INNSPUB

Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 25, No. 1, p. 176-183, 2024
http://www.innspub.net

RESEARCH PAPER OPEN ACCESS

Rapid geomorphic assessment of the Musimusi River in Balingasag Misamis oriental Philippines

Jr. Sansen A. Handag*[1], Frandel Louis S. Dagoc[2], Wella T. Tatil[2], Peter D. Suson[2], Jr. Ruben F. Amparado[2]

[1]*Department of Environmental Science and Technology, College of Science and Mathematics, University of Science and Technology of Southern Philippines, Cagayan de Oro City, Philippines*

[2]*Department of Biological Sciences, College of Science and Mathematics, Mindanao State University, Iligan Institute of Technology, Iligan City, Philippines*

Article published on July 13, 2024

Key words: Channel stability index, Rapid geomorphic assessment, Stream reach

Abstract

The study was conducted to identify locations of streambank instability to prioritize restoration needs and slow sedimentation rates on the Musimusi River. Relying on rapid geomorphic assessments (RGAs) has been a common practice for determining the priority of stream reaches. In this study, an established RGA called the channel stability index (CSI) was utilized to evaluate multiple sections of the Musimusi and Camuayan rivers. Four (4) stream reaches got a CSI score higher than 20, considered "highly unstable." These are the streams that reach 6, 10, 11, and 12. The CSI scores for at least one reach at all the sites fell within the higher range of the "moderately stable" classification, as indicated by the fact that the rest had CSI scores ranging from 10 to 20, which is considered "moderately unstable." This indicates that the four highly unstable reaches are in a state of degradation, evident by the lowering of the channel bed and consequent increase of bank heights, incision without widening, and bank toe material removed, causing an increase in bank angle while those moderately unstable reaches in the Musimusi River. Its main tributary- the Camuayan River, is in a state of aggradation and widening, evidenced by the lowering of the river bed due to deposition and shifting of the channel banks

***Corresponding Author:** Jr. Sansen A. Handag ✉ sansen.handagjr@ustp.edu.ph

Introduction

Soil erosion is defined as the natural phenomenon in which the removal and transportation of soil material occur mainly through the action of erosive agents such as water, wind, gravity, and human disturbances (Bhandari *et al.,* 2021.) in a riverbank environment erosion of river banks results in alterations to the shape and size of the river and is a necessary process that moves floodplain sediment to contribute to the overall sediment supply of the basin (Allmanová *et al.,* 2021). Sediment is one of the leading causes of water impairment. Identifying areas susceptible to streambank erosion within stream and river networks is essential in understanding the source of instream sediment (Jiang *et al.,* 2020).

Current stability conditions within a river basin can be examined using diagnostic criteria of contemporary geomorphic processes. These are called rapid geomorphic assessments (RGAs), and they use diagnostic criteria of channel form to infer dominant channel processes and the magnitude of channel instabilities through a series of questions. The channel stability index (CSI) is one of the RGAs that is most frequently utilized. Through geomorphic assessment, the rivers and streams comprising a watershed drainage network can be broken into distinctive reaches and similar reach types grouped (Papangelakis *et al.,* 2023). Rapid geomorphic assessments (RGAs) provide a quick method for characterizing stream reaches, defined as lengths or segments of a stream with similar streambank characteristics in terms of bank height and stratigraphy and their degree of stability (Miller *et al.*, 2021). The leading cause of the streambank failures observed in small agricultural catchments is the undercutting of bank toe and resulting steepening of the slope, while the triggers are either hydrological factors (snow melt, intensive/prolonged rainfall) or human activity (using heavy machinery close to the edge of streambanks) (Sidle *et al.*, 2023). Numerous research studies have demonstrated the significant contribution of streambank erosion to total sediment loading (Hughes *et al.*, 2022). Therefore, this study aims to assess and identify locations of streambank instability to prioritize restoration needs and slow sedimentation rates on the Musimusi River.

Materials and methods

Study area

Musimusi Watershed is situated in the municipality of Balingasag, Misamis Oriental. It is geographically located approximately between 8°41" to 8°48" north latitudes and 124°45" to 124°54" east longitude, as shown in Fig. 1.

