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Research Article

A Review on Design of Conventional and Remote Sensing Based River Bank Protection System

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Abstract – Riverbank protection is critical for mitigating erosion, enhancing stability, and safeguarding infrastructure. Conventional methods include hard and soft engineering techniques, as well as soil bioengineering. Hard engineering solutions, such as riprap and sheet piling, are effective in preventing bank collapse but can significantly impact local ecosystems by altering habitats and reducing biodiversity. In contrast, soft engineering, like vegetation-based stabilization, is environmentally friendly, particularly suitable for low-energy rivers, and offers long-term ecological benefits. Soil bioengineering integrates plants like willows and native shrubs to stabilize riverbanks, balancing erosion control with environmental sustainability. Remote sensing and geospatial analysis, including satellite imagery, LiDAR, and GIS tools, have become essential for assessing river morphology and monitoring erosion dynamics. These technologies enable river managers to detect erosion-prone areas and optimize protection strategies based on spatial data. Hydrodynamic models and manual calculations also play a crucial role in understanding flow-induced forces on riverbanks, informing design choices. Software tools, such as HEC-RAS and ArcGIS, enhance analysis by simulating river flow, sediment transport, and bank erosion patterns, facilitating more precise, efficient decision-making. Design checks ensure that protection systems meet engineering and environmental standards, evaluating factors like structural stability and ecological impact. Incorporating both technical and ecological considerations, these methods ensure sustainable and effective riverbank protection, balancing engineering needs with environmental preservation.

Keywords – Riverbank Erosion, Hydrodynamic Modeling, Remote Sensing, Geospatial Analysis, Bioengineering Solutions.

I. INTRODUCTION

Riverbank erosion is a significant issue for environmental and infrastructural stability, prompting the development of various protection techniques. Traditionally, conventional methods have been employed to mitigate erosion, enhance stability, and safeguard infrastructure from the detrimental impacts [2] of riverbank collapse. These techniques can be broadly categorized into hard engineering, soft engineering, and bioengineering approaches, each with distinct advantages and limitations. This review delves into these traditional methods and explores recent advancements in remote sensing, geospatial analysis, manual and software-based models, and design checks for riverbank protection.

Hard Engineering Techniques focus on direct physical interventions to stabilize banks and include methods such as riprap, stone masonry, sheet piling, and concrete slabs. These approaches are known for their strong resistance to erosion, but their environmental costs—such as habitat disruption and reduced biodiversity—are well-documented [3].These techniques are particularly effective for steep riverbanks but often fail to integrate natural ecosystems.

In contrast, Soft Engineering Techniques prioritize ecological methods such as vegetation-based stabilization, where plant roots play a crucial role in holding the soil together and reducing erosion. These methods are environmentally sustainable and are most effective in low-energy river systems [4]. The use of bioengineering, such as planting willows and native shrubs, integrates long-term ecological benefits with erosion control [5]. The development of Remote Sensing and Geospatial Analysis technologies has revolutionized riverbank monitoring. Satellite imagery, LiDAR, and GIS tools enable river managers to assess river morphology, detect erosion-prone areas, and predict erosion events [6]. These technologies allow for data-driven, real-time decision-making in planning effective riverbank protection strategies.

Additionally, Manual and Software-Based Models offer essential tools for simulating river flow dynamics, sediment transport, and bank stability. Manual calculations, such as those based on hydrodynamic principles, provide a foundational understanding of riverbank erosion, while software programs like HEC-RAS and ArcGIS integrate large datasets for more accurate predictions [7].

