River Bank Protection with Porcupine and Groynes System

Rhitwika Barman[1] ;
[1]Assistant Professor, Assam Engineering College,
Guwahati-13, Assam, India

Gitartha Kalita[2*]
[2]Assistant Professor, Assam Don Bosco University,
Guwahati-13, Assam, India
[*]Corresponding Author
[*](gitartha.kalita@dbuniversity.ac.in, +919707488554)

ABSTRACT

River bank protection efficiently training the river, excessive flowing, channel change, and navigability can be maintained. However, a frequent issues faced during floods is scouring of the river bed and bank, subsequently leading to a change in the course of the river along with losses to both land and property and the intensity of flow at the point of river attack is not controlled. Hence, the novel technique namely **River bank protection with porcupine and groynes system** has introduced in which the Porcupines and Groynes system has been developed as a preventive measure which traps the sediments, thereby controlling scouring and porcupine has been developed to reduce the intensity of flow at the point of river attack. Moreover, in previous methods the efficiency of sediment is not appropriate and did not consider the sediment deposition pattern for a particular discharge, water depth and sediment concentration. Hence the loam based sediment modeling and MS rod based model has been introduced to evaluate the efficiency of various porcupine field models in terms of their sediment trapping efficiency with the proper discharge, water depth and sediment concentration. In the existing techniques the effect of porcupines on the velocity of flow and their ability to capture sediment. To get the velocity of flow the acoustic dopples velocimeter is used. The loam is the combination of sand-silt-clay based model and MS rod is a mild steel rod based model with three dimensional techniques to analyse the effects of placing groynes and to find the most effective arrangement for minimizing the erosion and to get the changes in the bed form.

Keywords: *River bank protection, river bed, porcupine and groynes system, sediment trapping, velocity of flow, sand, silt, clay, mild steel rod, erosion.*

I. INTRODUCTION

Rivers with a meandering nature are prone to severe erosion, which can lead to a catastrophic and uncontrollable situation if not properly addressed. This is particularly problematic during the monsoon season, when river erosion accelerates and access to materials and labour becomes limited [1]. Groynes are structures built perpendicular to the flow of water in a river or stream to control its direction [2]. They interrupt the current, causing the water to deposit sediment on the upstream side and promoting the development of a scour hole on the downstream side. This helps to prevent erosion and stabilize the river banks. Groynes are used to control sediment movement and erosion in rivers and streams [3,4]. Groynes are a pro-siltation technique used in rivers and streams to control the movement of sediment and reduce erosion. Groynes are structures built perpendicular to the flow of water, which interrupt the current and cause water to deposit sediment on the upstream side, building up the riverbank and reducing erosion [5]. An open channel is a passage through which liquid flows with a free surface exposed to the atmosphere. This type of flow, known as open channel flow or free surface flow, is driven by the component of gravity and is characterized by a hydrostatic pressure distribution. The amount of sediments entering the channel greatly influences the channel flow, cross-section and regime. Sediment deposition refers to the process by which sediment (bed load, suspended load and dissolved load) is deposited and builds up in a river or stream channel [6,7].

The sediment is deposited when the flow velocity of the water decreases, such as in areas of the channel with a lower slope or where the water is impounded by a dam [8]. Bed load sediments move close to the riverbed through rolling, sliding, and hopping, while suspended load sediments move at a large fraction of the mean flow velocity in the stream [9]. Suspended load is the sediment carried by the flow in suspension, supported by the surrounding fluid, and consisting mostly of smaller particles like clay, silt, and fine sands. It settles when flow velocity decreases [10]. Dissolved load, on the other hand, is carried within the water column. It is a much smaller component of the total sediment transport than suspended and bed load. The dissolved load consists of particles that are soluble in water and can be derived from the dissolution of rocks in the channel, as well as from tributaries entering the stream [11,12]. Erosion is the process by which soil, rock, or dissolved material is removed from one location on Earth's crust and transported to another location by the actions of surface processes such as water flow or wind [13]. This process can be further divided into physical or mechanical erosion, in which rock or soil is broken down into elastic sediment, and chemical erosion, where soil or rock is dissolved into a solvent and then transported away. The transported material can range from a few millimetres to thousands of kilometres away [14, 15].