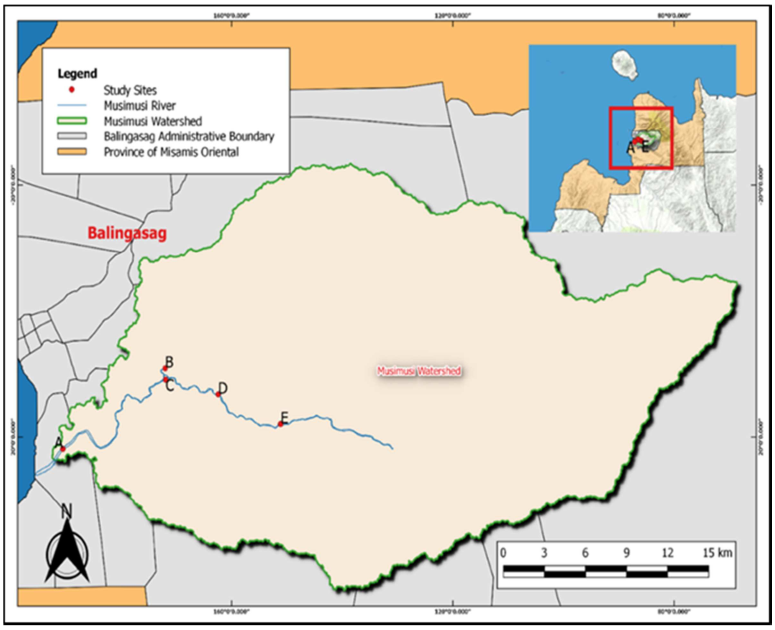

Fig. 1. Location map showing the study area in the Municipality of Balingasag, Misamis Oriental, Philippines

The river basin has an approximate area of 7,772 ha. It covers 16 barangay local government units, 15 of which belong to the Municipality of Balingasag and one barangay to the Municipality of Claveria. The majority (77%) of the watershed falls within Balingasag, and the rest (23%) is under the Municipality of Claveria. The river comprises 29 streams with a total stream length of 71.50 kilometers and a drainage density of 0.0020941 meters. Two of the most noticeable streams in the basin are the Musimusi River and Camuayan River; due to its diverse landscape, the topography of Balingasag varies from flat near the coast to very steep towards the deep gully of Mt. Balatukan, being an active volcano.

Flooding is a common occurrence in Balingasag. The town is built over an alluvial fan formed by the deposition of sediments carried by the Balatukan River from Mt. Balutakan. Heavy precipitation over the volcano often causes the swelling of the river and the inundation of many areas in the alluvial fan.

Rapid geomorphic assessment

The research centered on the CSI protocol for quickly identifying unstable sections within a stream network. It is a scheme that assesses nine unique criteria for recording observations of field conditions during RGAs. Each criterion was ranked from zero to four, and all values were summed to provide an index of relative channel stability (Sulaiman *et al.*, 2021). The study of Nandi *et al.* (2023) has categorized stream reach stability as follows: stability is classified as ≤10, moderately unstable falls between 10 and 20, and highly unstable is classified as ≥20. Through geomorphic assessment, the rivers and streams comprising a watershed drainage network can be broken into distinctive reaches and similar reach types grouped together (Rabanaque *et al.*, 2022). To conduct a CSI assessment, you need to measure the height of the riverbank, the length of the riverbank face, the river's stage during baseflow, the degree of constriction, and the average diameter of sediment in the streambed (Crespo-Azorín, 2021). The field measurements are shown in Fig. 2.

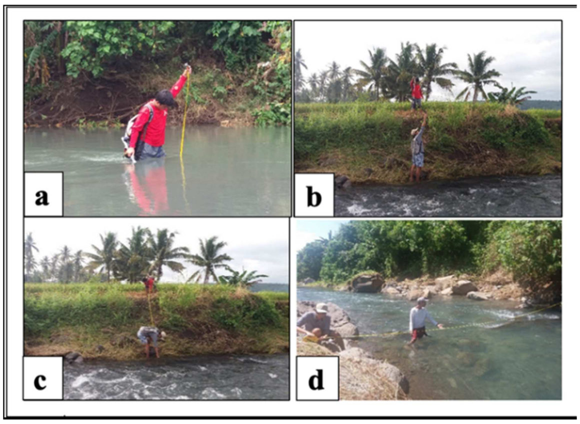

Fig. 2. Field Measurements on the study area; a) river stage at base flow b) bank height c) bank face length and d) channel wid

A representative river stage was measured along the thalweg, defined as the line outlining the lowest points along the length of a river bed or valley of the stream. Measurement was done by placing a steel ruler on the streambed and recording the water surface height. Care was taken to avoid local scour pools. The river channel width at the cross-section and approximately one-quarter of a meander length upstream was measured at the bank's total height.