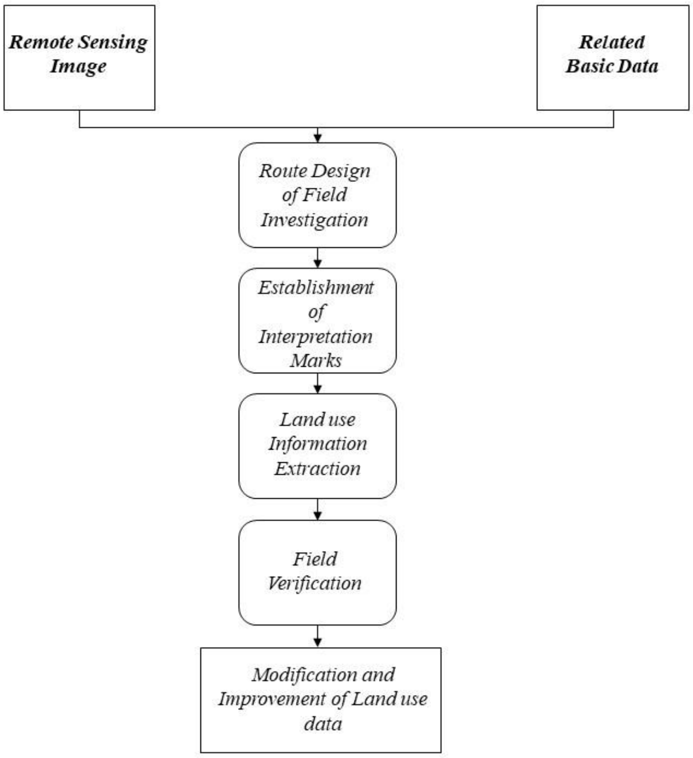

Figure 1: Remote Sensing and geospatial analysis for River bank protection [8]

These modeling techniques, coupled with design checks, ensure that the proposed riverbank protection systems meet both engineering standards and ecological requirements. By combining traditional and modern approaches, the design of riverbank protection systems can optimize both structural stability [9] and environmental sustainability. This review discusses these diverse methodologies and presents their practical applications, helping to guide future research and implementation in riverbank protection.

II. LITERATURE REVIEW

The present study investigates various conventional and modern techniques for riverbank protection, focusing on their effectiveness in mitigating erosion, enhancing stability, and protecting infrastructure. The research combines field-based data collection, laboratory testing, remote sensing, geospatial analysis, hydrodynamic modeling, and environmental impact assessments to evaluate the efficacy of different riverbank protection methods. Below is a detailed description of the materials and methods used in conducting the study. The study was conducted along the Padma river located in Bangladesh [10] an area known for significant seasonal flow variability and riverbank erosion. The river is characterized by a mix of steep and low-energy riverbanks, which allowed for testing various protection strategies. For topographic Survey a detailed topographic survey of the riverbanks was performed using traditional measurement tools, combined with LiDAR scanning to create accurate Digital Elevation Models (DEMs) as explained in Figure [2]. Soil and Sediment Analysis can be performed by collecting soil from various locations along the riverbanks for laboratory analysis. The parameters analysed included grain size distribution, shear strength, and organic content using standardized methods such as ASTM D422-63 for grain size analysis and ASTM D3080-11 for shear strength [13].

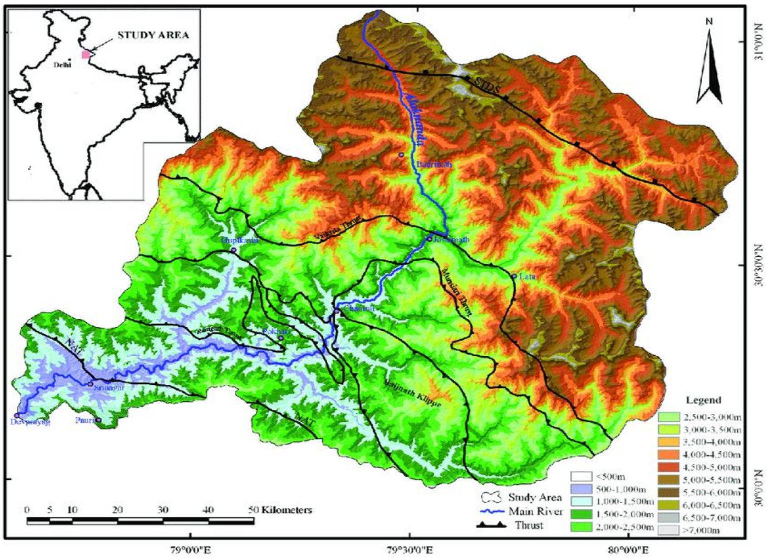

Figure 2: Digital Elevation Model [11]

Vegetation Mapping and Root Tensile Strength Testing: The plant species present along the riverbanks were documented to assess their suitability for bioengineering techniques. Root tensile strength testing was carried out on key species to understand their potential for stabilizing the soil and reducing erosion [14].

