

Experimental Study On Porcupine Structures To Enhance Sediment Accumulation

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Abstract

Riverbank erosion poses a significant challenge in the field of fluvial geomorphology, with wide-ranging impacts on ecological balance and socioeconomic infrastructure. This study explores the potential of porcupine structures in controlling erosion and enhancing sediment deposition within riverine systems. Scaled-down models were constructed from mild steel rods to replicate porcupine structures and were tested in a laboratory setting designed to emulate natural river conditions, utilizing bed material collected from the Brahmaputra River. Flow characteristics were measured using Acoustic Doppler Velocimeter (ADV) technology. To evaluate trap efficiency, the porcupines were strategically positioned in both straight reaches and along outer bends of the channel. Experimental results indicate a marked reduction in flow velocity and an increase in sediment accumulation, with optimal trap efficiency observed in the straight sections. These findings underscore the promise of porcupine structures as an innovative solution for erosion control, providing valuable guidance for river engineering and ecosystem restoration initiatives.

Keywords: Porcupines; Trap efficiency; Sedimentation patterns; Bed deposition factor

1. INTRODUCTION

River erosion is a natural process that significantly impacts landscapes, ecosystems, and human settlements. It occurs due to the continuous action of water flow, which removes soil, sediment, and rock from riverbanks and beds. While erosion is a fundamental geomorphic process, excessive or uncontrolled riverbank erosion can lead to the loss of fertile land, damage to infrastructure, and threats to local communities. Therefore, effective riverbank stabilization techniques are essential to mitigate the adverse effects of erosion and ensure the sustainability of riverine environments.

Several studies have explored different riverbank erosion control techniques. Garde and Raju's (2000) seminal review shed significant light on the intricate mechanisms driving sediment transport in alluvial streams, providing a foundational understanding of fluvial sediment dynamics. In a study by Singh and Goswami (2012) investigated the human-induced alterations to sediment regimes within the Brahmaputra River Basin. Baishya and Sahariah (2016) assessed the efficacy of protection measures by conducting a detailed analysis of erosion patterns. Moran et al. (2013) undertook an experimental study on bank erosion management along the old Rhine River, evaluating the performance of various restoration strategies. Saikia (2017) investigated the interplay between sediment characteristics and erosion processes in the Brahmaputra River, shedding light on its dynamic sedimentology. Goswami and Singh (2010) provided a comprehensive overview of strategies for flood protection and erosion prevention, highlighting effective measures for mitigating these hazards. Thompson et al. (2020) examined the stability of geobags as a means of preventing riverbank erosion. Bhuiyan et al. (2010) assessed the effectiveness of bank-attached vanes in controlling erosion along riverbanks. Recking et al. (2019) investigated the use of fascines to enhance riverbank toe protection. Dey et al. (2017) evaluated the role of submerged vanes in reducing scour depth. Kharya and Kumar (2012) analyzed the anti-erosion performance of RCC porcupines, while Aamir and Sharma (2015) conducted laboratory experiments to assess the sediment trapping efficiency of porcupine

systems. Additionally, Kharya and Kumar (2012) investigated the effectiveness of RCC porcupines in reducing erosion in Majuli Island of Assam, noting that their deployment in high-velocity flow regimes is limited due to stability concerns. This paper explores the effectiveness of porcupine models as pro-siltation measure by examining their implementation techniques. Experimental findings will be analyzed to assess the practical applications and long-term impacts of porcupine structures. By understanding the role of these models in erosion control, this study aims to contribute valuable insights into sustainable riverbank management practices. So based on the research gap and discussion, the objectives of the study are as follows:

- To study the dynamics of bedform under the pro- siltation measure porcupine, with a focus on comparing different arrangements of porcupines.
- To investigate the impact of porcupines under different flow conditions.
- To examine the impacts of application of porcupines in the bedform geometry at the sharp bends.

2. MATERIALS AND METHODOLOGY

Upon defining the research objectives, an experimental flume measuring 35 meters in length, 1.8 meters in width, and 1.275 meters in depth was selected for the study. The porcupine models, each 12.5 cm in height, were used as the primary test material. These porcupine units were arranged in two distinct configurations, each comprising two sets. The specific details of these configurations and their respective arrangements are presented in the following sections.

2.1 Experimental Channel Description

The experimental study was conducted in the Hydraulics Laboratory Channel at Assam Engineering College, Guwahati, India, as illustrated in Figures 1 and 2. The flume features a sand bed and measures 35 meters in length, 1.8 meters in width, and 1.275 meters in depth, with a bank-to-bed depth of 35 centimeters. Water flow within the channel was regulated using pumps rated at 3 HP, 5 HP, and 10 HP. Additionally, an energy dissipater was installed at the inlet to minimize turbulence and ensure uniform flow conditions. This setup provided a controlled environment for evaluating erosion control and bank stabilization techniques. Flow velocity measurements were captured using an Acoustic Doppler Velocimeter (ADV) operating at a frequency of 16 MHz, offering high-resolution data. A sampling rate of 25 Hz was employed to record detailed and continuous flow dynamics throughout the experiment.