The degree of constriction is the relative decrease in channel width from upstream to downstream. To estimate the average diameter of streambed sediment (gravel, boulder/cobble, or bedrock), the grain size of the average particle from a sample of bed material was measured in the field using a metric ruler during the Wolman Pebble Count Method (Galia *et al.,* 2017). Occasionally, the difference between gravel and boulder/cobble was split if the streambed particle size distribution contained a large portion of both gravel and cobbles. Bed protection measured the risk of bed scour or incision.

The stream received a score of 0 if it had bed protection (e.g., bedrock or armoring). A score of 1 was assigned if the stream lacked bed protection. An extra 2 points were added if one bank had protection, and an additional 3 points were added if both banks had protection. A stream lacking bed or bank protection received a score of 1 point, whereas a stream with both banks protected but no bed protection received a score of 4 points. The bank received a higher protection score than the bed, as the energy not dissipated at the bank was transferred to the bed (Mondal and Patel, 2022).

The amount of cutting into the land was determined by comparing the water depth at baseflow (*D*) and the height of the riverbank (*BH*). This was expressed as the ratio of the baseflow elevation to the floodplain elevation, that is, $D/(BH + D)$. Channels with significant cutting (low ratio) were given a high score, while channels with minimal cutting (high ratio) received a low score. Both sides of the river were inspected for signs of erosion and landslides: no erosion was given a score of 0, fluvial erosion a score of 1, mass wasting a score of 2, and both mass wasting and fluvial erosion a score of 3.

The scores for the left and right banks were combined to create a total score of up to 6 points. Signs of mass wasting include slumping banks, topsoil that has fallen at the base of the bank, and rough edges at the top of the banks. Both banks may exhibit one or more erosion types in straight sections, with mass wasting being the most prevalent on the critical banks. The percentage of banks that experienced mass wasting was estimated based on a percentage of total reach length. Each bank's percentage of reinforcement by riparian vegetation was calculated, and the resulting scores for the two banks were combined.

Woody vegetation with the canopy extending over the bank's edge was viewed as providing support. Woody vegetation not extending to the streambank was not deemed to offer support. It was generally believed that the extent of roots was roughly the same as the canopy crown. Therefore, even if the roots were not visible, a canopy over the stream was assumed to offer some geotechnical support against potential failure planes.

The estimated percentage of banks experiencing accretion (deposition) was based on the proportion of reach length showing signs of accretion, such as gravel or small sediment bars near the banks and point bars. It is important to note that when assessing the outer bends, the inner bend is typically a point bar and is considered depositional. The reach was then given a stage in the channel evolution model using the six-stage model illustrated in Fig. 3. According to Crespo-Azorín (2021), each stage was assigned a distinct point value. The state of the riparian vegetation, erosion, and deposition determined the stage.

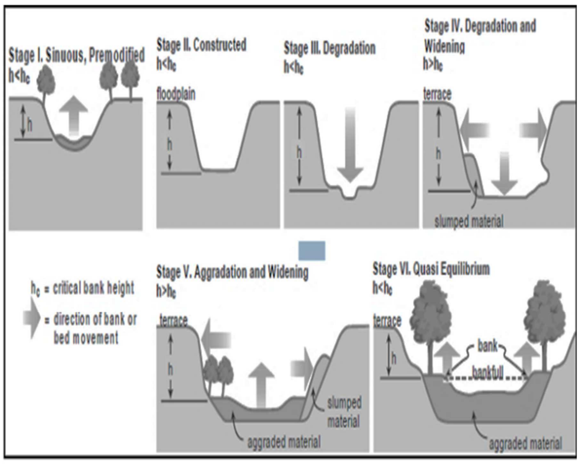

Fig. 3. Six stages of channel evolution from Simon and Hupp (1986) and Simon (1989b) identifying Stages I and VI as 'reference' channel conditions

Results and discussion

The streambank condition of Musimusi river

One key study component was to rank potential reaches for streambank stabilization in the Musimusi River. Consequently, the RGA scores were utilized to categorize the banks' stability in each specified section, using RGA scores as depicted in Fig. 4. A total of five sites with twenty-three (23) stream reaches were studied in the study area. These sites (Fig. 1) are marked with letter identifiers, and stream reaches (Fig. 4) are marked with numbered identifiers.