The study evaluates both hard and soft engineering techniques, commonly used for riverbank protection, in terms of their effectiveness and environmental impact. Hard Engineering Techniques include the following materials and methods were assessed for their effectiveness in preventing erosion. Riprap include large stones were placed along selected sections of the riverbank to prevent erosion. The stability of these stones under different flow conditions was checked using Hudson's equation for hydraulic stability [15]. For Gabions Wire mesh cages filled with stones were installed to provide additional structural support and erosion resistance. Design checks were conducted to ensure the gabions' ability to withstand high-flow conditions, including checking the mesh strength and stone abrasion resistance [16]. For Sheet Piling and Concrete Slabs certain materials were considered for their ability to offer strong resistance against bank collapse, although their environmental impacts were noted.

Table 1: Various Applications of satellite series [17]

Applications	**Satellite System**	**Resolution**	**Band Used**
Depth of River	Lidar	10 cm	NIR
Drainage system	ASTER, SRTM	90 m, 30 m	C-band, X-band, SWIR
Vegetation cover	LANDSAT	1 Km	VIS, NIR
Land use pattern	LANDSAT	30 m	NIR
Erosion monitoring	LANDSAT	30 m	VIS

III. METHODOLOGY

Soft Engineering Techniques includes the vegetation-based solutions were implemented as more environmentally sustainable methods and bioengineering techniques include native plants, such as willows, shrubs, and grasses, were used to stabilize the soil and reduce erosion through their root systems. The effectiveness of these species was evaluated based on root tensile strength and their ability to grow in riparian environments [18]. Soil Bioengineering includes the techniques such as live staking and planting of native shrubs were employed to integrate natural plant growth with erosion control, promoting long-term ecological stability [19].

Remote sensing technologies played a key role in monitoring and analysing riverbank conditions over large areas. There are following tools that were employed like Satellite Imagery it includes the high-resolution satellite images from sources like WorldView-3 (1-meter resolution) were used to assess river morphology, identify erosion-prone areas, and monitor changes in vegetation cover over time [20]. Image analysis was performed using software like ArcGIS. LiDAR and Aerial Photography includes the LiDAR data were collected to create highly accurate DEMs, which allowed for tracking riverbank changes, especially in areas prone to erosion (Lagasse et al., 2006). Aerial photography provided additional topographic and vegetation data. GIS tools, including ArcGIS and QGIS, were used to integrate satellite imagery, LiDAR data, and field data for spatial analysis. GIS was instrumental in identifying vulnerable riverbank sections and simulating different erosion control strategies [21]. Spatial models were created to predict the impacts of various protection techniques.

