EDITORIAL PAPER

ADVANCES IN CATCHMENT AND RIVER EROSION AND POLLUTANTS' TRANSPORT STUDIES: FROM MONITORING TO MODELLING TO MANAGEMENT

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ABSTRACT. Catchment erosion, channel erosion and sediment transport are connected processes within fluvial system forming a sediment cascade. Studies related to connectivity between a specific source and its multiple sinks within catchment, and rivers, and their multiple impacts have expanded in scope and sophistication during the last two decades, and were recently broadly presented at numerous international conferences and workshops. The International conference on transboundary catchment erosion and pollution problems was held in Belgrade, Serbia, in July 2023. The outcome of this conference as comprehensive literature review on the topic initiated this review which is aimed at classification the functional scheme of soil erosion, channel processes and sediment transport, and their impacts which include natural hazards, river pollution and hydrogeochemistry, catchment management, and hazards prevention, and technologies. We summarize established and emerging papers related to both regional studies on catchment erosion and management, as well as channel processes modelling and hydrogeochemical impact in streams and rivers. Finally, we discuss future directions and challenges to bridge scientific and management gaps by promoting a holistic understanding of river systems and catchment conditions.

KEYWORDS: sediment transport, river pollution, catchment science

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INTRODUCTION

In a river, sediments and particulate pollutants go through erosion, transport, and deposition by flowing water. Connectivity between a specific source and its multiple sinks in which the output of one process is the input of another is a dominant feature of catchment-river interaction. Various terms have been proposed to this phenomena such as sediment cascade (Burt and Allison 2010) or integrated erosion-deposition processes (Alekseevskiy et al. 2008). A plethora of studies in this area are motivated by various impacts associated with erosion and particulate transport phenomena. The International conference on transboundary catchment erosion and pollution problems was held in Belgrade, Serbia, in July 2023. It was organized by the University of Belgrade, Center of Russian Geographical Society in Serbia, Lomonosov Moscow State University, Geographical Institute "Jovan Cvijić" SASA, University of Banja Luka, and under auspices of World Association of Soil and Water Conservation (WASWAC), and International Association of Hydrological Sciences (IAHS). It encompassed around 50 presentations addressing numerous aspects of hydrological studies in catchments ranging from bed erosion to transboundary river systems' management.

Here, based on the outcomes of this conference, we reveal two major categories of studies according to spatial scale of research (Table 1): catchment erosion and channel processes. For each of the categories we reviewed potential impacts related to the focus of the particular research: natural hazards, hydrogeochemistry and water pollution, catchment management and hazard mitigation, technologies underlined by technologies in erosion, sediment and pollutants transport monitoring and modelling. We assume that catchment and river management is generally complex, such that continual research is needed, ranging from improved sediment and pollutants mobilization models to large-scale river experiments (Rheinheimer and Yarnell 2017). The aim of this paper is to provide classification of the erosion and channel processes studies based on the contribution of the International conference on transboundary catchment erosion and pollution problems with a focus on the different aspects of its contributions.

CATCHMENT EROSION

Quantifying catchment erosion under different conservation practices is crucial for watershed management framework. The reviewed collection of papers includes two chapters in soil erosion problems: Management and hazard mitigation and Technological advances.

Management and hazard mitigation issues are observed by (Kovačević-Majkić et al. 2024) for extreme flood events due to torrential rainfall in three catchments of Morava tributaries in Serbia. The catchments are zoned according to the potential exposure to flood impact without river runoff observation data, only based on satellite images, digital elevation model analysis and slope geomorphology.

