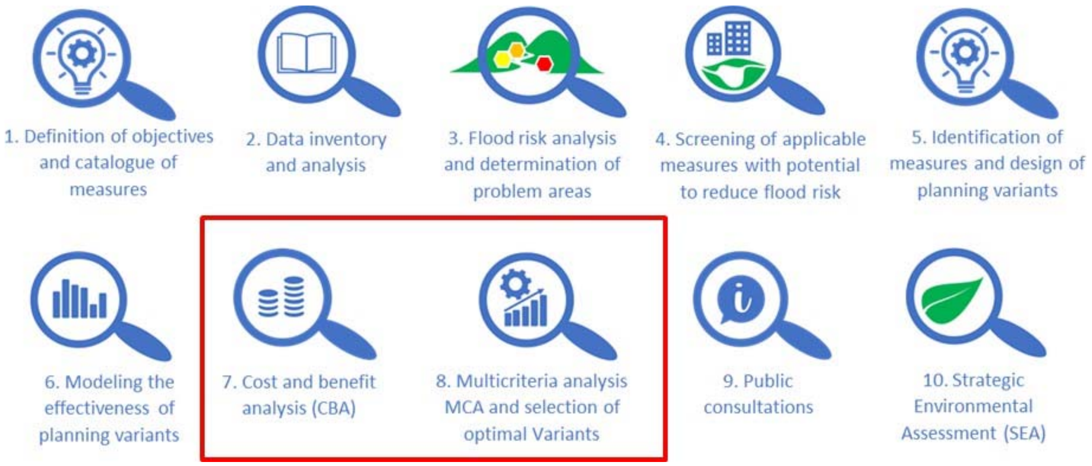
3. Research methodology

Worldwide, the MCA and CBA have different applications for flood risk mitigation at different land scales (Kundzewicz et al., 2018). These follow the general guidelines, which are usually transposed into local legislation, adapted to the national context, but can have different particularities (EEA, 2007). For example, the Netherlands, known for its advanced flood management, employs engineered and nature-based solutions to manage water levels and protect urban areas, using comprehensive cost-benefit analyses to guide investments (Brouwer and van Ek, 2004). The Federal Emergency Management Agency's National Flood Insurance Program utilizes risk assessments and economic incentives to promote flood resilience in the United States (FEMA, 2022). In Bangladesh, in the flood-prone regions, economic analyses support investments in community-based flood management and early warning systems, emphasizing cost-effective and sustainable solutions. Romania has a national methodology for the development of programs of measures, where MCA and CBA applications are described, aligning the approach when it comes to the management of flood risk.

These methods, originally designed for flood risk management at the national level, demonstrate their adaptability by being effectively downscaled to smaller units, such as subbasin or municipality level. They form part of a comprehensive sequence of actions that are undertaken to create a flood risk management plan (Fig. 1).

The cost estimation for the baseline (do-nothing with maintenance) and alternatives involves inputting a stream of costs into the ‘costs’ worksheets. These include initial investment, replacement, operating and maintenance costs, land purchase costs, revenues, and other expenses. This process is part of the MCA and carried forward to the CBA. Mitigation costs are noted but only required for the CBA. In the MCA, residual impacts (scores less than 100) are included in the weighted score, not as separate costs, but potential mitigation costs should be considered to avoid selecting an alternative with prohibitively high mitigation costs. Three are three cases of uncertainty in cost estimates:

Figure no. 1. Example of diagram with the general technical process of developing a River Basin Management Plan