Figure 1. 180° bend in the channel

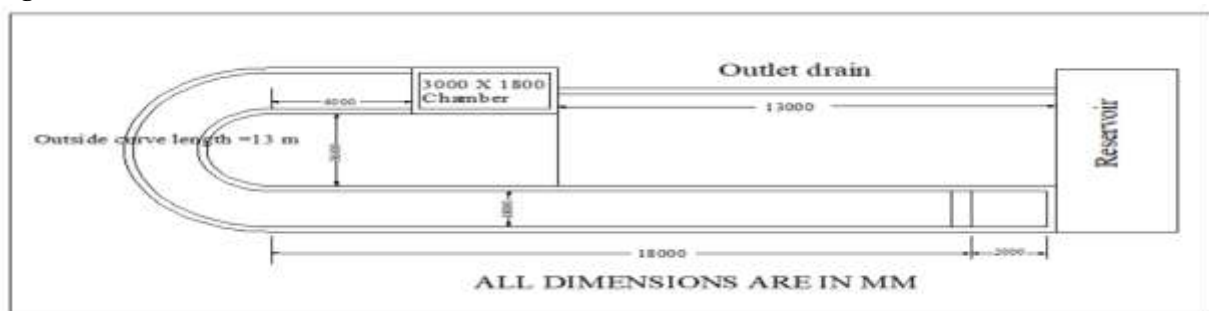


Figure 2. Experimental Channel Layout

2.2 Materials Used

For this study, scaled-down porcupine structure models were used, as shown in Figure 3. These models were designed to maintain the original symmetrical configuration while fitting within the constraints of the laboratory flume. A geometric scale ratio of 1:100 was adopted, based on the maximum water depth of approximately 35 meters observed in the Brahmaputra River near Guwahati (Pareta, 2021). Accordingly, the model porcupines were constructed with a height of 12.5 cm, representing full-scale structures of 12.5 meters in height under field conditions. A total of thirty porcupine models were fabricated, allowing for a detailed, practical, and cost-effective evaluation of their performance in controlling erosion and enhancing sediment deposition.



Figure 3. Structure of a porcupine Model

The bed material used in the laboratory flume was sourced directly from the banks of the Brahmaputra River in Guwahati, India, to closely replicate natural riverbed conditions. The collected material was air-dried and subjected to particle size distribution analysis to ensure accurate representation of in-situ sediment characteristics. To simulate real-world scenarios, the experiments tested the performance of porcupines in controlling erosion and stabilizing riverbanks. By using actual Brahmaputra riverbank materials, the study achieved a realistic and precise simulation of sediment interaction with the porcupine structures.

2.3 Overview of Experiments

First, the channel bed was made level, and water flow was slowly increased until the sand particles on the bed just started to move, showing the start of sediment motion. The flow speed was then kept just below the critical level to avoid full movement of the sand. After running clear water for 30 minutes, porcupine model structures were placed in the channel. Then, sediment was added for three hours. After that, the water was slowly drained out, and the height of the sand bed was measured.

There were two types of porcupine models: one with two compartments and another with three, as shown in Figure 4. Details of both setups are listed in Table 1. In the first setup (Arrangement 1), both types of porcupine models were placed so that their retard angles were at 90° to the flow direction, and the diversion lines were placed along the direction of the flow. In the second setup (Arrangement 2), the diversion lines were still kept in the direction of the flow, but the retard angles were set at 110° to both the diversion lines and the flow direction, as shown in Figures 5 and 6. This idea of using diversion lines with several retards was inspired by the jack jetty design developed earlier.

Table 1. Arrangement details

Arrangement type	Set No.	No. of compartment	Angle of retards with direction of flow	Angle of diversion line with direction of flow
Arrangement 1	Set 1	2	90°	0°
	Set 2	3	90°	0°
Arrangement 2	Set 1	2	100°	0°
	Set 2	3	100°	0°



(a) Set 1



(b) Set 2

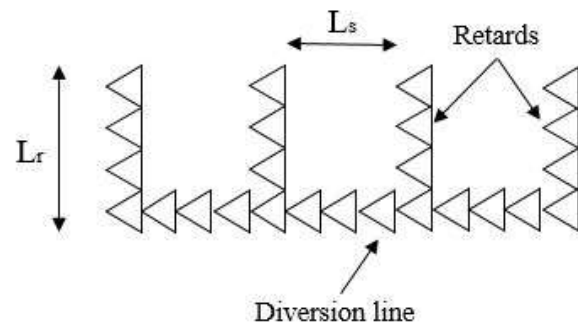
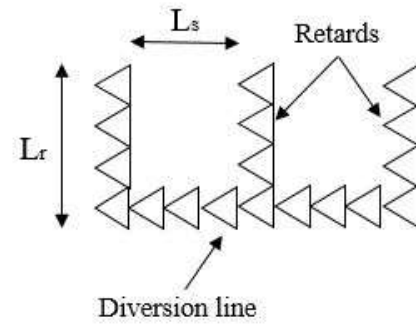


Figure 4. Typical layout of porcupine field model

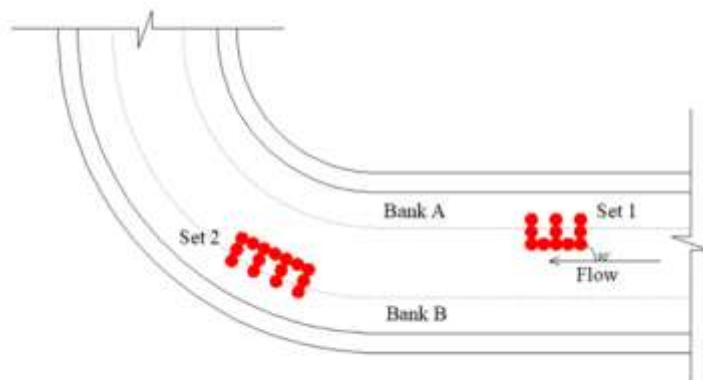


Figure 5. Porcupine placement in arrangement 1

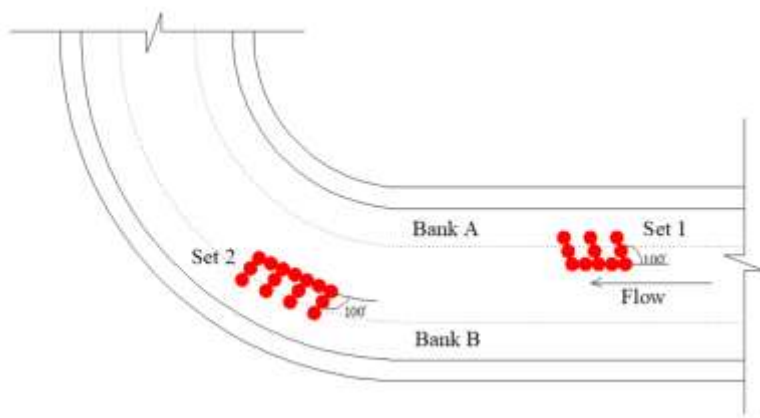


Figure 6. Porcupine placement in arrangement 2

3. EXPERIMENTAL RESULTS AND ANALYSIS

Porcupine models were made and placed in a channel that had an artificial riverbed. Observations were