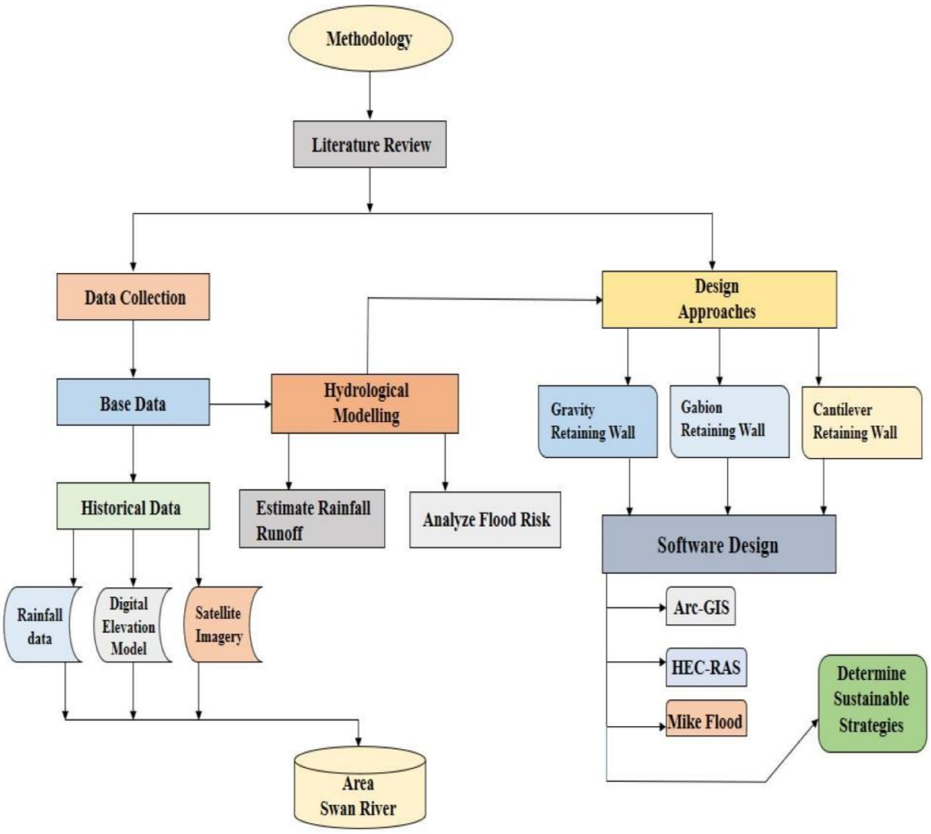

Figure 3: Flowchart of Design of Riverbank Protect Approaches [22]

Manual calculations and advanced hydrodynamic modeling were used to simulate river flow and assess the stability of different protection techniques. Hydrodynamic Modeling simulations were conducted using HEC-RAS (Hydrologic Engineering Center's River Analysis System) to model flow velocity, sediment transport, and erosion patterns. The Shields Criterion and Manning's equation were applied to estimate shear stress and flow velocities at various sections of the river, helping to predict the potential for erosion [23].

$$\boldsymbol{Shear\ Stress\ (\tau) = \rho . g . S . R^{2/3} . n^{-2}} \text{ .... } \mathbf{(2.1)}$$

Where:

- $\rho = water\ density$
- $g = acceleration\ due\ to\ gravity$
- $S = slope\ of\ the\ river$
- $R = hydraulic\ radius$
- $n = Mannings's\ roughness\ coefficient$

In Sediment Transport Models uses the Einstein-Brown Sediment Transport Model and the Meyer-Peter and Müller equation were used to estimate sediment transport rates along the river and understand the potential impacts of erosion on riverbanks [24].

Einstein-Brown Sediment Transport Model:

$$\boldsymbol{q_s = \rho_s \,.\, g \,.\, D^{2/3} \,.\, (S - S_c)} \text{ ………………… } \mathbf{(2.3)}$$

Where:

- $q_s = sediment\ transport\ rate\ (kg/m/s)$
- $\rho_s = density\ of\ sediment\ (kg/m^3)$
- $g = acceleration\ due\ to\ gravity\ (m/s^2)$
- $D = sediment\ diameter\ (m)$
- $S = slope\ of\ the\ riverbed$
- $S_c = critical\ slope\ for\ motion\ of\ sediment$

Meyer-Peter and Müller Equation:

$$\boldsymbol{q_s = \alpha \,.\, \rho_\omega \,.\, g \,.\, d^{3/2} \,.\, (\frac{\Delta}{S} - 1)\ 3/2} \text{ ……………….. } \mathbf{(2.4)}$$

Where:

- $q_s = sediment\ transport\ rate\ (kg/m/s)$
- $\alpha = empricial\ constant\ (usually\ 8)$
- $\rho_\omega = density\ of\ water\ (kg/m^3)$
- $g = acceleration\ due\ to\ gravity\ (m/s^2)$
- $d = sediment\ diameter\ (m)$
- $\Delta = relative\ density\ difference\ (\frac{\rho_s}{\rho_\omega})$
- $S = bed\ slope$

Software tools were used for more advanced, time-efficient modeling and analysis. HEC-RAS include the 1-D and 2-D modeling capabilities of HEC-RAS were used to simulate river flows, sediment transport, and hydraulic forces under different conditions. The software provided insights into riverbank erosion patterns and the performance of various protection methods under different flow scenarios [25].GIS Integration include software like ArcGIS and QGIS were used to process remote sensing data, model spatial patterns, and integrate hydrodynamic simulations to assess the suitability and effectiveness of different riverbank protection strategies [26].