River Erosion is that in which the river erodes away the bed and banks of its channel vertically and laterally. Vertical erosion is the downward erosion which deepens the river channel. Lateral erosion is sideward erosion which widens the river channel [16]. There are four ways in how the river erode the bed and the bank. Hydraulic action is the force of river flow helps to break the rock and dragging them away from the bed and the banks of the river. Abrasion is the grinding of the rock fragments carried by the river against the banks and bed of the channel. This grinding action will widen and deepen the channel. Attrition is the knocking of rock fragments in the water against each other. The fragments are broken into smaller and become smoother pebbles. Corrosion is the process in which the water reacts chemically with soluble minerals in the rocks and dissolves them [17]. Protection of river banks is a part and parcel of river training works. Permeable structures in the form of RCC porcupine screens/spurs/dampeners are a cost-effective alternative to the impermeable bank protection works for the rivers carrying considerable amount of silt [18]. RCC porcupine is a prismatic type permeable structure, comprises of six members of made of RCC, which are joined with the help of iron nuts and bolts. It provides protection to the bank by dampening the velocity of flow along the bank [19]. The porcupines can make the river deposit its silt in and around the porcupine and it slow down the velocity of flow of the river also stop riverbank erosion. Porcupines reclaim land i.e., build up scoured or a low area to utilizable level and stop bed scour. It maintains bed level, in case there is no silt in a river (or in lean season), and silt is artificially placed inside porcupine's influence zone, the silt will get retained instead of getting washed out [20-22]. Although many studies and research have been done on a river bank protection but still intensity of flow at the point of river attack is not controlled. To overcome these issues, the novel method porcupines and groynes system combinedly has been proposed. The focus of this research is to create a sediment trapping efficiency, thereby controlling scouring. The main contribution of this paper are as follows:

- In river bank protection, Porcupines and Groynes system has been developed as a preventive measure which traps the sediments, thereby controlling scouring and porcupine has been developed to reduce the intensity of flow at the point of river attack.
- Loam based sediment modeling and MS rod based model has been introduced to evaluate the efficiency of various porcupine field models in terms of their sediment trapping efficiency with the proper discharge, water depth and sediment concentration and effective arrangement for minimizing the erosion and to get the changes in the bed form.

The content of the paper is organized as follows: section 2 describes related works, section 3 provides novel solution, the implementation results and its comparison are provided in section 4; finally, section 5 concludes the paper.

II. LITERATURE REVIEW

Suvendu Roy et al [23] studies that floods in India have been a typical yearly event. In 1954, National Floods Control Program (NFCP) was embraced a few measures to limit their decimation. However, Floods proceeded with its yearly appearance with fluctuating degrees of influencing power. Now and then, Embankment, a significant auxiliary measure for floods may make negative condition for flood and water logging condition for any floodplain. Singh et al [24] conducted a study that investigated the impacts of human activities on the flow and sediment regime as well as on the biogeochemical flux of nutrients in the Brahmaputra River Basin. The study found that human activities, such as land-use change and development practices, have a significant impact on the erosion and sediment discharge of the river, and pose a potential threat to the biogeochemical fluxes of nutrients. Additionally, demographic and socio-economic factors were found to play a role in these impacts, and the study suggests that if current practices continue, these activities will have a significant impact on the biogeochemical cycles and emissions of key elements in the basin. Furthermore, the study noted that the ecosystems in the Brahmaputra River Basin are largely shaped by the monsoon climate, and the adverse changes in the local ecological climate are likely linked to ongoing deforestation and increasing land denudation. Guwahati et al [25] The Brahmaputra Board, based in Guwahati, conducted a study in 2012 that revealed the detrimental impact of erosion on Majuli Island due to the powerful Brahmaputra River. To address this issue, the Board developed a scheme in November 1999 for the protection of the island from floods and erosion, with an estimated cost of 86.56 crores. The scheme was executed in three phases, with Phase 1 starting in March 2005 and being completed in April 2011. Phases 2 and 3 were ongoing as of 2012. During Phase 1, the use of permeable RCC porcupine screens, spurs, and dampeners were implemented at various locations, leading to a substantial arrest of erosion in affected areas. In Phases 2 and 3, the casting and laying of 1,27,396 porcupines encouraged heavy siltation, resulting in an increase in the island's area from 502.21 sq. km (2004) to 520.21 sq. km (2011). Additionally, the remaining protection works, including the completion of 5 spurs, river bank revetment, and the laying of porcupines at vulnerable locations, were targeted for completion. Overall, the efforts of the Brahmaputra Board have proven to be successful in protecting and preserving the landmass of Majuli Island. Aamir et al [26] conducted a study on the effectiveness of porcupine systems as a cost-effective measure for river training. The study was conducted in the Outdoor River Engineering laboratory of the Department of Water Resources Development and Management at IIT Roorkee, near the Toda Kalyanpur village. The research results showed that porcupine systems have a good ability in capturing sediment, with graphs indicating that trap efficiency is inversely proportional to submergence, and directly proportional to sediment concentration when keeping the Porcupine Field Density Index (PDFI) and Porcupine Field Submergence Index (PFSI) fixed. The results also demonstrated that densely configured porcupines have greater efficiency in capturing sediment, but a compromise between density and cost-effectiveness has to be made. The study also highlights that porcupine systems are very effective in low submergence and high sediment concentration scenarios.