taken to study how sediment (like sand) settled around these test models, following a set method. After each experiment, the riverbed surface was measured using a point gauge at three imaginary lines (A, B, and C) along the direction of water flow. The average amount of sediment deposited was then calculated, as shown in Figure 8. Some important values—like Field Density Index (FDI), Compartment Density Index (CDI), Field Length Factor (FLF), Bed Deposits Factor (BDF), and Submerged Depth Ratio (SDR)—were also calculated based on a method by Aamir and Sharma (2015), and are given in Table 2. These values help compare how different arrangements of the porcupine models affect sediment deposition.

Table 2. Calculation of Flow indices

Flow Indices	Calculation of Flow Indices
Field Density Index (FDI)	Length of one retard (L_r) / Spacing between two retards (L_s)
Compartment Density Index (CDI)	Length of one retard (L_r) / Total Length of compartment (Diversion line) (L_c)
Field Length Factor (FLF)	Spacing between two retards (L_s) / Total Length of compartment (Diversion line) (L_c)
Bed Deposits Factor (BDF)	$\frac{\text{Depth of sediment deposited} \times 100\%}{\text{Depth of water}}$
Submerged Depth Ratio (SDR)	$\frac{\text{Height of model}}{\text{Depth of water}}$

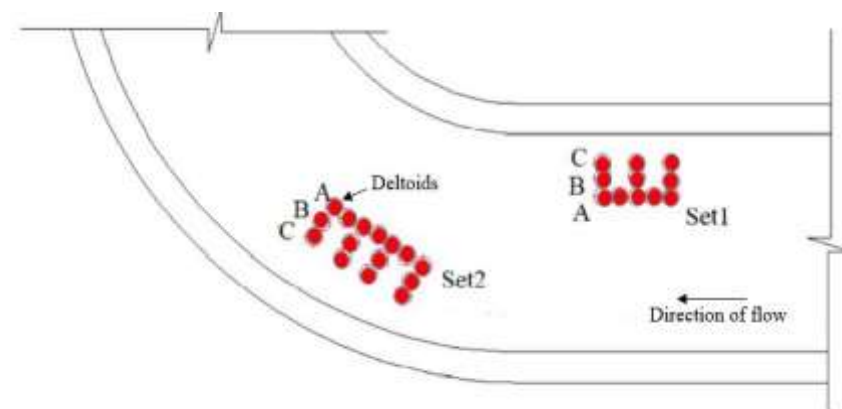


Figure 7. Imaginary lines A, B and C on the channel bed along the flow.

3.1 Bed and bank material

The particle size of the bed material was studied using dry sieve analysis, following IS 2720 (Part 4)-1985. The results, shown in Table 3, highlight some differences between the bed and bank materials. The bed material is finer than the bank material. This is seen in the fineness modulus: 0.99 for the bed and 1.728 for the bank. Both materials have uniform particle sizes based on their uniformity coefficients. The bed material has a higher coefficient of curvature (1.48), which means its particles follow a more regular size pattern. According to IS 2720 (Part 4)-1985, both materials are classified as poorly graded sand (SP), meaning their particles are mostly of similar sizes. The bed material also has a slightly higher specific gravity (2.62) and lower porosity (34%) compared to the bank material, which has a specific gravity of 2.57 and porosity of 35%. These properties can affect how easily water flows through the material and how well it

resists erosion, which is important in river channel design.

Table 3. Experimental result of bed and bank material

	Bed Material	Bank Material
Fineness Modulus	0.99	1.728
Uniformity Coefficient	2.23	2.27
Coefficient of Curvature	1.48	1.27
Classification (IS)	Poorly graded sand (SP)	Poorly graded sand
Specific Gravity	2.62	2.57
Porosity	34%	35%

3.2 Experiments with Porcupine Models

3.2.1 Arrangement 1

For the first trial, the retards are placed at 90° to the flow direction and diversion line is parallel to the flow direction in both the sets (set 1 and 2). The values of indices are given in Table 4. 3 kg of sediment was introduced for every run. The sediment deposition measurement was done for set 1 and 2 at imaginary lines A, B and C for low, medium and high depth. Here low depth means depth of water is less than height of porcupine ($SDR > 1$), medium depth means depth of water is 1 to 1.5 times of height of porcupine ($SDR < 1$) and high depth means depth of water is 1.5 to 2 times of height of porcupine ($SDR < 1$).

Table 4. Range of dimensional parameters for the arrangement 1 of porcupine field models (Set 1 and 2)

Trial Set No.	Retard angle with flow	Diversion line angle to the flow	Length of Retards (cm) L_r	Spacing of Retards (cm) L_s	No. of compartment	Length of compartment (cm) L_c	FLF (L_r/L_c)	CDI (L_r/L_c)	FDI (L_r/L_c)
Set 1	90°	0° (Parallel)	40	14.5	2	75	0.193	0.533	2.75
Set 2	90°	0° (Parallel)	42	15	3	105	0.142	0.40	2.8