Fourteen (14) of these reaches are in the Camuayan River, one (1) is in the Biasong Stream, and eight (8) in the Musimusi River. Four (4) stream reaches got a CSI score higher than 20, considered "highly unstable." These are the streams that reach 6, 10, 11, and 12, with the former 3 having a CSI score of 22 and the latter having a CSI score of 21, as shown in Table 1. The CSI scores for at least one reach at all the sites were on the higher side of the "moderately stable" category, indicated by the remaining with CSI scores between 10-20, which is deemed "moderately unstable".

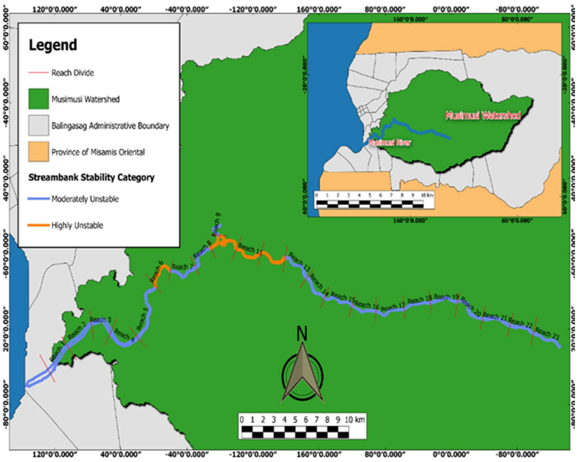

Fig. 4. The stability category of the stream reaches the Musimusi River

Table 1. Identified stream reaches along with its Channel Stability Index scores and category in the Musimusi River

Sites	Reach	Reach Length (m)	CSI Score	CSI Category
Musimusi River				
Site A	1	440	12.5	Moderately unstable
	2	440	15.5	Moderately unstable
	3	440	18.5	Moderately unstable
	4	440	18	Moderately unstable
	5	440	16.5	Moderately unstable
	6	440	22	Highly unstable
	7	440	16.5	Moderately unstable
	8	440	18.5	Moderately unstable
Biasong Stream				
Site B	9	240	12	Moderately unstable
Camuayan River				
Site C	10	440	22	Highly unstable
	11	440	22	Highly unstable
	12	440	21	Highly unstable
Site D	13	440	18	Moderately unstable
	14	440	15	Moderately unstable
	15	440	15.5	Moderately unstable
	16	440	18	Moderately unstable
Site E	17	440	16.5	Moderately unstable
	18	440	14	Moderately unstable
	19	440	12.5	Moderately unstable
	20	440	12.5	Moderately unstable
	21	440	14	Moderately unstable
	22	440	13.5	Moderately unstable
	23	440	14.5	Moderately unstable

Channel instability of reaches 6, 10, 11, and 12 was evident during the RGA assessment due to their higher width/depth ratios, steeper slopes due to decreased sinuosity, and excessive bar deposition, which in turn increases stress in the near-bank region. An increase in channel slope, discharge, or decrease in sediment supply has tipped the scale toward degradation. The channel cross-section is deepening due to excess scouring. The channel has disconnected from the floodplain. Bank erosion and cutting are excessive along the inside and outside bends, and bank angles are starting to steepen. When this happens, a stream can be less competent to move its sediment and, thus, aggraded. The unstable sites are located throughout the mainstem, which indicates active channel processes occurring throughout the Upper and Middle Musimusi River and not just in isolated areas. These active channel processes include deepening the channel bed and widening the channel; this was evident in the unstable sites (Eaton *et al.*, 2020).

The downstream of the study area (reaches 1 to 5) mainly has silt and clay bed material, while reaches 6, 10, 11, and 12 are mainly composed of gravel and sand. On the way upstream, the foremost bed material is boulder or cobble. It was also observed that the accumulation of large amounts of silt had raised the streambed downstream of the Musimusi River. A shallower channel cannot accommodate significant and rapid stormwater runoff and may produce flooding in the study area.

Reach 6, 10, 11, and 12 are mainly gravel and sand. Cohesionless sand formation is the most dominant in the streambanks, so streambank erosion occurs with lower stream discharge due to lower bed shear stress for sediment transport (Duru, 2017). Over the last few years, deep pools, stable stream banks, and narrow stream channels slowly changed to shallow, wide, and eroding streams in these reaches. Sandy beds depend on vegetation to stabilize their banks. On the way upstream, the foremost bed material is boulder or cobble. A rubble (boulder, cobble) stream bottom is found in rugged high-gradient streams, primarily in the upstream part of the study area. These are generally inundated permanently. The bottom may consist of cobbles or small to massive boulders. The rock in these stream bottoms is often accumulated to considerable depths. Most stream reaches have no bed or bank protection except for some small stretches in reach 5 and 7 composed of bedrock banks.