Aamir et al [27] conducted a study to compare the performance of triangular and prismatic porcupines for erosion control. The experiments were carried out in the Outdoor River Engineering laboratory of the Department of Water Resources Development and Management at IIT Roorkee, near the Toda Kalyanpur village. The results of the study showed that, for a given sediment concentration, the trap efficiency of triangular porcupines was higher than that of prismatic porcupines. The research was supported by the graphs, which plotted the relationship between trap efficiency and the Porcupine Field Density Index (PDFI) and Porcupine Field Submergence Index (PFSI). These graphs indicated that trap efficiency is inversely proportional to submergence and directly proportional to sediment concentration. The results were compared between triangular and prismatic porcupines. The study concluded that triangular porcupines have a better performance in capturing sediment as compared to prismatic porcupines. However, it is worth noting that the use of prismatic porcupines may be more economically advantageous and can be safer for trimmed bank slopes of rivers. Aamir et al [28] logically studied the pattern of deposition caused by various configurations of porcupine field layout and hence to propose a preliminary design methodology. The experiments for their study were carried out in the Outdoor River Engineering laboratory of the Department WRD&M, IIT Roorkee, situated near the Toda Kalyanpur village, Roorkee in two phases. In phase 1, the effect of porcupines on the fluvial parameters was studied. In phase 2, the effect of various layout combinations of porcupines on the sediment laden flow of water was investigated to come up with the optimum layout combination of porcupine field to meet with the required objective of erosion control, moderate reclaim or high reclaim. Results showed that a second tier of porcupines can be placed over the outer to improve their performance in the cases of high submergence. Preliminary design template is developed which can provide the designer with the range of values of PDFI for different sediment concentration and PFSI, to achieve the desired objective of erosion control, moderate reclaim and heavy reclaim in the reach. Kalita et al [29] made critical comparisons between the performances of various models of vegetation fields (defined on the basis of some dimensionless parameters), in terms of their sediment trapping efficiency and finally compared the results with the trap efficiency of porcupine model. Results showed that sediment trap efficiency depends on the quantity of sediment that is laden in the flow, i.e., more the sediment inflow with the clear water, more will be its trapping efficiency. Sinha et al [30] made critical comparisons between the performance of various models of porcupine fields (defined on the basis of some dimensionless parameters), in terms of their sediment trapping efficiency. Results showed that that more the transverse extend of the porcupine field for a given spacing between successive retards, more will be its sediment trapping efficiency. For a given value of length of single compartment, the increase of sediment trapping efficiency of porcupine fields with increasing density of retards (represented by the ratio PFDI) gets more and more enhanced as the porcupine field gets longitudinally expanded. More the ratio between the lateral and linear extends of the porcupine field; more is its sediment trapping efficiency. For a given value of length of single compartment, the increase of sediment trapping efficiency of porcupine fields with increasing ratio of its lateral to linear spread (represented by the ratio PCDI) gets more and more enhanced as the porcupine field gets longitudinally expanded. Guwahati et al [31] studied about Majuli Island that has been under serious attack by the mighty Brahmaputra. It was studied that loss of land mass on account of erosion of Brahmaputra River right bank has been regular feature for Majuli Island. Brahmaputra Board prepared a scheme in November 1999 for “Protection of Majuli Island from floods and erosion” at the estimated cost of Rs. 86.56 crores. The work was carried out in three phases- phase 1 started in March 2005 and was completed in April 2011. Phase 2 and Phase 3 were on progress till 2012. During Phase 1, casting and laying of permeable RCC porcupine screen/spur/dampeners at various locations were done due to which erosion got arrested substantially in the severely affected reaches. During Phase 2 and 3, casting and laying of 1,27,396 porcupines were done which encouraged heavy siltation. Area of Majuli Island increased from 502.21 sq.km (2004) to 520.21 sq.km.(2011). Further remaining protection works, such as completion of 5 spurs, river bank revetment, laying porcupines at vulnerable locations, contemplated under Phase 2 and Phase 3 were targeted to be completed. Baishyaa et al [32] explored the effects of bank erosion on the river Baralia in Assam, India. The area studied situated in the district of Kamrup is quite prone to river erosion. The study focused on the pattern of erosion process and the protection measures undertaken. Primary data through survey and field observation along with secondary data from official documents and maps were processed and analyzed. Drastic shifts in the Bankline were observed and the high susceptibility of the Bankline to erosion was attributed to the high content of moisture, fine soil having less amount of clay. Other causes attributing to the bank failure were found to be erosion of bank toe, liquefaction of bank material and scour along the water line. The measures implemented were impermeable spurs, revetments but were easily eroded too. Bamboo and concrete porcupines were then implemented but also needed shank protection. Sharma et al [33] assessed the effect of erosion on the Majuli Island and its ecosystem using satellite data and survey maps. The annual rate of erosion of the island was found to be 0.71 sq.km calculated over a period of 1914 to 1949. However, for the succeeding years the annual erosion rate was alarming at 3.43 sq.km. Checks and measures undertaken by the state government post 1953 in Assam include embankment, impermeable spurs, dowel bunds which could not give results. Moreover, the utilization of solid deflecting spurs and groynes with rock armor has also appeared as strategy. Shriwastava et al [34] studied RCC Jack Jetty as a cost-effective river training measure on sound scientific basis to tackle the twin burning problems of flood and erosion along with facilitate channelization in Indian rivers. Results showed that there is significant reduction in flow velocity due to the presence of submerged jacks which depends on variety of situations such as, reduction in velocity with bigger jacks than smaller ones. Reduction in velocity is pronounced and is more enhanced in the initial stretch which then tapers off to minimize further downstream of the jack. Effect of submergence could be faintly observed. Analysis of the bed profile data has facilitated, helped in summarizing, that jetty field performed better with lower jetty field submergence index and high sediment concentration in densely configured jetty fields, erosion is also controlled. From the analysis, it is clear that [23] a significant auxiliary measure for floods may make negative condition for flood and water logging condition for any floodplain, [24] adverse changes in the local ecological climate are likely linked to ongoing deforestation and increasing land denudation, [25] the remaining protection works, including the completion of 5 spurs, river bank revetment, and the laying of porcupines at vulnerable locations, were targeted for completion, [26] porcupine systems are low submergence and high sediment concentration scenarios, [27] use of prismatic porcupines may be more economical, [28] to achieve the desired objective of erosion control, moderate reclaim and heavy reclaim in the reach, [29] more the sediment inflow with the clear water, more will be its trapping efficiency [30] gets more and more enhanced as the porcupine field gets longitudinally expanded, [31] completion of 5 spurs, river bank revetment, laying porcupines at vulnerable locations, contemplated under Phase 2 and Phase 3 were targeted to be completed, [32] Bamboo and concrete porcupines were then implemented but also needed shank protection, [33] embankment, impermeable spurs, dowel bunds which could not give results, [34] there is significant reduction in flow velocity due to the presence of submerged jacks.