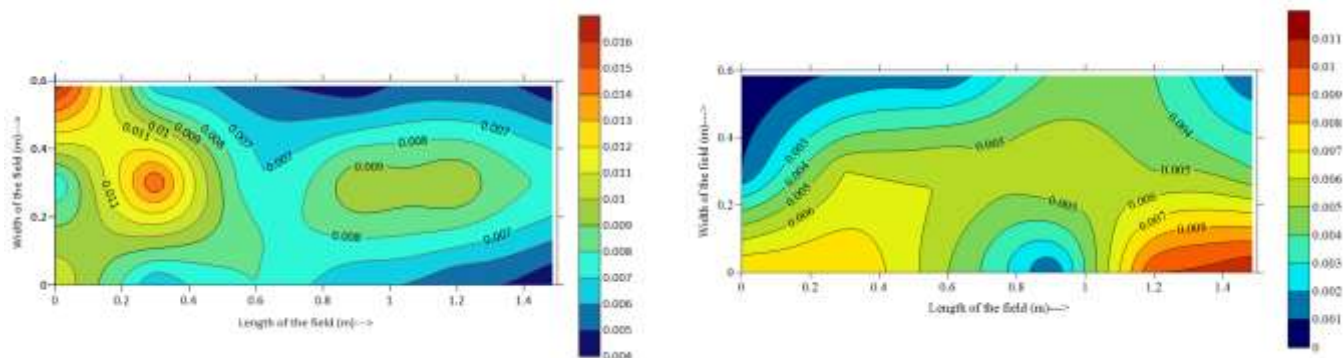
The Table 5 presents sediment deposition data for arrangement 1, under varying depth conditions. In the low depth condition, for set1 and 2, the deposition is less (0.033kg & 0.01 kg) compared to medium depth condition (0.081 kg & 0.012 kg) but more compared to high depth condition (0.024 kg & 0.0013 kg).

The data shows that low-depth water condition shows the most prominent sediment deposition in terms of bed deposition factor (BDF). Although sediment deposition is lower under shallow flow conditions, the Bed Deposition Factor (BDF) is highest (7.08% and 4.99%) because it represents the ratio of deposited sediment depth to water depth. Therefore, erosion control structures like porcupine models used in this study—should be strategically placed in shallow regions where sediment accumulation is proportionally more significant. In contrast, as sediment deposition diminishes in deeper water conditions, erosion control strategies must be adapted to suit areas with higher water depths to ensure continued effectiveness.

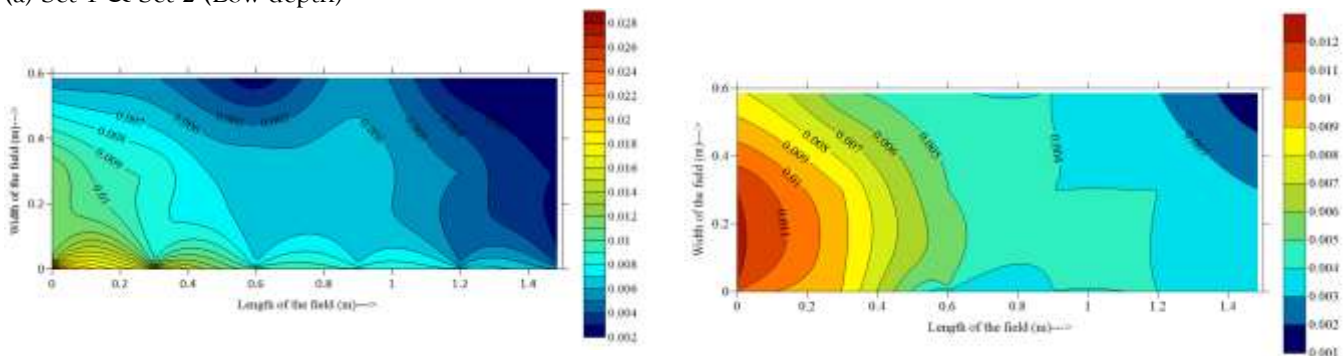
Table 5. Summary of Sediment Deposition for low, medium and high depth

Set	Section	Total sediment deposited (kg)	Depth of sediment deposited (m)	Total sediment deposited (kg)	Average depth of sediment (m)	Depth of water (H) (m)	BDF (%)
Low depth ($SDR > 1$)							
1	A	0.0056	0.0067	0.033	0.0077	0.128	7.08
	B	0.0148	0.0095				
	C	0.0124	0.0068				

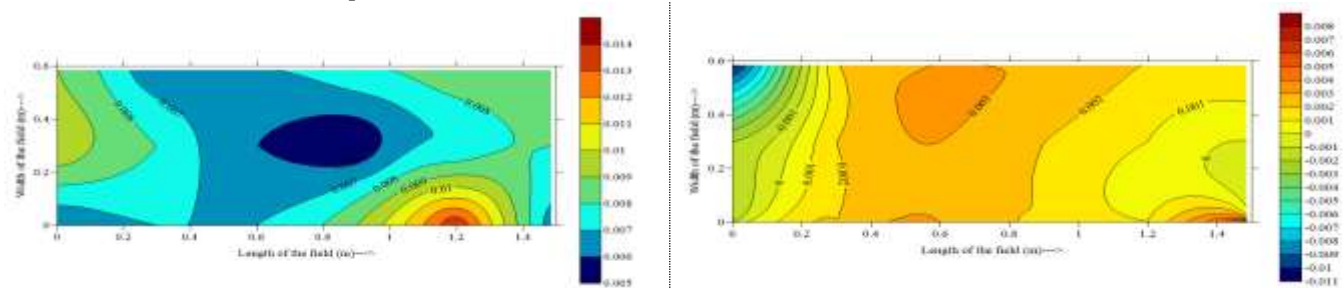
2	A	0.0079	0.0072	0.01	0.0046	0.125	4.99
	B	0.0019	0.0047				
	C	0.0003	0.0018				
Medium depth (SDR<1)							
1	A	0.072	0.0145	0.081	0.0085	0.17	4.98
	B	0.0074	0.0072				
	C	0.0011	0.0037				
2	A	0.0037	0.0052	0.012	0.0052	0.165	3.15
	B	0.0062	0.0062				
	C	0.0018	0.0042				
High depth (SDR<<1)							
1	A	0.0104	0.008	0.024	0.0078	0.225	3.5
	B	0.0061	0.007				
	C	0.0074	0.008				
2	A	0.0043	0.005	0.0013	0.0016	0.221	0.7
	B	0.0002	0.002				
	C	0.0004	0.003				