Incision and constriction vary among the 23 reaches from upstream to downstream. Mass wasting flu, vial, and erosion are also prominent, particularly in the midstream of the river. When the sediment enters the river, part of it is carried downstream by the current, and the remaining part deposits at the foot of the bank. In contrast, the deposited sediment, under the action of water flowing, is further activated and then transformed into bed load and suspended load, which is transported downstream within the water (Shu *et al*., 2019). There are numerous catchments worldwide where surface and riverbank contributions are greater than 25% and 90%, respectively (Abbas *et al*., 2023). However, the contribution from surface sources tended to occur in the 75–97% range, and the contribution from riverbanks alone tended to fall in the range of 3–25%, suggesting that these may be considered general values (Abbass *et al*., 2023). The majority of the 23 reaches are already in the stage of aggradation, especially in the upstream and midstream of the river. Conversely, the downstream part of the river reaches 1 to 5 and is in the restabilization stage. This is evident with the reduction in bank heights, aggradation of the channel bed, and the deposition on the upper bank, therefore visibly buried vegetation and floodplain terraces in these reaches.

Conclusion

This study was conducted to identify locations of streambank instability to prioritize restoration needs and slow sedimentation rates on the Musimusi River. Four (4) stream reaches got a CSI score higher than 20, considered "highly unstable." These streams reach 6, 10, 11, and 12. The CSI scores for at least one reach at all the sites were classified as "moderately stable," as indicated by CSI scores falling between 10-20, which is considered "moderately unstable." This indicates that the four highly unstable reaches are in a state of degradation, evident by the lowering of the channel bed and consequent increase of bank heights, incision without widening, and bank toe material removed, causing an increase in bank angle. In contrast, those moderately unstable reaches in the Musimusi River. Its main tributary- the Camuayan River, is in a state of aggradation and widening, evidenced by the lowering of the river bed due to deposition and shifting of the channel banks.

Recommendation(s)

It is essential to observe that the metrics of CSI carried the same significance or span of values compared to each other. Although there is flexibility in the range of each metric corresponding to a specific score, the worst (and best) case is valued equally across all categories. As mentioned earlier, lower scores are meant to indicate more excellent stability. For this method to work effectively, at least one of two conditions must be satisfied: (1) each metric must contribute equally to stability, or (2) the RGA must be applied in regions where the sources of instability from one section to another are similar. It is reasonable to acknowledge that the first condition cannot be universally true. Therefore, the second statement must be correct, and it can be confirmed. As a result, RGA scores from various regions may be different. This study needs further validation to triangulate the data and prevent bias.

References

Abbas G, Jomaa S, Bronstert A, Rode M. 2023. Downstream changes in riverbank sediment sources and the effect of catchment size. Journal of Hydrology: Regional Studies **46,** 101340. https://doi.org/10.1016/j.ejrh.2023.101340

Abbass ZD, Maatooq JS, Al-Mukhtar MM. 2023. Monitoring and Modelling Morphological Changes in Rivers Using RS and GIS Techniques. Civil Engineering Journal **9(3),** 531–543. https://doi.org/10.28991/CEJ-2023-09-03-03

Allmanová Z, Vlčková M, Jankovský M, Allman M, Merganič J. 2021. How can stream bank erosion be predicted on small water courses? Verification of BANCS model on the Kubrica watershed. International Journal of Sediment Research **36(3),** 419–429. https://doi.org/10.1016/J.IJSRC.2020.10.008

Bhandari D, Joshi R, Regmi RR, Awasthi N. 2021. Assessment of soil erosion and its impact on agricultural productivity by using the RMMF model and local perception: A case study of Rangun Watershed of Mid-Hills, Nepal. Applied and Environmental Soil Science **2021,** 1–10. https://doi.org/10.1155/2021/5747138

Crespo-Azorín Martínez C. 2021. Evaluación de la estabilidad del cauce y diseño de la restauración ecológica del río Baron Fork, Condado de Adair, Oklahoma (EE. UU.). https://riunet.upv.es:443/handle/10251/173297

Duru U. 2017. The role of human activities in streambank stability: Lower Sakarya River (NW Turkey). Journal of Geosciences and Geomatics **5(3),** 130–135. https://doi.org/10.12691/jgg-5-3-4