III. RIVER BANK PROTECTION WITH PORCUPINE AND GROYNES SYSTEM

Protection to the river banks is normally accomplished by a variety of river training works including a marginal embankment or levees, guide banks, guide bunds, groynes or spurs, submerged vanes, cut offs, pitching of banks, pitched islands, sills, closing dykes, and longitudinal dykes. A common problem faced during floods is scouring of the river bed and bank, subsequently leading to a change in the course of the river along with losses to both land and property and the intensity of flow at the point of river attack is not controlled. Hence, the novel technique namely **River bank protection with porcupine and groynes system** has combinedly introduced in which the Porcupines and Groynes system has been developed as a preventive measure which traps the sediments, thereby controlling scouring and porcupine has been developed to reduce the intensity of flow at the point of river attack. In big Indian rivers like Ganga, Brahmaputra and Kosi groynes system have been deployed as a cost-effective measure for river training and have produced good results in capturing sediment. In the existing techniques did not consider the sediment deposition pattern for a particular discharge, water depth and sediment concentration and the effect of porcupines on the velocity of flow and their ability to capture sediment. Moreover, in previous methods the efficiency of sediment is not appropriate. Hence the loam based sediment modeling and MS rod based model has been introduced to evaluate the efficiency of various porcupine field models in terms of their sediment trapping efficiency with the proper discharge, water depth and sediment concentration and the velocity of the flow. To get the velocity of flow the acoustic dopples velocimeter is used. The loam is the combination of sand-silt-clay based model and MS rod is a mild steel rod based model with three dimensional techniques. It is used to analyze the effects of placing groynes and to find the most effective arrangement for minimizing the erosion and to get the changes in the bed form. In this study, an attempt has been made to study the sediment trap efficiency of groynes and porcupines laboratory experiments. Various configurations of layout of groynes and porcupines have been investigated to gain an insight into the sediment deposition pattern for a particular discharge, water depth and sediment concentration.