Table 2: Comparison of Accessibility and Modelling Techniques used by Tools [27]

Sr.No.	**Model Name**	**1-D Technique**	**2-D Technique**	**Downloadable**	**Open Source**	**Commercially Adopted**
1	HEC-RAS	✓	✓	✓	✓	✓
2	MIKE FLOOD			✓		✓
3	ARC GIS	✓	✓	✓		✓

The final design checks ensured that the riverbank protection systems met engineering standards and environmental sustainability goals. Hydraulic Stability Checks include for structures like riprap and gabions, hydraulic stability was ensured by using formulas such as Hudson’s equation to determine the appropriate stone size based on flow velocity and sediment transport potential [28].

Structural Integrity Checks are basically for engineered solutions like gravity and cantilever retaining walls, structural stability was assessed based on factors such as the Factor of Safety (FoS) for sliding and overturning resistance [29]. Ecological Impact Assessment is for the environmental impacts of the different riverbank protection techniques were evaluated, particularly with respect to their effect on local flora and fauna, water quality, and habitat integrity. Bioengineering techniques were assessed for their potential to support native vegetation and promote ecosystem health [30].

Table3 : Design Checks [31]

Design Stages	**Design Checks**	**Value Ranges**
Gravity Retaining Wall	Structural Stability	Wall Height ≥ 1.5 times the lateral force
	Factor of Safety	FoS ≥ 1.5 for all checks (Sliding, Overturning)
	Sliding Resistance	Friction angle of base (30°- 40°) depend on soil properties.
	Overturning Resistance	FoS for overturning ≥ 1.5 wall base width (1.5 - 3m)
	Base Pressure	Max allowable base pressure (200-300 KN/m²)
Gabions Retaining Wall	Structural Stability	Gabion wire thickness (3-4mm), Mesh Size(100-200mm)
	Erosion Resistance	Gabion stone should have abrasion resistance ≥50%
	Wall strength	Wire mesh strength (Mini 500MPa to tensile strength)
	Wall Drainage	Drainage 0.5-2% slope behind the gabion for proper flow.
	Factor of Safety	FoS ≥ 1.5 for sliding, overturning and structural failure.
Cantilever Retaining Wall	Structural Stability	Lateral forces (typically from water, soil pressure) 10-50KN/m²
	Factor of Safety	Sliding (FoS ≥ 1.5) for overturning it is (FoS ≥ 1.5)
	Wall Reinforcement	Steel bars (Grade 60), Spacing 200-300mm, Fy = 420MPa
	Drainage	Pipe size 200-300mm dia, Backfill drainage layer 10-20%
	Wall Height and stability	Typical height (2-5m), Maximum height (6-10m)

IV. DISCUSSION

This study presents several riverbank protection methods, ranging from traditional hard engineering techniques to more sustainable bioengineering approaches. Remote sensing and geospatial analysis were identified as key tools for monitoring and planning riverbank protection efforts. Manual calculations and hydrodynamic modeling provided foundational insights into the forces at play in erosion, while software approaches enabled more advanced and efficient analyses. Design checks focused on ensuring both engineering stability and environmental sustainability. The tools and techniques evaluated, including GIS, remote sensing, and advanced modeling software like HEC-RAS and MIKE FLOOD, all proved essential in understanding and mitigating riverbank erosion.

V. CONCLUSION

- Integration of traditional engineering methods with modern technological tools enhances riverbank protection strategies.
- Hard engineering solutions provide short-term stability but can disrupt ecosystems, while soft engineering and bioengineering offer more sustainable, ecological benefits.
- Remote sensing, GIS, and hydrodynamic modeling enable precise assessments, better design decisions, and continuous monitoring of riverbank conditions.
- Advanced software tools like HEC-RAS and MIKE FLOOD improve modeling accuracy and efficiency for more effective and adaptive riverbank protection.

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