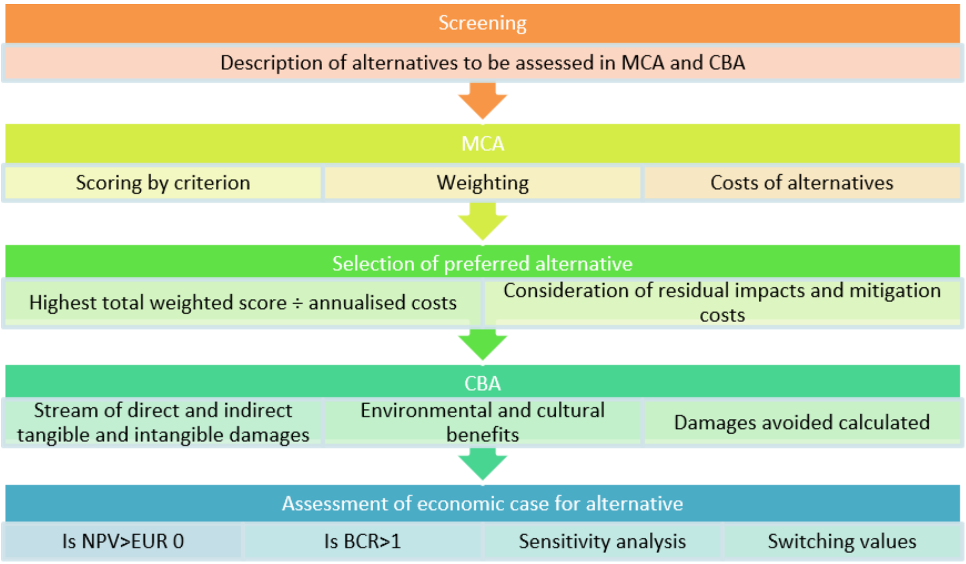
Source: Author’s contribution

- Costs-worst case: Records higher or upper-bound costs, accounting for possible optimism bias.
- Costs-realistic case: Records the best estimate of costs.
- Costs-best case: Records lower costs, assuming everything goes as planned.

4. Findings

In practice, the MCA and CBA evaluation process looks like the one described in Fig.2, which was extracted from the Romanian national methodology for a program of measures.

Figure no. 2. Steps for applying the MCA and CBA (source: Romanian national methodology for development of program of measures)



Source: Author’s contribution

A case study for a preliminary flood risk area in Romania (called Tazlau) will be presented. It will show the actual application and calculation of the MCA and CBA to test the viability of the flood mitigation measures. The case study will not provide details about assessing the preliminary flood risk, hazard mapping, or risk calculation. These activities were part of the study to provide the necessary input for the flood hazard, so identifying potential measures and their assessment is possible.

As a first step, screening of existing infrastructure (baseline) and two alternative packages of flood mitigation measures were inventoried (Fig. 3). For each of these variants, an MCA ranking was performed considering social, economic, environmental, and cultural factors, implementing viability in three scenarios: pessimistic, best estimate, and optimistic. Scores were given for each option, and a ranking in the best estimate scenario indicated the second alternative as the optimum to be further implemented to lower the flood risk (Fig.4).

Figure no. 3. Measures description (source: Romanian national methodology for development of program of measures)

Baseline (B)	**Existing infrastructure – local dikes and bank protections**
Alternative 1 (A1)	Alternative 1 is centered on retention in lateral accumulations, complemented by longitudinal and transverse dams but also by some measures to redirect the flow away from the risk areas on the opposite bank
Alternative 2 (A2)	Alternative 2 is focused on floodplain protection through a combination of longitudinal and transverse dikes. The works in the second category have the role of limiting the transfer of risk downstream. Lateral accumulations are replaced by dikes to divert the flow in the main bed as an alternative form of retention, but also to redirect the flow away from the risk areas on the opposite bank.