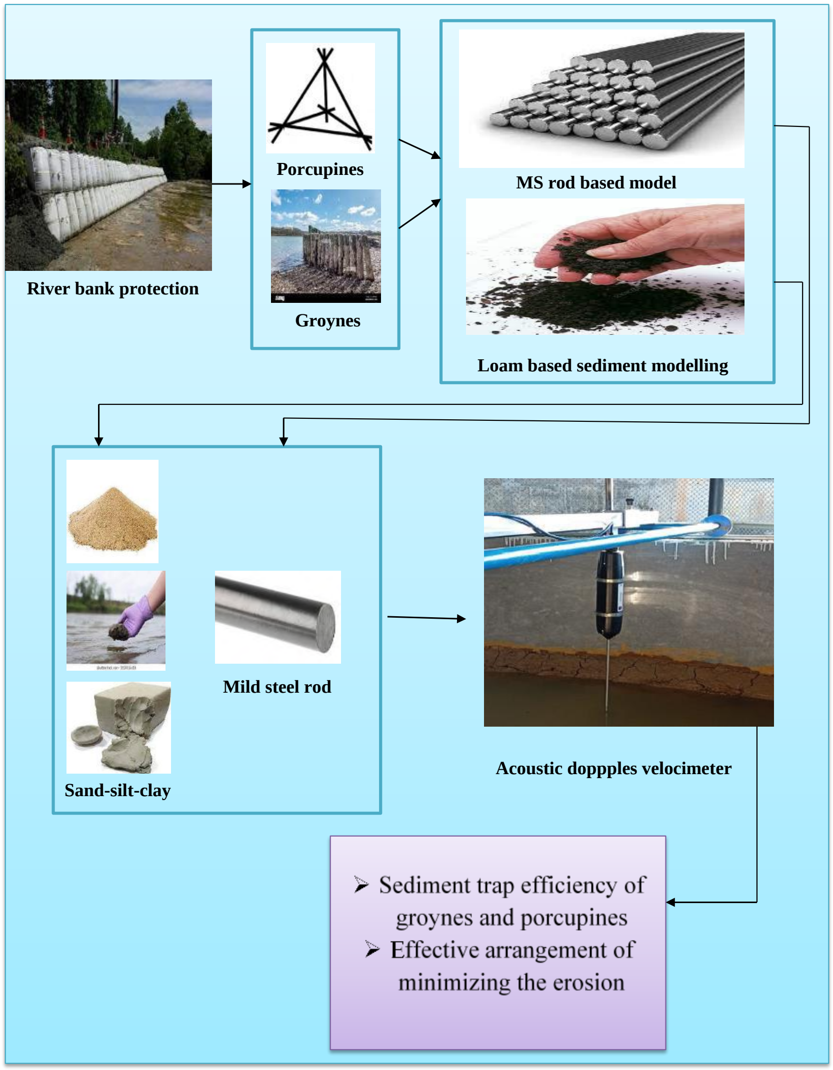

Figure 1: Architecture diagram of the river bank protection with groynes and porcupines

Figure 1 represents, for river bank protection utilizing the combined system called as porcupine and groynes system to control the scouring and reduce the intensity flow of the river attack. Then the loam based sediment modeling and MS rod based model has been developed. Here loam means the combination of sand-silt-clay and MS rod means mild steel rod has been introduced to proper discharge, water depth and sediment concentration and the velocity of the flow and effective arrangement for minimizing the erosion.

A. PORCUPINES AND GROYNES SYSTEM

Porcupines and Groynes system been developed as a preventive measure which traps the sediments, thereby controlling scouring and porcupine has been developed to reduce the intensity of flow at the point of river attack. Due to the high speed of water, contraction and expansion will occur at both the ends of the channel which will cause end effects. To prevent this, a bank made of river bed material is built immediately in the upstream and downstream side of the channel, maintaining a slope of 1.5H: 1V. A trapezoidal section of the channel features a 900 mm clear waterway between the two banks. The banks measure 450 mm in width and 300 mm in height. The bank materials to be used in the model channel are collected and tested for its properties. The soil sample from bank undergoes Liquid limit and Plastic limit test and Plasticity index has been calculated.

The bank was constructed with a slope of 1.5H: 1V on both sides of the channel. The bank is built layer by layer accordingly and the final layer is leveled to maintain shape and stability. The bed materials to be used in the channel including the sediments were collected, air dried and tested for their properties. The materials undergo sieve analysis and their passing percentage was calculated. Specific gravity and porosity of the bed material and sediments were also tested and calculated. Sediments were placed along the path prior to site where groynes are supposed to be installed. A fixed quantity of sediment was injected into the channel at the upstream of the groynes field before the flow is initiated.