(a) Set 1 & Set 2 (Low depth)



(b) Set 1 & Set 2 (Medium depth)



(c) Set 1 & Set 2 (High depth)

Figure 8. Contour map of the sediment deposition (Arrangement 1)

Table 6. Model and flow indices for arrangement 1

Trial	Set No.	FDI	CDI	FLF	BDF (%)	SDR	Trap efficiency (%)	Velocity (m/s)
Low depth	Set 1	2.75	0.533	0.193	7.08	1.05	1.09	0.094
	Set 2	2.80	0.42	0.15	4.99	1.08	0.33	0.094
Med. depth	Set 1	2.75	0.53	0.193	4.98	0.79	2.69	0.105
	Set 2	2.80	0.42	0.15	3.15	0.82	0.39	0.105
High depth	Set 1	2.75	0.533	0.193	3.47	0.6	0.79	0.106
	Set 2	2.8	0.42	0.15	0.71	0.61	0.04	0.106

Table 6 presents data on model and flow indices for various trials of arrangement 1. Trap efficiency reflects the sediment retention capability of a structure, with higher values signifying more effective erosion control. Meanwhile, velocity measurements offer valuable insights into flow behavior and sediment transport mechanisms. Trap efficiency ranges from 0.04% to 2.69%, highlighting the varying sediment retention capabilities of the tested structures. Flow velocity remains relatively consistent across conditions, suggesting stable hydraulic behavior. Set 1 consistently exhibits higher trap efficiency at low and medium water depths, indicating its greater suitability for straight channel reaches under such conditions. Although Set 2 performs well in terms of CDI and FLF, set 1 demonstrates superior overall efficiency due to its placement in a straight reach. However, the effectiveness of both configurations declines markedly under high-depth flow conditions.

3.2.2 Arrangement 2

For second arrangement of porcupine field model layout, in set 1 & 2, the retards are placed at 100° to the flow direction and diversion line is kept parallel to the flow direction. Here 3 kg of sediment was injected for each run. The values of indices are described in Table 7.

Table 7. Range of dimensional parameters for the arrangement 2 of porcupine field models (set 1 and 2)

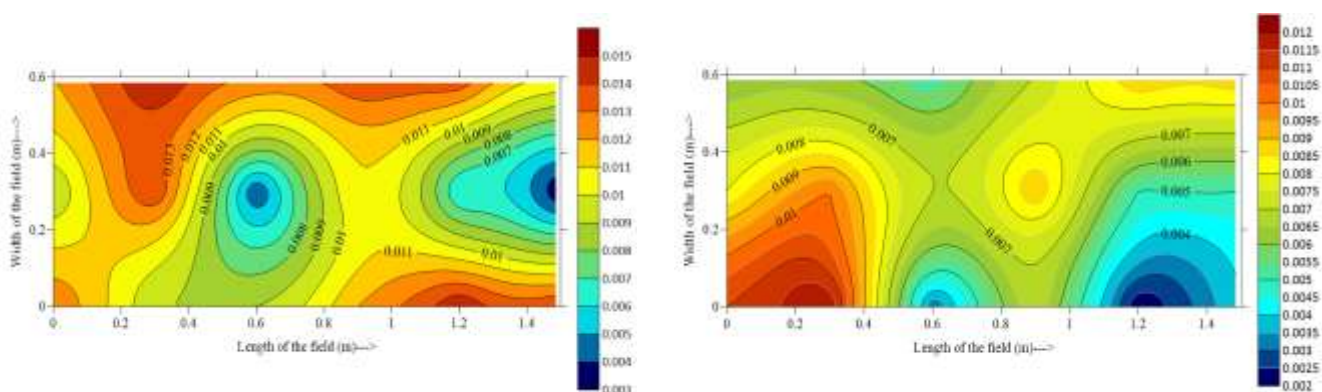
Trial Set No.	Retard angle with flow	Diversion line angle to the flow	Length of Retards (cm) L_r	Spacing of Retards (cm) L_s	No. of compartment	Length of compartment (cm) L_c	FLF (L_r/L_c)	CDI (L_r/L_c)	FDI (L_r/L_c)
Set 1	100°	0° (Parallel)	40	15	2	80	0.188	0.5	2.6
Set 2	100°	0° (Parallel)	42	15	3	105	0.142	0.40	2.8

In the table 8 and 9 and figure 10, summary of sediment deposition, the deposition pattern and the trap efficiencies along with the flow indices are shown.

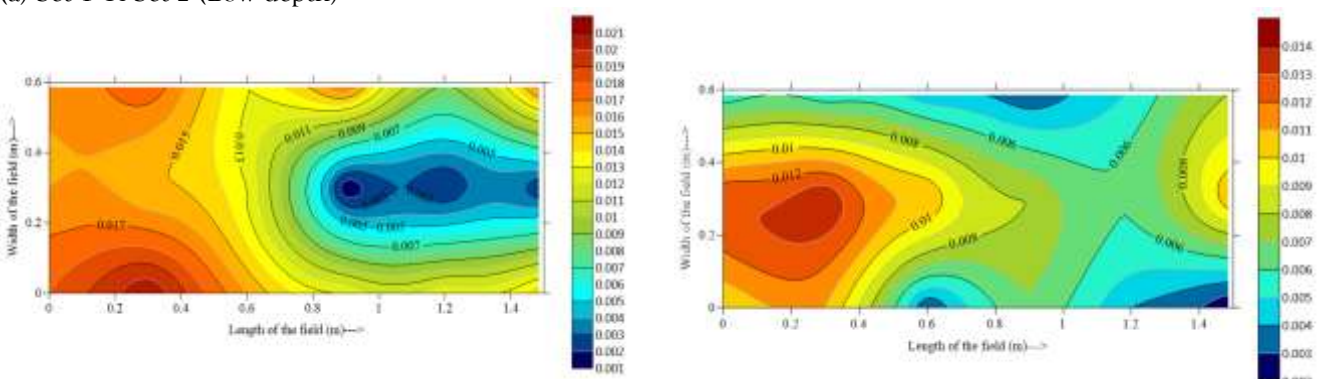
Table 8. Summary of Sediment Deposition for various depths (Arrangement 2)

