Research article

Development of Erosion Protection Zones in the Catchment of the Kalimanci Reservoir, North Macedonia

IVAN MINCHEV*
Hans Em Faculty of Forest Sciences, Landscape Architecture and Environmental Engineering, Ss. Cyril and Methodius University in Skopje, Republic of North Macedonia
Email: ivan.minchev@sf.ukim.mk

IVAN BLINKOV
Hans Em Faculty of Forest Sciences, Landscape Architecture and Environmental Engineering, Ss. Cyril and Methodius University in Skopje, Republic of North Macedonia

ALEKSANDAR TRENDAFILOV
Hans Em Faculty of Forest Sciences, Landscape Architecture and Environmental Engineering, Ss. Cyril and Methodius University in Skopje, Republic of North Macedonia

BOZHIN TRENDAFILOV
Hans Em Faculty of Forest Sciences, Landscape Architecture and Environmental Engineering, Ss. Cyril and Methodius University in Skopje, Republic of North Macedonia

Received 26 February 2023 Accepted 20 May 2023 (*Corresponding Author)

Abstract Construction of reservoirs is a priority for ensuring sustainability of water resources. In the Republic of North Macedonia, there are 23 big and over 120 small water reservoirs. On the other hand, erosion and the filling of reservoirs with sediment is one of the main problems in reducing the lifespan of the reservoir. The total annual accumulated sediment in all the reservoirs in the Republic of Macedonia is 3,000,000 m^3 (Erosion map of RM, 1993). The selected study area for the current research is the Kalimanci reservoir in the frames of the catchment of the Bregalnica River, North Macedonia. The main method used to estimate the sediment transport on catchment level is the Erosion Potential Method (EPM; Gavrilovic method), and the validity is assessed on the basis of accumulated sediment in the reservoirs. The EPM method only estimates the total transported sediment at one point. To estimate how the sediment is transported, re-transported, and accumulated in the river bed, a hydraulic sediment transport model (HEC RAS) was used. Then the critical sub-catchments from an erosion point of view are delineated. Most of the critical sub-catchments are situated around the Kalimanci reservoir, while the middle of the catchment experiences erosion of medium severity, and the highest parts of the Bregalnica River are the least critical. The largest part of the sediment transported by the Bregalnica River (nearly 75%) is deposited in the valleys. With the aggregation of the previous steps, the erosion zones of the Kalimanci reservoir were identified.

Keywords erosion, bathymetry, GIS, zoning, erosive sediment material

INTRODUCTION

The soil and the water are two out of three components of the natural environment. Water is a renewable resource, but the soil genesis on the other hand is a long-term process. So, in other words the soil is not a renewable resource (Blinkov et al, 2003). Soil erosion is deemed as the most important, most dangerous, and most spread type of soil degradation and it is the limiting factor of the sustainable use of the land and development of the areas, states, and regions.

The construction of reservoirs is a priority for providing sustainability of the water resources. In the Republic of North Macedonia, there are 23 big and over 120 small water reservoirs. On the other hand, erosion and filling the reservoirs with sediment are one of the main problems in reducing the lifespan of the reservoir. The total annual accumulated sediment in all the reservoirs in the Republic of Macedonia is 3,000,000 m^3 (Erosion map of RM, 1993). It is estimated that worldwide, annually, from 0.5% to 1% of the total storage of reservoirs is lost because of filling up the reservoirs with sediment (White, 2001).

Soil erosion is the main cause of filling up the water reservoirs with sediment. The intensity of the erosive processes in the catchment is the main driver for sedimentation but on the other hand, it is very important where those processes occur. If the erosion hotspots are in the vicinity of the reservoir or on the main waterway it can be assumed that the produced sediment will be mostly transported into the reservoir. In this manner, it is very important to perform zoning of the reservoir catchment to prioritize anti-erosive activities and do appropriate land management.

OBJECTIVE

The main objective of this study was to develop a methodology for erosion protection zones in the catchment of a water reservoir. The case study for the development of this model is the Kalimanci water reservoir.

METHODOLOGY

The study area is situated in the North-East part of North Macedonia, and it is encompassing the middle and the upper catchment of the Bregalnica River. The catchment of the Kalimanci reservoir is taken as a case study (Fig. 1). The area of the catchment of the reservoir is 1,135.3 km^2, and the length of the longest Bregalnica River is 94 km. The dam was built in 1969 and the total reservoir storage was $127x10^6$ m^3.