Eaton BC, MacKenzie LG, Booker WH. 2020. Channel stability in steep gravel–cobble streams is controlled by the coarse tail of the bed material distribution. Earth Surface Processes and Landforms **45(14),** 3639–3652. https://doi.org/10.1002/esp.4994

Galia T, Škarpich V, Gajdošová K, Krpec P. 2017. Variability of Wolman pebble samples in gravel/cobble bed streams. Acta Scientiarum Polonorum Formatio Circumiectus **1,** 237–246. https://doi.org/10.15576/ASP.FC/2017.16.1.237

Graziano MP, Deguire AK, Surasinghe TD. 2022a. Riparian buffers as a critical landscape feature: Insights for riverscape conservation and policy renovations. Diversity **14(3),** 172. https://doi.org/10.3390/d14030172

Hughes AO, Huirama MK, Owens PN, Petticrew EL. 2022. Stream bank erosion as a source of sediment within New Zealand catchments. New Zealand Journal of Marine and Freshwater Research **56(4),** 632–655. https://doi.org/10.1080/00288330.2021.1929352

Jiang G, Lutgen A, Mattern K, Sienkiewicz N, Kan J, Inamdar S. 2020. Streambank legacy sediment contributions to suspended sediment-bound nutrient yields from a Mid-Atlantic, Piedmont watershed. JAWRA Journal of the American Water Resources Association **56(5),** 820–841. https://doi.org/10.1111/1752-1688.12855

Knehtl M, Podgornik S, Urbanič G. 2021a. Scale-depended effects of hydromorphology and riparian land-use on benthic invertebrates and fish: implications for large river management. Hydrobiologia **848(15),** 3447–3467. https://doi.org/10.1007/s10750-021-04589-8

Miller JR, Grow D, Philyaw LS. 2021. Influence of historical land-use change on contemporary channel processes, form, and restoration. Geosciences **11(10),** 423. https://doi.org/10.3390/geosciences11100423

Mondal S, Patel PP. 2022. Mapping, measuring and modelling common fluvial hazards in riparian zones: a brief review of relevant concepts and methods. In: Ghazavi R, Norouzi B, Malekian A (eds). Mapping, Measuring and Modelling Common Fluvial Hazards in Riparian Zones: A Brief Review of Relevant Concepts and Methods. 1st ed. 353-389. https://doi.org/10.1007/978-3-030-75197-5_16

Nandi KK, Pradhan C, Dutta S, Khatua KK. 2023. Identifying the stability trajectory of a large braided Brahmaputra river using reach-scale process-based approach. Journal of Hydrology **626,** 130329. https://doi.org/10.1016/J.JHYDROL.2023.130329

Nóbrega RLB, Ziembowicz T, Torres GN, Guzha AC, Amorim RSS, Cardoso D, Johnson MS, Santos TG, Couto E, Gerold G. 2020. Ecosystem services of a functionally diverse riparian zone in the Amazon–Cerrado agricultural frontier. Global Ecology and Conservation **21,** e00819. https://doi.org/10.1016/J.GECCO.2019.E00819

Papangelakis E, Hassan MA, Luzi D, Burge LM, Peirce S. 2023. Measuring geomorphology in river assessment procedures 1: a global overview of current practices. JAWRA Journal of the American Water Resources Association **59(6),** 1342–1359. https://doi.org/10.1111/1752-1688.13146

Rabanaque MP, Martínez-Fernández V, Calle M, Benito G. 2022. Basin-wide hydromorphological analysis of ephemeral streams using machine learning algorithms. Earth Surface Processes and Landforms **47(1),** 328–344. https://doi.org/10.1002/esp.5250

Shu A, Duan G, Rubinato M, Tian L, Wang M, Wang S. 2019. An experimental study on mechanisms for sediment transformation due to riverbank collapse. Water, **11(3),** 529. https://doi.org/10.3390/w11030529

Sidle RC, Caiserman A, Jarihani B, Khojazoda Z, Kiesel J, Kulikov M, Qadamov A. 2023. Sediment sources, erosion processes, and interactions with climate dynamics in the Vakhsh River Basin, Tajikistan. Water **16(1),** 122. https://doi.org/10.3390/w16010122

Sulaiman MS, Goh QY, Sang YF, Sivakumar B, Ali A, Rasit N, Abood MM. 2021. Development of river morphologic stability index (RMSI) to assess mountain river systems. Journal of Hydrology: Regional Studies **37,** 100918. https://doi.org/10.1016/J.EJRH.2021.100918