Arrangement	Section	Total sediment deposited (kg)	Depth of sediment deposited (m)	Total sediment deposited (kg)	Average depth of sediment (m)	Depth of water (H) (m)	SDR	BDF (%)
Low Depth (SDR>1)								
Set 1	A	0.026	0.012	0.0694	0.011	0.127	1.06	8.66
	B	0.0115	0.0078					
	C	0.0319	0.0132					
Set 2	A	0.0079	0.0065	0.0196	0.0069	0.125	1.08	5.55
	B	0.0064	0.0073					
	C	0.0053	0.007					
Medium Depth (SDR<1)								
Set 1	A	0.061	0.016	0.138	0.0132	0.17	0.8	7.74

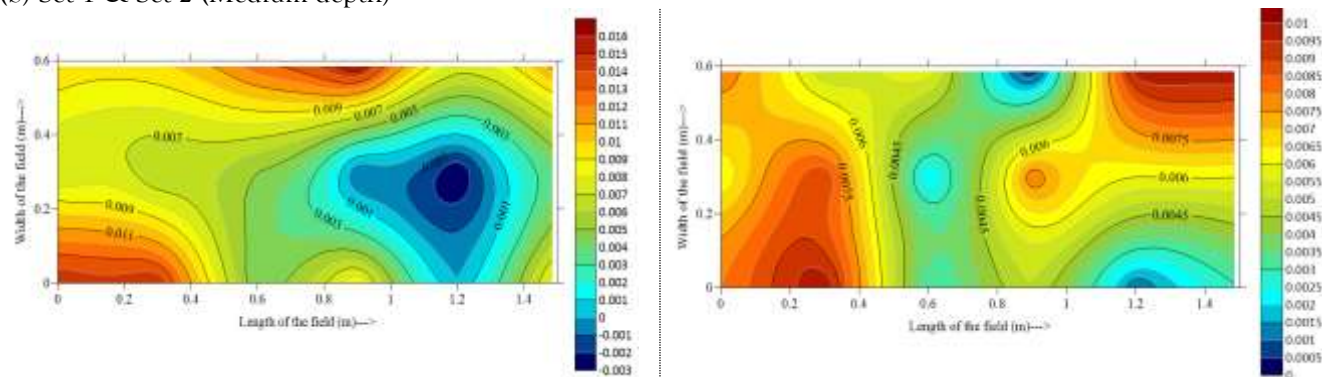
	B	0.022	0.0082					
	C	0.055	0.0153					
Set 2	A	0.0063	0.0062	0.027	0.0072	0.165	0.82	4.38
	B	0.0188	0.0105					
	C	0.0022	0.005					
High Depth (SDR<<1)								
Set 1	A	0.0187	0.009	0.0459	0.0078	0.225	0.6	3.46
	B	0.0016	0.003					
	C	0.0256	0.012					
Set 2	A	0.0123	0.005	0.0145	0.0059	0.221	0.61	2.67
	B	0.0129	0.006					
	C	0.0252	0.0065					



(a) Set 1 & Set 2 (Low depth)



(b) Set 1 & Set 2 (Medium depth)



(c) Set 1 & Set 2 (High depth)

Figure 9. Contour map of the sediment deposition (Arrangement 2)

Table 9. Model and flow indices of arrangement 2

Trial	Set No.	FDI	CDI	FLF	BDF	Trap efficiency (%)	SDR	Velocity (m/s)
Low depth	Set 1	2.75	0.533	0.193	8.66	2.31	1.06	0.094
	Set 2	2.8	0.42	0.15	5.55	0.65	1.08	0.094
Med. depth	Set 1	2.75	0.533	0.193	7.74	4.60	0.79	0.105
	Set 2	2.8	0.42	0.15	4.38	0.91	0.82	0.105
High depth	Set 1	2.75	0.533	0.193	3.46	1.53	0.6	0.106
	Set 2	2.8	0.42	0.15	2.67	0.48	0.61	0.106

Set 1 consistently shows greater sediment deposition and higher BDF values compared to Set 2 under low and medium water depth conditions. However, at higher depths, set 2 exhibits increased sediment deposition. Despite this, both configurations demonstrate reduced efficiency at greater depths, as indicated by lower BDF values, highlighting the need for design enhancements specifically suited for high-depth flow environments. Table 9 presents the results of experimental trials using porcupine field models, highlighting key indices and their respective values. The Flow Distribution Index (FDI) ranges from 2.75 to 2.8, indicating consistent structural geometry across configurations. The Compartment Density Index (CDI) varies between 0.42 and 0.53, reflecting differences in the density of structural arrangements. Variations in the Bed Deposition Factor (BDF) are influenced by the submergence height, while trap efficiency ranges from 0.48% to 4.6%. The highest trap efficiency is observed in Set 1 under medium-depth conditions, reaching 4.6%. Higher Submergence Depth Ratio (SDR) values suggest increased submergence, which may affect sediment deposition. Flow velocity remains consistent throughout the experiments, indicating stable flow dynamics. Under low-depth conditions, Set 1 exhibits a BDF of 8.66%, with 0.0694 kg of sand deposited and a trap efficiency of 2.31%. The SDR in this case is 1.06, indicating moderate submergence. In contrast, Set 2 shows a lower BDF of 5.55%, with only 0.0196 kg of sediment deposited and a reduced trap efficiency of 0.65%. For medium-depth conditions, Set 1 records a BDF of 7.74%, with 0.138 kg of sediment deposited and the highest observed trap efficiency of 4.6%. The corresponding SDR is 0.79, suggesting more favorable conditions for sediment retention. Set 2, though slightly lower in performance, achieves a BDF of 4.38% and deposits 0.027 kg of sediment, indicating a notable improvement over its performance at lower depths. In high-depth conditions, Set 1 demonstrates the lowest BDF across all trials at 3.46%, with 0.0459 kg of sediment deposited and a trap efficiency of 1.53%. The SDR is 0.6, signifying reduced submergence. Set 2 also performs poorly under these conditions, with a BDF of 2.67%, 0.0145 kg of sediment deposited, and a trap efficiency of just 0.48%. These findings suggest that both sets show reduced effectiveness in sediment capture at greater depths.