The catchment of the Kalimanci reservoir mainly consisted of natural-rural elements: forests 46.1%, arable land 19.1% meadows 18.2%, and shrubs 12.7%. The geology consists of granites and granite porphyry 20.3%, marl clay, sands, and gravel 16.6%, and also more than 20% consists of not stable schist formations. The main soil type is cambisol and cambisol with regosol 29% and also ranker 37%. The annual total rainfall in the catchment is from 591 mm, on the lower slopes, to 1114 mm on the highest peaks or the mean value is 748 mm.

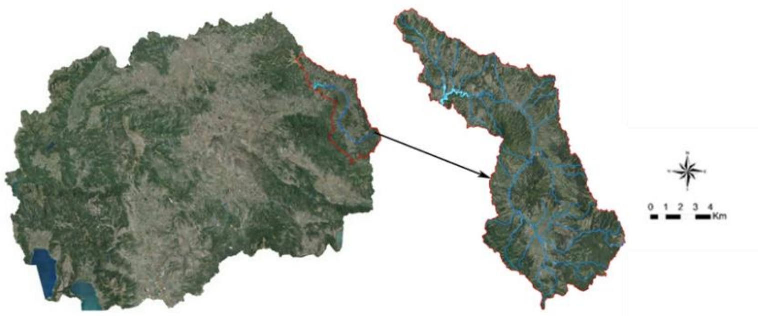

Fig. 1 Study area showing catchment of the Kalimanci reservoir in North Macedonia

The main method used to estimate sediment transport on the catchment level is the Erosion potential method (EPM) developed by Professor Gavrilovic (1972). At the moment, there are several methods used for estimating erosion on-site and on the catchment level. Blinkov and Kostadinov (2010) in their paper stress the good and bad sides of several models for the estimation of erosion: EUROSEM, USLE, PESERA, KINEROS, WEP, WEPP, and EPM. Several of these methods can model erosion from different points of view. Only a few deals with the transport and deposition of the sediment: EUROSEM, WEPP, and EPM. EPM was chosen to be used in the study because it has the unique trait that was developed in the Balkan region, south Serbia, which is very similar in climatic conditions to North Macedonia, secondly, the ability to predict sediment transport and deposition was developed with calibration of deposited sediment in the existing reservoirs and also the data produced about the erosion potential in North Macedonia was developed with the EPM, so the results would be comparable and the methodology would be transferable (Mincev, 2018).

The validity of the model is assessed with the accumulated sediment in the reservoirs. The Kalimanci reservoir was measured for deposed sediment 12 times, between 1969 and 1997. The measuring was done on already established profiles. To estimate the current situation, in 2013, the accumulated sediment was measured directly through bathymetric measurements using eco-sounding equipment on the established transect profiles in the reservoir.

RESULTS AND DISCUSSION

From the measurements can be distinguished two separate periods 1969-1985 and 1985-2013 according to the rate of sedimentation. In the first period, the annual sedimentation of the reservoir is 467,686 m^3/year and in the second the sedimentation decreased to 214,325 m^3/year. The sedimentation in the first period is more than double. According to Mincev (2015), this can be accounted to different factors: climate change, migratory processes, changes in land use and animal husbandry, the effects of implemented erosive measures and works, and consolidation of the sediment. The annual sedimentation of 214,325 m^3/year will be taken as the true sedimentation of the recent period and will be compared with the modeled values of the transported sediment.

The EPM method only estimates the total transported sediment at one point. To estimate how the sediment is transported, re-transported, and accumulated in the river bed, a hydraulic sediment transport model HEC-RAS was used. The hydraulic calculations were done in the HEC-RAS on transect profiles. The output of the software was the total load of transported sediment of the Bregalnica River in the reservoir and zones of sedimentation in the river bed based on cumulative input and output of sediment.