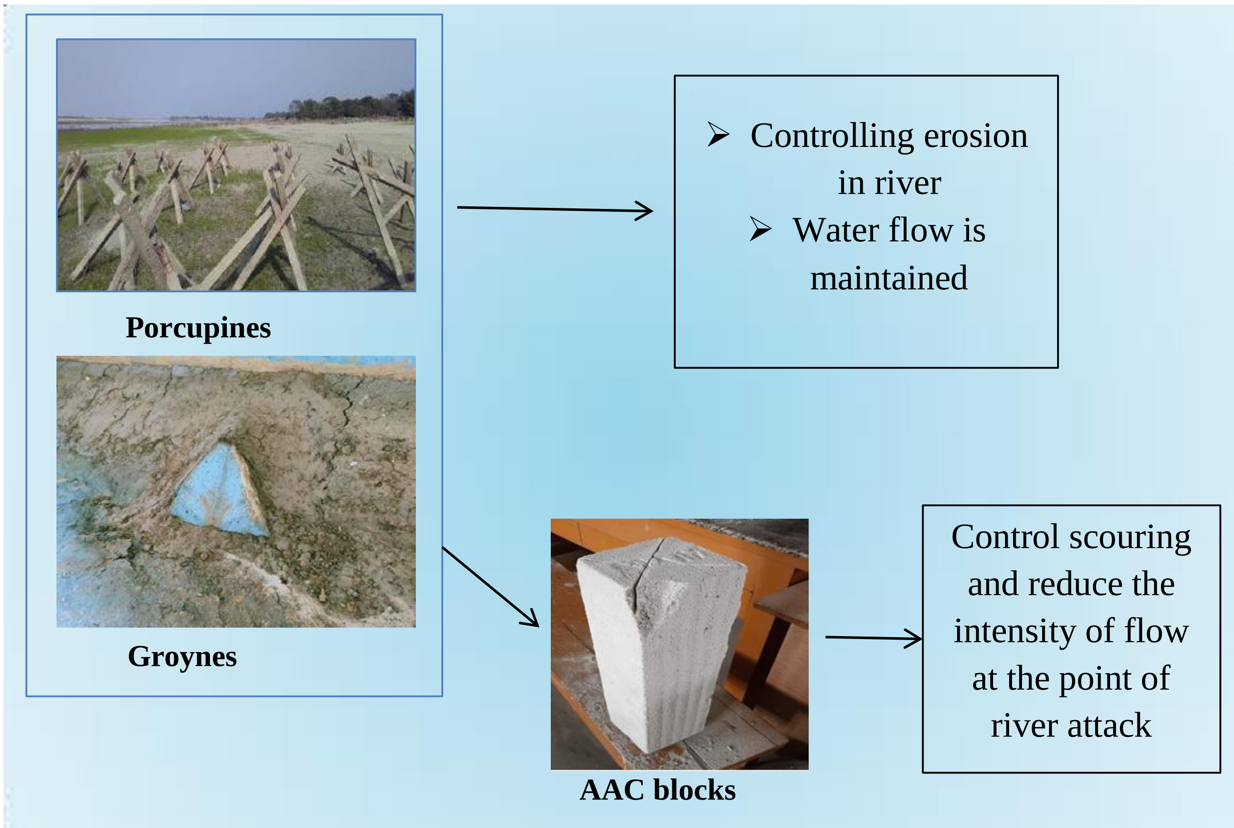

Figure 2: Architecture diagram of Porcupines and Groynes system

Figure 2 represents the combined system of porcupines and groynes. It is utilized to control the erosion in river and the water flow is maintained. By using AAC blocks placing the groynes at various angles to analyze the effects of different and to find the most effective arrangement for minimizing the erosion. Thereby it controls the scouring and reduce the intensity of flow at the point of river attack. The flow is gradually introduced into it by releasing the discharge valve slowly until a point at which the bed materials just tend to lift representing incipient motion condition. The valve was then readjusted back a little so that the velocity of flow remains a little less than the critical velocity (that corresponds to incipient motion condition). Before starting of experimentation with the groynes field models, this clear water run was continued for half an hour. Then the motor was shut and letting the water to drain out gradually from the channel without disturbing the sand bed. The position of the discharge valve (that regulates the quantity of flow into the channel) was thus fixed and was kept constant for the rest of all experiments. Sand bed levels were measured with the help of point gauge.

Then the porcupines used to efficacy of porcupine systems in controlling erosion and facilitating channelization in rivers. The bed materials were collected, air-dried and then evaluated for particle size distribution, in order to determine the relative percentages of fine and medium-grained sand, as well as fines present in the sample. Specific gravity of the sample was determined by using a pycnometer.

To replicate the natural conditions of the river bed, the simulated river bed in the laboratory channel, which had a depth of 0.49 meters, was prepared by maintaining the same relative percentages of fine and medium sand that were present in the actual river bed material sample collected from the site. This ensured that the laboratory channel closely mimicked the real-world conditions, providing a more accurate representation of the porcupine system's performance in controlling erosion and facilitating channelization in rivers. The water flow in the channel was maintained by utilizing two pumps of5 HP and 10 HP. Water from the pumps was collected in a tank, passed through a combined arrangement of energy dissipater and wire mesh screens to reduce turbulence, and then fed into the channel through an inlet. The water at the outlet was collected in a rectangular tank and the flow rate into the channel was controlled using a discharge valve at the inlet. The slope of the channel bed was taken 1:250 and the slope of the bank was taken as 1.5H:1V.

To design of groynes assuming the river has a width of 1 km and the width of the channel is 1.8m. Autoclaved Aerated Cements (AAC) blocks were used to construct groynes. AAC blocks were adopted as groynes for the experiments because they can be easily cut, drilled, nailed, and grooved to fit according to requirements.