3.3 Comparison of Trap Efficiency with Different Indices and Their Graphical Representation

Table 10. Comparison of Trap Efficiency with Submergence depth ratio (SDR) for both the set in two arrangements

Trap efficiency (%) of set 1 (CDI =0.5)			Trap efficiency (%) of set 2 (CDI =0.42)		
SDR	Arrangement 1	Arrangement 2	SDR	Arrangement 1	Arrangement 2
SDR>1	1.09	2.31	SDR>1	0.33	0.65
SDR<1	2.69	4.60	SDR<1	0.39	0.91
SDR<<1	0.79	1.53	SDR<<1	0.04	0.48

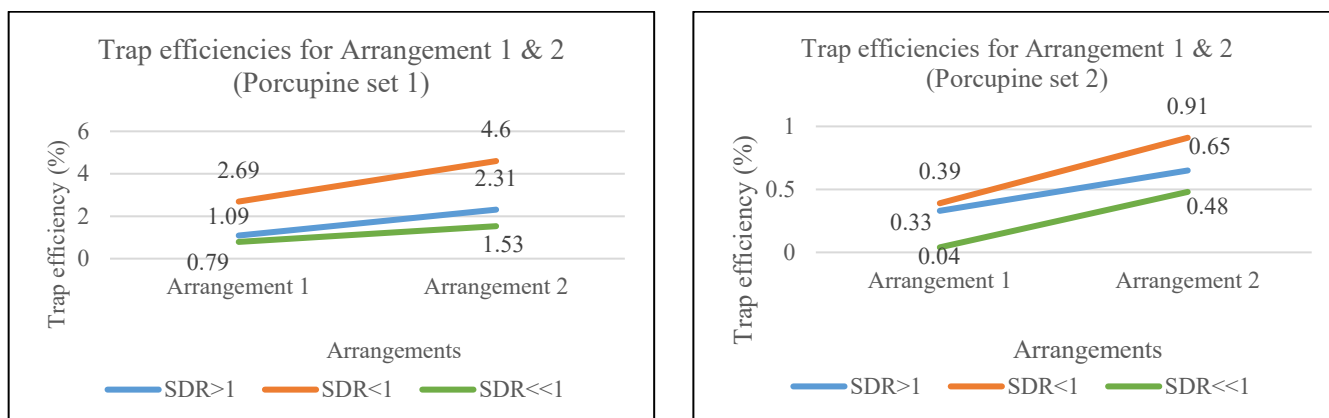


Figure 10. Trap efficiency of arrangement 1 vs 2

From Table 10 and Figure 10, it is observed that across all depths in Set 1, Arrangement 1 consistently exhibits lower trap efficiency compared to Arrangement 2. At high depth, where the water level significantly exceeds the height of the porcupine structures, sediment deposition is minimal. In contrast, under medium-depth flow conditions, sediment deposition is maximized across all sets and arrangements, indicating more favorable conditions for effective sediment capture.

Table 11. Comparison of Trap Efficiency (%) of set 1 and set 2 for arrangement 1 and 2 (Low depth, SDR > 1)

Set	Arrangement 1	Arrangement 2
Set 1	1.09	2.31
Set 2	0.33	0.65

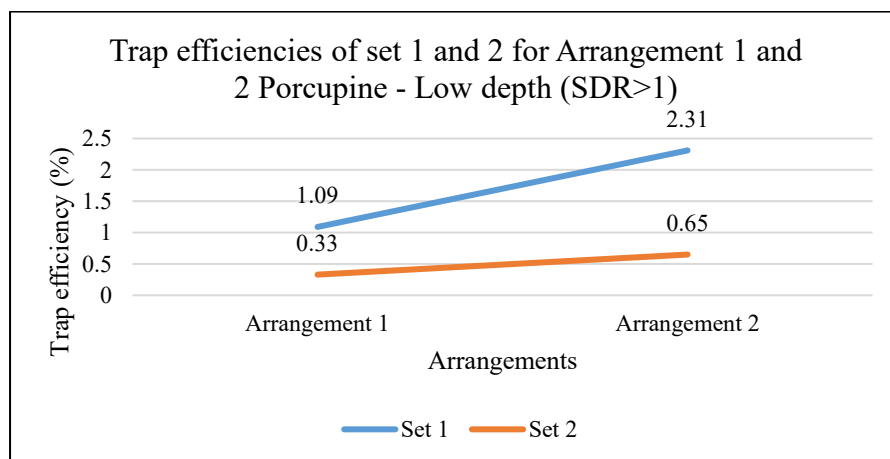


Figure 11. Trap efficiency of set 1 vs set 2 for arrangement 1 and 2 (Low depth)

Table 12. Comparison of Trap Efficiency (%) of set 1 vs set 2 for arrangement 1 and 2 (Medium depth, SDR < 1)

