RP Materials: Proceedings (e-ISSN: 2583-8342)
Vol. 5, Part 1 (2026) pp. 36–38

Cite this article: S. Mukherjee, Streambank erosion and sustainable protective materials: An integrated technical review, *RP Materials: Proceedings* Vol. 5, Part 1 (2026) pp. 36–38.

**Mini Review Article**

# Streambank erosion and sustainable protective materials: An integrated technical review

**Dr. Sanchayan Mukherjee**

Associate Professor, Department of Mechanical Engineering, Cooch Behar Government Engineering College, Vill-Harinchowrah, P.O-Ghughumari, Dist-Cooch Behar, West Bengal, PIN-736170, India
*Corresponding author, E-mail: sanchayan.mukherjee@kgec.edu.in

****Selection and Peer-Review under responsibility of the Scientific Committee of the 4th International Conference on Recent Trends in Materials Science & Devices 2026 (ICRTMD 2026) held at JVMGRR College, Charkhi Dadri, Haryana, India during 6–8 April 2026.**

**ARTICLE HISTORY**
Received: 08 April 2026
Revised: 27 May 2026
Accepted: 27 May 2026
Published online: 12 June 2026

**KEYWORDS**
Streambank erosion; Sustainable protection; Bioengineering; Geosynthetics; hydraulic forces; Soil stabilization.

**ABSTRACT**

Streambank erosion is a dynamic geomorphological process driven by hydraulic forces, sediment characteristics, and environmental conditions. It poses a significant threat to agricultural land, infrastructure, water quality, and ecosystem functions globally. Traditional hard-engineering remedies such as concrete revetments and gabions have provided localized protection but often fail to support ecological integrity or long-term sustainability. This paper reviews the mechanisms of streambank erosion and evaluates a range of sustainable protective materials and methods, including bioengineering, geosynthetics, and hybrid systems. Emphasis is placed on understanding the interactions between flow hydraulics, soil properties, and reinforcement materials to optimize design and performance. It is argued that environmentally compatible materials such as vegetative geogrids, coir fiber revetments, and live fascines can reduce sediment loss while enhancing habitat quality when integrated with adaptive design approaches. The paper concludes with recommendations for future research to advance streambank protection strategies that balance engineering effectiveness with ecological sustainability.

## 1. Introduction

Streambank erosion is the gradual entrainment of soil from banks owing to high flow shear stress, pore water pressure changes, and the hydrostatic force on to the bank. This may be a matter of great concern when entrainment surpasses deposition, resulting in loss of agricultural land, vulnerability of infrastructure, increased turbidity, and degradation of aquatic flora and fauna. The mechanism of bank erosion arises out of the interaction of hydraulic forces during water level fluctuations, soil matrix and cohesive force, vegetation effect, and anthropogenic activities including land use pattern and channelization.

Even without the presence of extreme precipitation due to climate change can have a telling effect on the flow dynamics, resulting in higher erosive forces at the bank–water interface. Therefore, the need of the hour is to devise protective strategies, which are environmentally sustainable apart from being mechanically viable and cost effective.

Darby and Thorne (1996) proposeded an approach to estimate the longitudinal extent of mass failures by applying mixed layer theory [1]. Rinaldi and Casagli (1999) studied partially saturated soils formed bank stability and adverse pore water pressure impacts on the Sieve River, Italy [2]. Duan (2005) in her analytical model amply demonstrated the combined effect of the suspended weight of the particle, the force of cohesion, and the lift force acting on a grain [3]. Soulie et al. (2006) suggested a relation between the inter-particle forces and the irregular radii of the particles' geometric characteristics [4]. "Truncated Pyramid Model" for the orientation towards the stability of particles was proposed by Mukherjee and Mazumdar (2010). They have analyzed the impact of the inter-grain separation length on the erosion along a bank of river under the action of cohesive force. They have shown that the escape velocity is a function of separation distance between sediment particles for coarse sand [5]. Mukherjee (2011) applied "Truncated Pyramid Model" to find particle escape velocity for different sizes of the particle under different volume of liquid-bridge entrapped between the particles [6]. Geosynthetic materials have established themselves as solutions to streambank stabilization by strengthening the soil matrix, filtration, and offering considerable erosion resistance under variable hydraulic loads as elaborated by Koerner (2012) [7]. Their work on the streambank protection system has shown significant improvements in structural stability and longevity, especially when mixed up with natural materials in environment-friendly designs as proposed by Bhatia and Smith (2014) [8]. Biswas et al. (2024) devised a new approach to transform micro analysis into macro analysis of forces to study the chronology of the journey from erosion to failure [9].

## 2. Mechanism of streambank erosion

### 2.1 Hydraulic forces

Stream velocity and water level variations give rise to shear stress on the streambank surface. When the working shear stress surpasses the critical shear strength of bank materials and the rate of deposition, net detachment and entrainment of soil grains occur. The value of this shear stress is a function of channel gradient, volume flow rate, and roughness agents such as vegetation and channel bed characteristics.

### 2.2 Soil properties and cohesion

Resistance to erosion is governed by particle size distribution, cohesion, pore water pressure, gravity force, purity of water and organic content. Fine-grained cohesive soils exhibit higher apparent cohesion due to electrochemical forces and capillary action, whereas coarse sands and gravels are frictional by nature. Changes in soil-water bridge volume, pore pressure (and seepage force), inter-grain distance can significantly alter bank stability.