Source: Author’s contribution

Figure no. 4. Measures description (source: Romanian national methodology for development of program of measures)

Weighted score	**Best estimate**										
Max score	35	29	24	6	6	100			Ranking of alternatives by MCA Score		
	Social	Economic	Environmental	Cultural	Implementability	All	Pessimistic (all)	Optimistic (all)	Pessimistic	Best	Optimistic
B	8	0	13	5	0	25	59	59	1	3	1
(A1)	27	22	4	4	1	58	59	59	1	2	1
(A2)	27	22	6	5	1	61	59	59	1	1	1

Source: Author’s contribution

Following the MCA, the CBA analysis was further conducted reaching the estimations shown in Table 1. Based on the data provided in the CBA analysis, the best alternative is determined by comparing the Benefit-Cost Ratio (BCR) and the Net Present Value (NPV) for each alternative. Here's a summary of the key results from the CBA:

Table no. 1 Determining the best alternative (source: Romanian national methodology for development of program of measures)

	Present Value Damages for BCR(€)	**Benefits from damages avoided**	**Realistic costs (€)**	**Quick CBA: BCR**	**Quick CBA: NPV**	**Change in NPV**	**Quick CBA: ERR**
B	118,464,598		-				
A1	27,256,888	91,207,710	9,729,917	9.37	81,477,793	81,477,793	837%
A2	27,334,388	91,130,210	6,350,219	14.35	84,779,991	3,302,198	1335%
Incremental analysis		Change in benefit	Change in costs	Inc BCR	Change in NPV		
2nd lowest cost v 1st lowest cost		- 77,500	-3,379,698	0.02	3,302,198		
3rd lowest versus 'best of 2nd/1st'		- 91,130,210	-6,350,219	14.35			

Source: Author’s contribution

- ✓ Baseline:
  - Present Value Damages: €118,464,598
  - Benefits from Damages Avoided: €0
  - Costs: Not provided for baseline
  - BCR: Not applicable
  - NPV: Not applicable
- ✓ Alternative 1:
  - Present Value Damages: €27,256,888
  - Benefits from Damages Avoided: €91,207,710
  - Realistic Costs: €9,729,917
  - BCR: 9.37
  - NPV: €81,477,793
  - Economic Rate of Return (ERR): 837%
- ✓ Alternative 2:
  - Present Value Damages: €27,334,388
  - Benefits from Damages Avoided: €91,130,210
  - Realistic Costs: €6,350,219
  - BCR: 14.35
  - NPV: €84,779,991
  - ERR: 1335%

Analyzing the results and looking at the Benefit-Cost Ratio (BCR), it results that Alternative 2 has a higher BCR (14.35) compared to Alternative 1 (9.37), indicating that for every euro spent, Alternative 2 yields more benefits. From the Net Present Value (NPV) perspective, Alternative 2 also has a higher NPV (€84,779,991) compared to Alternative 1 (€81,477,793), which means Alternative 2 provides greater net benefits after accounting for costs.

Finally, looking at the Economic Rate of Return (ERR), Alternative 2 has a higher ERR (1335%) than Alternative 1 (837%), indicating a higher return on investment.

In conclusion, after performing the Cost-Benefit Analysis, Alternative 2 is the best option as it offers the highest Benefit-Cost Ratio (BCR), Net Present Value (NPV), and economic rate of Return (ERR). This makes it the most economically advantageous option for flood risk mitigation.

5. Conclusions

Integrating environmental economics into flood risk management is crucial in addressing the increasing frequency and severity of flood events driven by climate change and urbanization. This paper has highlighted the importance of considering economic, social, and environmental factors in selecting and implementing flood mitigation measures. By employing tools like Multicriteria Analysis (MCA) and Cost-Benefit Analysis (CBA), policymakers can comprehensively evaluate flood mitigation strategies, balancing effectiveness, cost-efficiency, and sustainability.

The study emphasizes that the economic viability of flood mitigation measures varies significantly across different national contexts due to varying costs and available data. However, leveraging expert judgment and proportional data from countries with established methodologies can bridge these gaps, facilitating more informed decision-making.

Through a detailed case study from Romania, the paper demonstrates the practical application of MCA and CBA in evaluating flood risk mitigation options. The findings underscore the importance of thorough cost assessments and sensitivity analyses to identify the most economically advantageous solutions. In the case study, Alternative 2 emerged as the preferred option through MCA and CBA due to its balanced consideration of social, economic, and environmental impacts indicating the highest economic benefits relative to its costs.