Catchment erosion due to delivery of sediment into the rivers system is the main global threat to sustainability of reservoirs (Vörösmarty et al. 2003) which requires catchment management plans. In the paper (Minchev et al. 2024) results of soil erosion calculations using the Gavrilovich method (or EPM) for two contrasting river basins in North Macedonia are presented. One of the river basin, the Globocica River, belongs to the territories with high projective slopes covered with vegetation, while there are several hot spot with high rates of water erosion in the other river basin (Spilje). The obtained calculation data were compared with the results of field evaluation of the total sedimentation in reservoirs located in the lower reaches of each of the basins. In general, the calculation results coincide very well (error of the order of 10%) for the Globocica river basin. However, in the case of the Spilje catchment, where the average annual sedimentation volumes in reservoir are an order of magnitude higher, the calculations based on the EPM model underestimate the volumes of sediment inflow by 30%.

Technological advances in catchment science and soil erosion include development of novel approaches to attempt more methods and perform comparative studies to attain accurate results for assessing soil erosion vulnerability (Pandey et al. 2021). In (Gartsman et al 2024) a new method for parameter calibration of distributed hydrological models in river catchments with a complex structure and a large number of gauges is considered. While the search for a local minimum of the optimization function is a complex multicriterial problem, using the principal component analysis, the most representative gauge or gauges are selected for optimization, and the rest are considered as information noise and removed. A fundamentally new concept for river catchment description, the catchment "compactness", is introduced as a measure of the consistency of water content fluctuations within the river network.

A comparison of the results of calculations of water erosion rates in the basin of the transboundary river Strumica, obtained on the basis of the RUSLE and the regional EPM model is presented in the article by (Trendafilov et al. 2024). The authors come to the conclusion that the accuracy of calculations undertaken with application of the RUSLE is higher than EPM model. Therefore, they recommend using RUSLE approach to assess erosion in this region.

RIVER EROSION AND POLLUTANTS' TRANSPORT

Rivers have been manipulated by humans for millennia, with built structures resulting in significant impacts to water flow, sediment transport, and channel stability (Nittrouer et al. 2012). The driving factors of the ongoing changes in channel processes include climate-related water flow changes and engineering projects which carry the potential for unintended consequences, including endangering human lives and infrastructure, and disrupting the commercial and ecological viability of river channels, floodplains, and deltas.

Erosion processes especially in mountain areas are typically associated with **natural hazards**. Example of these studies is given by (Pavlukevich et al. 2024) with the monitoring and assessment of Bashkara Glacier Lakes system after their outburst on September 1st, 2017. The Bashkara Glacier Lakes are located in the most glaciated and populated part of the Central Caucasus of Russia, in the Mt. Elbrus region. This area has been chosen as a polygon for international research in terms of sediment transport (e.g. (Rets et al. 2019; Tsyplenkov et al. 2020)). Studies highlight necessity to take measures to reduce the level of Bashkara Lake to prevent it from re-outburst.

In (Milanović Pešić et al. 2024) the flow patterns of rivers in Serbia and northern Montenegro are considered, and differences and trends in the current climate conditions are discussed. With no significant trends in precipitation an increase in air temperature has led to flow reduction in both winter and summer months. However, only climatic factors were analyzed as drivers for flow alteration, and not land use change in the catchment.

Technological advances in riverine sediment transport relate both to in *situ* automated measurements of water quality constituents, including both solutes and particulates (Bieroza et al. 2023), as well as novel modelling approaches (Gautier et al. 2021). Some recent examples include extended 1- and 2-dimensional models

Table 1. Classification of the erosion and channel processes impacts presented at the International conference on transboundary catchment erosion and pollution problems (Serbia, Belgrade, 2023)

Impacts	Catchment erosion	Channel processes
Natural hazards	-	Pavlyukevich et al. 2024 Milanović Pešić et al. 2024
Hydrogeochemestry and pollution	-	Lychagin et al. 2024 Korjenić, 2024
Management and hazard mitigation	Kovačević-Majkić et al. 2024 Minchev et al. 2024	Matić, 2024
Technological advances	Trendafilov et al. 2024 Gartsman et al. 2024	Krylenko et al. 2024 Nyiri and Török 2024

of large rivers which enable to provide long-scale temporal estimate the impact of interventions. In (Nyiri and Török, 2024), the upper Hungarian reach of Danube River is analyzed to quantify the impact of structural measures on sediment transport, such as: wing dam fields, water dams, artificial cutoffs. In (Krylenko et al. 2024) a novel approach in hydrodynamic 2D modelling and channel evolution forecasting of the most comprehensive channel patterns types strongly impacted by climate change is discussed on a case study of flow distribution and climate related projections of bed level changes of the Lena river anabranching channel.