### 2.3 Vegetation factor

Vegetation may increase bank stability through tensile strength of the roots as well as favourable pore pressure. They bind soil particles, prove the necessary tensile strength, and dissipate flow energy, reducing entrainment rates. The selection of appropriate plant species (like mangroves) is extremely critical for a successful bioengineering venture.

## 3. Protective materials and methods

### 3.1 Traditional engineering practices

Traditional methods, e.g., concrete walls, riprap and gabion baskets were aimed at providing structural resistance. Though effective for short-term bank protection, these methods often manipulate the natural course of the river, decrease the habitat complexity, and transfer the net erosion energy downstream.

### 3.2 Geosynthetics and hybrid systems

Geosynthetics are certain materials used to improve soil performance. They are generally classified into synthetic materials like polyester (PET) and natural fibers like jute..They are permeable fabrics facilitating separation and reinforcement by allowing water passage. Jute mats are biodegradable materials that protect the bank soil and provide support to vegetation growth. A synergy of jute and vegetation leads to both structural and ecological advantages.

## 4. Design considerations

### 4.1 Site assessment and testing

Effective bank protection starts with a rigorous site assessment, including streambank geometry, soil characteristics, hydrological data, and existing vegetation. A careful study and planning with understanding of the erosion and failure mechanism leads to appropriate protective materials.

### 4.2 Materials – selection and reliability

Material selection is a function of riverbank erosion mechanics, the flow characteristics, the climatic influence, the vegetation presence and the overall cost to incur. Biodegradable materials offer efficient short-term reinforcement while promoting vegetative growth, whereas reliable geosynthetics provide structural rigidity during target or mission time.

### 4.3 Integration with ecological objective

Sustainable bank protection has to improve habitat diversity, including bio-diversity, rectify water quality, and maintain connectivity with floodplain processes. Careful designs aiming at preservation or restoration of native vegetation and soil function yield larger and wider environmental benefits.

## 5. Applications

Numerous watershed projects throughout the globe have adequately established the effectiveness of sustainable protective materials. Projects using jute and vegetation in West Bengal have shown reduced bank erosion and improved aquatic life within years. For example, in Nayachar island, West Bengal, jute of 850 GSM ($g/m^2$) has been used, yielding satisfactory results. In rivers subject to flow level fluctuations, geocell installations with vegetative seeding have led to mechanical stability and ecological recovery in the long run. There are ample examples to prove that integrated bioengineering techniques can outperform traditional hard structures in terms of lifecycle cost and ecological benefits.

## 6. Conclusions

Streambank erosion being a complex phenomenon requires solutions that optimize between mechanical efficiency with environmental sustainability. Sustainable protective materials, especially when combined with bioengineering and customized design, may come out with outstanding outcomes vis-a-vis traditional engineering practices. By strengthening the soil, improving vegetation cover, and not disturbing natural riverine processes, these protections lead to long-term bank stability retaining the natural environment. Future work may include meticulous field study, material innovation, and multi-disciplinary participation that combine engineering goals with ecological sustenance.

Latest research concentrates on enhancing the appropriate failure analysis and efficiency of sustainable materials. Smart geosynthetics may incorporate sensors to monitor strain, water content, and soil degradation with time. Adaptive management practices use iterative methods to accommodate protective measures depending on actual performance. Here, life-cycle cost and performance assessment is now being used to quantify environmental costs from production to degradation and to provide effective sustainable material selection. Combination of remote sensing and hydrodynamic modeling may further refine design characteristics and optimize material selection.

## Authors’ contributions

The author reviewed and approved the final version of the manuscript for publication.

## Conflicts of interest

The author declares no conflict of interest.

## Funding

This research received no external funding.

## Data availability

No new data were created.

## References

[1] S.E. Darby, C.R. Thorne, Numerical simulation of widening and bed deformation of straight sand-bed rivers I: Model development, *J. Hydraul. Eng. ASCE* **122** (1996) 164–193.

[2] M. Rinaldi, N. Casagli, Stability of streambanks formed in partially saturated soils and effects of negative pore water pressures: The Sieve River (Italy), *Geomorphology* **26** (1999) 253–277.

[3] J.G. Duan, Analytical approach to calculate rate of bank erosion, *J. Hydraul. Eng.* **131** (2005) 980–989.

[4] F. Soulie, M.S. El Youssoufi, F. Cherblanc, C. Saix, Capillary cohesion and mechanical strength of polydisperse granular materials, *Eur. Phys. J. E* **21** (2006) 349–357.

[5] S. Mukherjee, A. Mazumdar, Study of effect of the variation of inter-particle distance on the erodibility of a riverbank under cohesion with a new model, *J. Hydro-Environ. Res*. (2010) 1–8.

[6] S. Mukherjee, Application of truncated pyramid model in determination of escape velocity of particles of different diameters in varying conditions, *Int. J. Soft Comput. Eng.* **1** (2011) 75–79.

[7] R.M. Koerner, Designing with Geosynthetics, 6th edn., Xlibris, USA (2012).

[8] S.K. Bhatia, J.L. Smith, Use of geosynthetics in erosion control and streambank stabilization, *Geotext. Geomembr*. **42** (2014) 214–226.

[9] D. Biswas, A. Dutta, S. Mukherjee, A. Mazumdar, A new approach to transformation of micro analysis into macro analysis of forces to study the dynamic behaviour of riverbank morphology, *ISH J. Hydraul. Eng*. **30** (2024) 1–13.