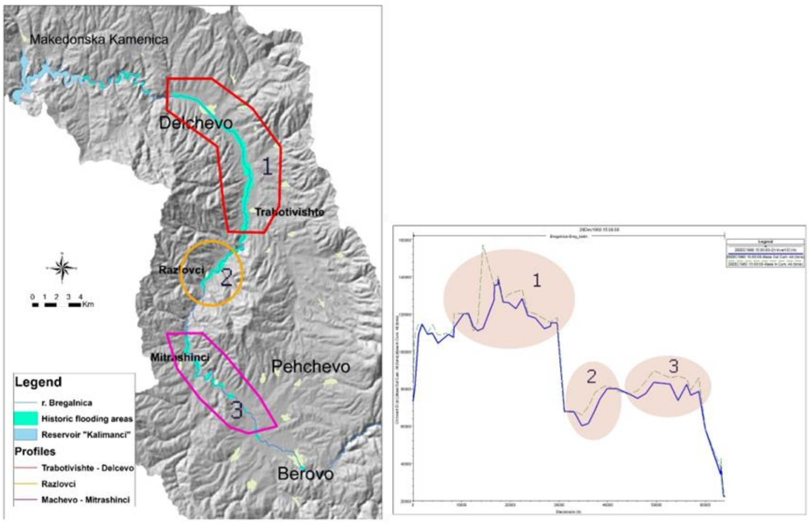

Fig. 2 Zones of sedimentation in the main Bregalnica River, Position of the historic flooding areas (left); sedimentation output of the HEC-RAS software (right)

From the HEC-RAS model, there can be distinguished three general zones of accumulation of sediment (Fig. 2). If the profiles of accumulation are spatially transferred on the map it can be seen that accumulation of the sediment is in the larger valleys: Machevo – Mitrashinci, Razlovci and Trabotivishte - Delchevo. Almost 75% of the input sediment in the Bregalnica River is deposited in the valleys. So, it can be concluded that all of the erosive hot spots upstream of the Bregalnica River are with lower erosion risk because a large portion of the sediment is deposited in the geomorphological expansions, flattened areas, or small valleys along the Bregalnica River. After considering this, there can be distinguished two zones of sedimentation, before and after the geomorphological expansions (Fig. 3). So, in this sense, the first zone is the immediate zone around the reservoir which encompasses catchments that have short transport distances and most of the sediment is deposited in the reservoir. The second zone is before the geomorphological expansions and in this case, 75% of the sediment is left behind and a small amount of the produced sediment is transported in the reservoir.

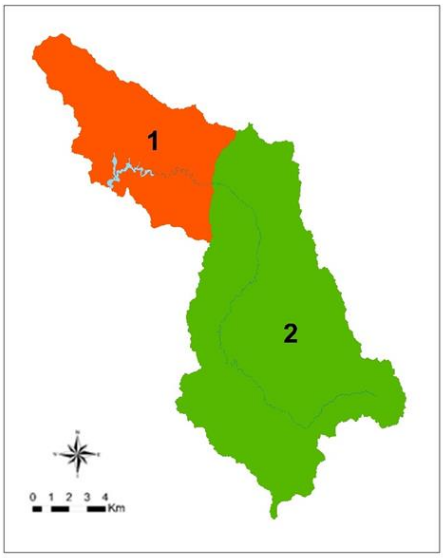

Fig. 3 Zones of sedimentation in the catchment of the Kalimanci reservoir

The EPM model produced quantities of transported sediment on the sub-catchment level in $m^3/km^2/ann$. These quantities were transformed into 4 categories according to the severity of the erosive processes in the sub-catchment (I – High risk > 300 $m^3/km^2/ann$.; II – Medium risk 201-300 $m^3/km^2/ann$.; III – Low risk 71-200 $m^3/km^2/ann$. and Very low risk <70 $m^3/km^2/ann$.) (Fig. 4a).

The next step is a combination of the severity of the erosive processes with the sedimentation zones. The rule imposed here is: if the sub-catchment is in the second sedimentation zone, then the severity of the erosion of the highest class is lowered by one category; if the sub-catchment is in the first sedimentation zone, then the severity of the erosion classes remains the same class (Fig. 4). The final step is defining a buffer zone around the reservoir with a distance of 100 m in which the land management practices are reduced to a minimum.