Set	Arrangement 1	Arrangement 2
Set 1	2.69	4.60
Set 2	0.39	0.91

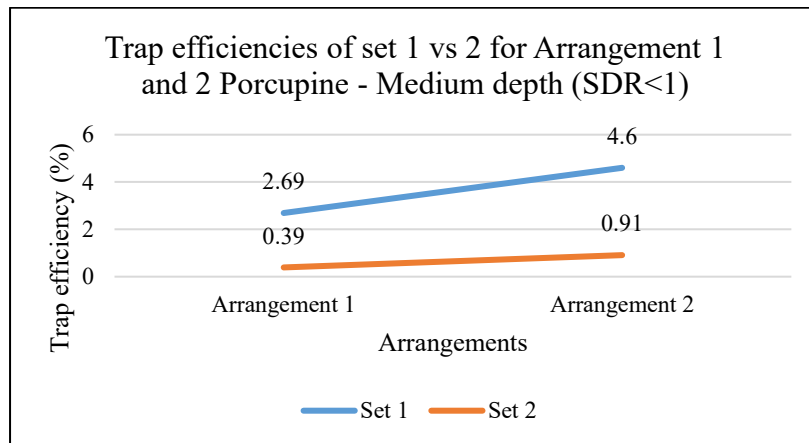


Figure 12. Trap efficiency of set 1 vs set 2 for arrangement 1 and 2 (Medium depth)

Table 13. Comparison of Trap Efficiency (%) of set 1 vs set 2 for arrangement 1 and 2 (High depth, SDR<<1)

Set	Arrangement 1	Arrangement 2
Set 1	0.79	1.53
Set 2	0.04	0.48

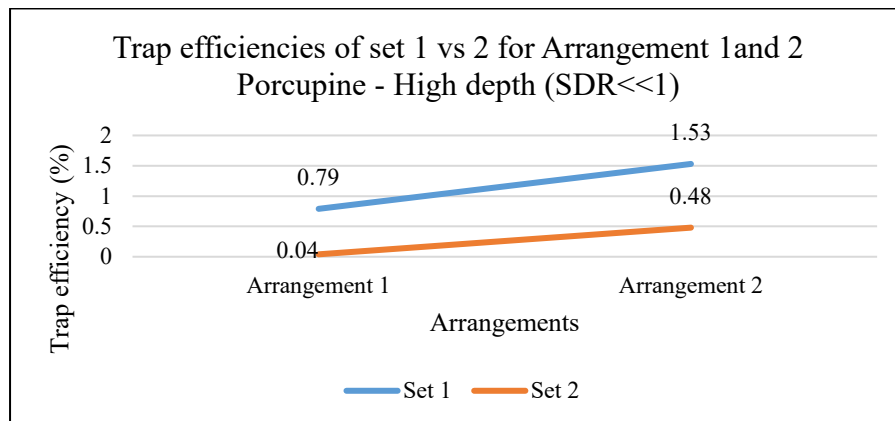


Figure 13. Trap efficiency of set 1 vs set 2 for arrangement 1 and 2 (High depth)

Based on observations from Tables 11–13 and Figures 11–13, arrangement 2 consistently outperforms Arrangement 1 across all flow depths and both structural sets. At high depths, where the water level significantly exceeds the height of the porcupine structures, sediment deposition is minimal. Conversely, under medium-depth flow conditions, sediment deposition is maximized in all sets and arrangements, suggesting optimal conditions for sediment capture. When the Submergence Depth Ratio (SDR) > 1—meaning the water depth is less than the height of the porcupines—sediment deposition is higher. As SDR drops below 1 (i.e., full submergence of the structures), deposition decreases, particularly when the water level rises well above the model height. It is also observed that in both arrangements, set 1, which represents a straight channel reach, shows higher trap efficiency compared to set 2, located on the concave bank, which is more prone to erosion. Despite set 2 having a lower CDI (denser arrangement), it still shows reduced deposition, likely due to flow concentration and erosion-prone characteristics. However, arrangement 2, which provides greater flow retardation, leads to improved trap efficiency in both set 1 and set 2, demonstrating the effectiveness of this configuration in enhancing sediment capture under varied hydraulic conditions.

The significant increase in trap efficiency observed in Arrangement 2 suggests that specific design or operational modifications contribute to enhanced sediment capture. The data clearly indicate that

medium-depth flow conditions result in the highest trap efficiency, highlighting the importance of optimizing sediment management systems for such conditions to achieve better performance. In contrast, both sets exhibit notably low trap efficiency at high depths, where the structures are fully submerged and less effective. This underscores the need for further investigation into design improvements or alternative configurations that can maintain or enhance sediment retention under high submergence conditions.

4. CONCLUSIONS

This study demonstrates the effectiveness of porcupine structures as a strategic intervention for mitigating riverbank erosion and managing sediment deposition in fluvial environments. Experimental investigations were conducted using two distinct arrangements: Set 1, positioned along a straight reach before a channel bend, and Set 2, placed on the outer bank of the bend, a zone typically more susceptible to erosion. The objective was to evaluate the impact of these configurations on flow dynamics and erosion control.

The findings indicate that porcupine structures act as effective flow retarders, capable of deflecting water currents away from vulnerable bank areas. Notably, set 1 demonstrated higher trap efficiency, particularly in terms of sediment capture, while Set 2 effectively reduced erosion along the concave bank. Maximum efficiencies for both sets were recorded under medium flow depths, corresponding to SDR values less than 1, suggesting that partial submergence enhances the structures' performance in sediment management and bank stabilization.

4.1 Limitations of the study

This study acknowledges several limitations and assumptions that must be considered when interpreting the results. The experimental setups were tested under controlled laboratory conditions, where turbulence levels were higher than those typically observed in natural river systems. Additionally, scale effects inherent to physical modelling could not be completely eliminated, and the narrow width of the laboratory flume introduced cross currents, which may have affected the accuracy of velocity measurements.

Although the findings demonstrate notable sediment deposition efficiency, the real-world applicability of these results may be influenced by environmental variables such as flow variability, sediment load, and riverbank geometry. Therefore, field-based validation is essential to assess the model's performance across a range of hydrological and geomorphological conditions, and to ensure its effectiveness and scalability for diverse river systems.

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