These models' outputs are typically used to develop **management plans** for management schemes. In (Matić 2024) the integrated water management plan for the transboundary Tisza River (shared by Ukraine, Slovakia, Hungary, Romania and Serbia) is discussed. Methods for flood risk reduction through ecosystem services are considered, such as flood risk management by incorporating natural retention basins (floodplains, marshes).

Finally, in-channel processes are related to water and constituents' fluxes from the continents to the Ocean and highlights the topic of **hydrogeochemistry and pollutants transport** in riverine studies. In Polar regions snow and ice melting are associated with dramatic changes in the hydrological regime and significantly enhance erosional processes. Such changes are the most important driver of the hydrological cycle of Polar rivers and dominate the fluxes of dissolved and particulate substances from land to the Arctic Ocean. In (Lychagin et al. 2024) the results of long-term observations of metals and metalloids migration in dissolved and suspended forms in the Pur River system located in the oil and gas province in Western Siberia are discussed. The dynamics of element concentration in three groups – dissolved, transitional and suspended – by hydrological seasons are analyzed. This paper significantly enhances existing databanks on Artic Polar geochemistry mostly presented by dissolved modes of pollutants transport (e.g. (Szumińska et al. 2023; Savenko and Savenko 2024)) and underlie studies to estimate background, baseline, and anthropogenic levels of dissolved and suspended metal(loid)s.

Another aspect of pollution problem in relation to channel behavior is migration of radioactive waste disposal (Bonavigo et al. 2009). Due to deposition in channel and floodplain sediment and secondary resuspension, studies of radionuclides fate in rivers is strictly related to sediment transport approaches (Chalov et al. 2017). In the paper by (Korjenić 2024) the potential impacts of the planned construction of radioactive waste disposal in the Croatian reach of the Una River basin is discussed. The smaller part of catchment is located in Croatia, while most of the catchment area is located in Bosnia and Herzegovina. The author has carried out a detailed analysis of the landscape features of the river catchment area and its hydrological regime and has convincingly shown that the placement of this waste disposal can lead to significant pollution of the river valley flowing in Bosnia and Herzegovina.

Studies related to connectivity between catchment erosion, channel erosion and sediment transport and their multiple impacts have expanded in scope and sophistication during the last few decades (Collins et al. 2024). Due to climate and land use change international attention should be focused on improvement of understanding of their impacts on river systems and improving their quantification through monitoring and modeling in order to better manage these issues. Advances in soil erosion and channel processes studies are essential for tackling transboundary catchment erosion and pollution problems (Chapman et al. 2016). Although the papers presented in this special issue of Geography, Environment, Sustainability seems to be very diverse in both processes and territory they analyze, we hope that they will provide excellent starting point for future joint research in this field.

CONCLUSION

This review and thorough analyses of the literature emphasized future need in comprehensive research of sediments and pollutants transport based on catchment-river approach which consider particles which are eroded and transported by flowing water or other transporting media. Existing examples demonstrate increased sediment-related hazards possibility over different regions which require. The latter consider both modelling and monitoring techniques development, in particular related to series of physical and chemical approaches for the characterization of river sediment and contaminants in river flow. This should underlie complementary options for sediment management which include catchment-scale conceptual models and budgets for sediment, basin land management (e.g., reforestation, better agriculture practices, etc.), sediment management through dams, and sediment augmentation below dams. There is a growing need to work internationally in developing a commonly accepted databanks and international protocol for measuring erosion, sediment transport and sedimentation in river systems. ■

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