Therefore,

$$\text{Scale Ratio} = \frac{1.8}{1000}$$

$= \frac{0.9}{500}$

which is approximately equal to $\frac{1}{500}$.

So, the scale ratio provided is 1:500.

- *Length of Groynes*

As per Clause 5.2 of IS 8408:1994,

The minimum length of the groynes = 2.5 x Maximum Scour Depth

Assuming that the anticipated maximum scour depth in the channel = 0.01 m

So,

Minimum length of groynes = (2.5 x 0.01) m
= 0.025 m

Now, assuming that, a groynes in a river is 200 m long.

Length of groynes = 200 x 1:500
= 0.4 m

The length of 0.42 m was selected for the study.

- *Effective length of Groynes*

As per Clause 5.2 of IS 8408:1994,

The maximum effective length of the groynes = $\frac{1}{5}$ x Width of Flow
= ($\frac{1}{5}$ x 1.8) m
= 0.36 m

The effective length of 0.20 m was selected for the study.

- *Top Width of Groynes*

As per Clause 5.4 of IS 8408:1994,

The top width should be between 3 to 6 m.

So, Minimum Top Width = 3 x 1:500
= 0.006 m
= 6 mm

And, Maximum Top Width = 6 x 1:500
= 0.012 m
= 12 mm

The top width of 10 m was selected for the study.

- *Freeboard*

As per Clause 5.5 of IS 8408:1994,

The freeboard of 1 to 1.5 m should be provided above the design flood level.

So, Minimum Freeboard = 1 x 1:500
= 0.002 m
= 2 mm

And, Maximum Freeboard = 1.5 x 1:500
= 0.003 m
= 3 mm

The freeboard of 3 m was selected for the study.

- *Side Slopes*

As per Clause 5.934 of IS 8408:1994,

The slope of the sides and nose of the groyne for concrete blocks would be 1.5H:1V and 3H:1V.

3.1.6 Height of Groyne

The water level in the channel is 9.5 cm and the freeboard is 0.3 cm.

Therefore,

Height of Groynes = (9.5 + 0.3) cm
= 9.8 cm

which is approximately equal to 10 cm.

The height of groynes of 10 cm was selected for the study.

- *Bottom Width of Groyne*

From Figure 3.2,

Bottom Width of Groyne = {(1.5 x 10) + 1 + (1.5 x 10)} cm
= 31 cm

The bottom width of groynes of 31 cm was selected for the study.

- *Spacing*

As per Clause 5.2 of IS 8408:1994,

Spacing of the groyne is normally 2 to 2.5 times the length of groynes.

Therefore, spacing between two groynes = (2.5 x 0.42)

= 1.05 m

Then, the porcupine models were placed across the channel bed at a distance of 9 m from the upstream end of the simulated bed in the channel. A total of three trials were done and after each run the height of sediment deposition was measured.

- *TRIAL 1*

Depth of flow = 5.6 cm
Upstream velocity = 9.33 cm/s
Downstream velocity = 5.02 cm/s
Bed level before porcupine = 19.8 cm
Bed level after porcupine = 21.1 cm
Therefore, Height of sediment deposited = 1.3 cm

- *TRIAL 2*

Depth of flow = 10.5 cm
Upstream velocity = 17.8 cm/s
Downstream velocity = 9.06 cm/s
Bed level before porcupine = 20.3 cm
Bed level after porcupine = 22 cm
Therefore, Height of sediment deposited = 1.7 cm

- *TRIAL 3*

Depth of flow = 21.1 cm
Upstream velocity = 24 cm/s
Downstream velocity = 20.4 cm/s
Bed level before porcupine = 23.3 cm
Bed level after porcupine = 2.9 cm
Therefore, Height of sediment deposited = 1.3 cm

This setup provided a controlled environment to study the performance of the erosion control measures and bank stabilization techniques in the laboratory setting. After performing this need to evaluate the various sediment trapping efficiency with proper discharge, water depth and sediment concentration and intensity of the flow by using the loam based sediment modeling and MS rod based model. Which is explained in the next subsection.

B. Loam based sediment modeling and MS rod based model

Loam based sediment modeling and MS rod based model to evaluate the efficiency of various porcupine field models in terms of their sediment trapping efficiency with the proper discharge, water depth and sediment concentration and the velocity of the flow.