In conclusion, integrating environmental economics into flood risk management enhances the decision-making process and ensures that the most effective and sustainable solutions are implemented.

This approach is essential for protecting communities, preserving ecosystems, and promoting economic stability in the face of growing flood risks. Future research should focus on improving data accuracy, valuing intangible benefits, and incorporating diverse stakeholder perspectives to refine these analytical tools further.

6. References

- Aven,T. 2016. Risk assessment and risk management: Review of recent advances on their foundation, *European Journal of Operational Research*, 253(1), pp.1-13, https://www.sciencedirect.com/science/article/pii/S0377221715011479.
- Brouwer, R., van Ek, R., 2004. Integrated ecological, economic and social impact assessment of alternative flood control policies in the Netherlands. *Ecological Economics*, 50(1-2), pp.1-21, https://doi.org/10.1016/j.ecolecon.2004.01.020.
- Costache, R., Bărbulescu, A., Pham, Q.B., 2021. Integrated framework for detecting the areas prone to flooding generated by flash-floods in small river catchments - a useful indicator for water quality. *Water*, 13, 758. https://doi.org/10.3390/w13060758.
- De Bruin, K., Ansink, E., 2011. Investment In Flood Protection Measures Under Climate Change Uncertainty. *Climate Change Economics*, 02(04), pp. 321-39, https://www.worldscientific.com/doi/10.1142/S2010007811000334.
- EEA, 2007. *Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks* (Text with EEA relevance), [online] Available at: https://www.eea.europa.eu/policy-documents/directive-2007-60-ec-of
- FEMA, 2022. *The Federal Emergency Management Agency's (FEMA) National Flood Insurance Program utilizes risk assessments and economic incentives to promote flood resilience in the United State*, [online] Available at: https://www.fema.gov/floodplain-management/intergovernmental/federal-flood-risk-management-standard.
- Gamper, C.D., Thöni, M., Weck-Hannemann, H., 2006. A conceptual approach to the use of Cost Benefit and Multi Criteria Analysis in natural hazard management. *Natural Hazards and Earth System Sciences*, 6, pp. 293-302, [online] Available at: https://nhess.copernicus.org/articles/6/293/2006/.
- Hudson, P., Wouter Botzen, W. J. 2019. Cost–benefit analysis of flood-zoning policies: A review of current practice. *WIREs Water*, 6(6), e1387, [online] Available at: https://wires.onlinelibrary.wiley.com/doi/10.1002/ wat2.1387.
- Kundzewicz , Z.W., Hegger, D.L.T., Matczak, P., Driessen, P.P.J., 2018. Flood-risk reduction: Structural measures and diverse strategies. *Proceedings of the National Academy of Sciences*, 115(49), pp. 12321–25, https://doi.org/10.1073/pnas.1818227115,
- MacNeil, C., 2024. *Cost-benefit analysis: 5 steps to make better choices*, [online] Available at: https://asana.com/resources/cost-benefit-analysis.
- Markandya, A. 2019. *Valuation of ecosystem services*, [online] Available at: https://seea.un.org/sites/seea.un.org/files/ 2.2.1_valuation_of_ecosystem_services.pdf.
- Popescu, N.C., Bărbulescu, A., 2022. On the flash flood susceptibility and accessibility in the Vărbilău catchment (Romania). *Romanian Journal of Physics*, 67, 811.
- Popescu, N.C., Bărbulescu, A., 2023. Flood Hazard Evaluation using a Flood Potential Index. *Water*, 15(20), 3533, https://doi.org/10.3390/w15203533.
- Salonen, A.O., 2021. Externalities. **In**: S. Idowu, R. Schmidpeter, N. Capaldi, L. Zu, M. Del Baldo, R. Abreu, R. eds. 2021. *Encyclopedia of Sustainable Management*. Cham: Springer, pp. 1-4 https://doi.org/10.1007/978-3-030-02006-4_73-1