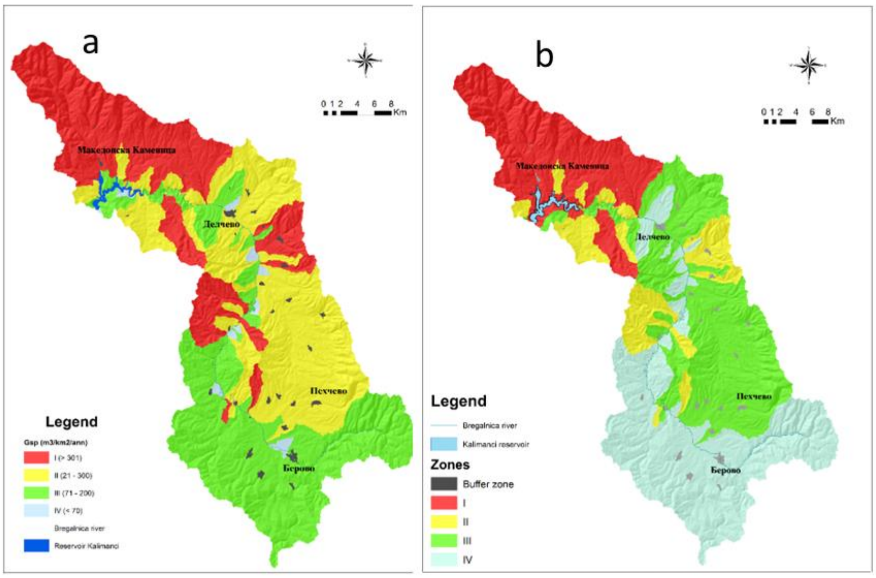

Fig. 4 Erosion severity on sub-catchment level (a), erosion protection zones in the catchment of the Kalimanci reservoir (b)

Figure 4b below shows the proposed zones around the Kalimanci reservoir in terms of erosion, where zone I represents the most critical zone, and accordingly, the catchments in zone IV are the least critical in terms of erosion.

The buffer zone is out of category and in this zone, there should not be any activities that would disturb the natural regime: conservation of agricultural practices, forests with a protective character without any invasive interventions, and construction activities that should be aimed at protecting the land from erosion, without major disturbances of the land.

In Zone I, activities should be aimed at soil conservation and forest practices that promote sustainability. Forestry activities should protect both the quantity and quality of forest resources in the medium and long term by balancing cuts/removals and yields, preferring techniques that minimize direct or indirect damage to forests, soil, and water resources. Appropriate practices should be undertaken to increase the increment in the direction of economic, environmental, and social benefits. It should also be considered the conversion of abandoned agricultural land into forest land if it contributes to the acquisition of economic, ecological, social, and cultural values.

CONCLUSION

The main motive for the preparation of this paper was to prepare a methodology for zoning the reservoirs in terms of erosion. There are examples of making such zones, but they are based on expert judgment. The goal, in this case, was to make an exact and applicable procedure, which will be reproducible on another case study and further the obtained results will be comparable.

The development of the methodology for the zoning of the reservoir catchment in terms of erosion should be understood as a basis for future considerations on the approach to its improvement. The research was done with an empirical model using measured bathymetric measurements of the reservoirs, to confirm the reliability of the results. The methodology is aligned to be able to use standardized spatial databases, which with standard reclassification fit easily into the model. From previous research, EPM methodology has been implemented in part because existing databases are taken as a finished product and directly reclassified, without any corrections.

The zoning of the reservoir catchment is a prerequisite for integrated catchment management. The approach of forming zones in the catchment areas of the reservoirs with spatial (GIS) support and cartographic display will facilitate the work of future spatial planners from several areas: urbanism, forestry, agriculture, pasture management, etc.

REFERENCES

Blinkov, I., Trendafilov, A. and Kaevski, I. 2003. The role of the forests on the water and sediment discharge. Research project, Ss. Cyril and Methodius University in Skopje, Forestry Faculty Skopje, Macedonia.

Blinkov, I. and Kostadinov, S. 2010. Applicability of various erosion risk assessment methods for engineering purposes. BALWOIS Conference 2010, Ohrid, Macedonia.

Gavrilovic, S. 1972. Engineering of torrents and erosion. Izgradnja, Special Issue, Belgrade, Yugoslavia.

Institute for Water Development. 1993. Erosion map of the Republic of Macedonia. Institute for Water Development of Republic of Macedonia.

Mincev, I. 2015. Development of methodology for determination of protection zones around water reservoirs from aspect of soil erosion and sediment transport. Doctoral Thesis, UKIM Forestry Faculty in Skopje, North Macedonia.

Mincev, I. 2018. Measuring v.s modeling sediment discharge, Case study: Kalimanci reservoir, Macedonia. Soil and Water Resources Protection in the Changing Environment, 88-100, Zlatic, M. and Kostadinov, S. (Eds.), Schweizerbart Science Publishers, Advances in Geoecology, Vol. 45, ISBN 978-3-510-65418-5.

White, W.R. 2001. Evacuation of sediments from reservoirs. Thomas Telford, London, UK.