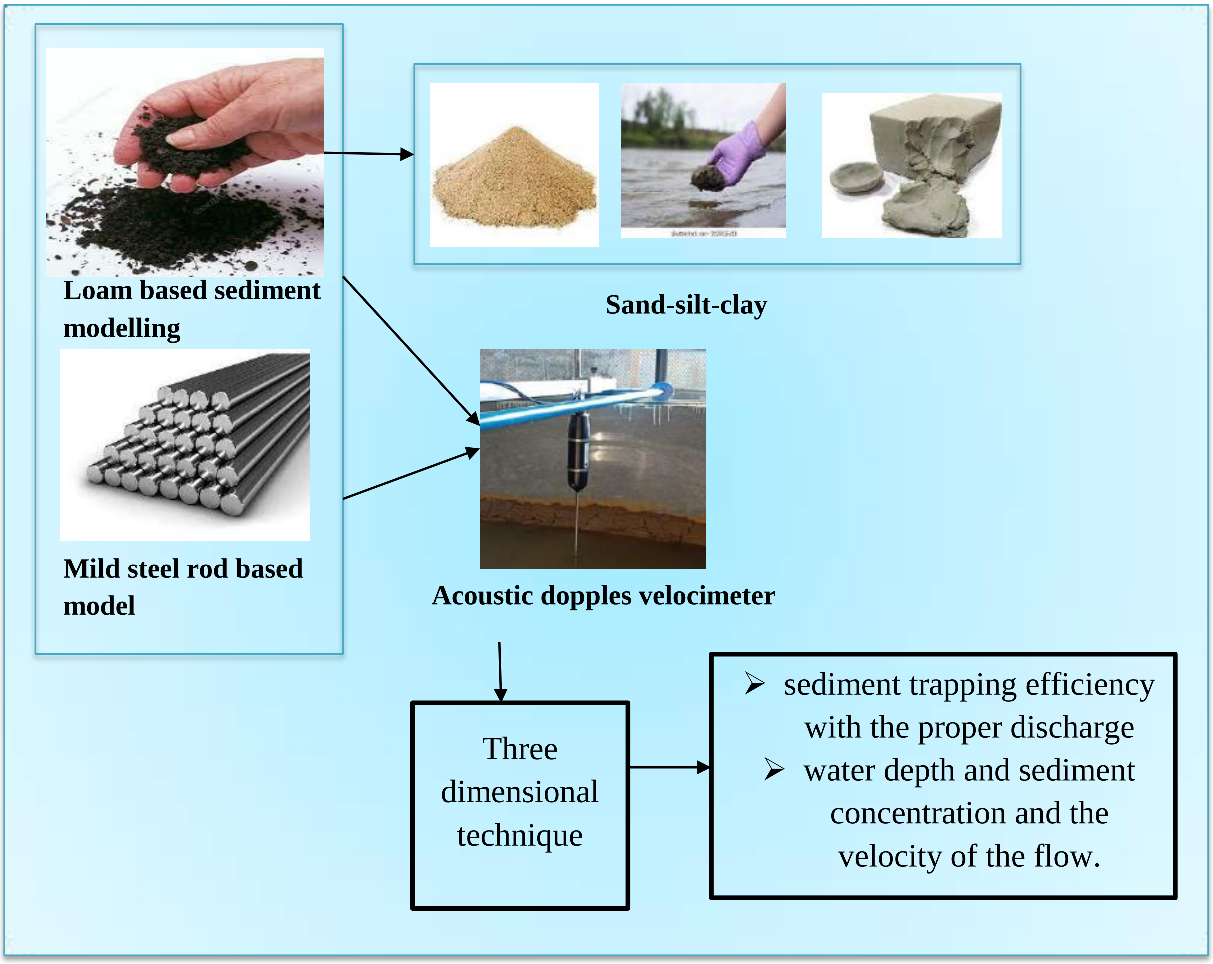

Figure 3: Architecture diagram of Loam based sediment modeling and MS rod based model

Figure 3 represents that the loam is the combination of sand-silt-clay based model and MS rod is a mild steel rod based model with three dimensional techniques. It is used to analyse the effects of placing groynes and to find the most effective arrangement for minimizing the erosion and to get the changes in the bed form. Sand was used as bed material. The properties mainly considered were gradation, particle size distribution and the specific gravity of the soil. Clay was used as bank material. The properties mainly considered were liquid limit and plastic limit of the clay. Silt sediments were injected into the flow of the channel. The properties mainly considered were particle size distribution, gradation, specific gravity and porosity of the sediment. To get the velocity of flow the acoustic dopples velocity meter is used. Velocity of water current was also measured with the help of an instrument called Acoustic Doppler Velocimeter (ADV). The velocities were measured at two points i.e at the upstream and downstream side.

The velocity of the water flow was measured with the help of Acoustic Doppler Velocimeter (ADV). The Vectrino Velocimeter is based on the principle of Doppler Effect by transmitting a short pulse of sound, listening to its echo and measuring the change in pitch or frequency of the echo. The Vectrino measures velocity components parallel to its three beams components. It reports data in Beam or XYZ coordinate systems. In groynes the XYZ coordinates are relative to the probe and independent of whether the Vectrino points up or down. The velocity was measured at two points for each trial i.e., at the upstream and downstream side. In porcupines the XYZ coordinates are relative to the probe and are not dependent on the orientation of the Vectrino. In the XYZ coordinate system, a positive velocity in the X-direction is indicated by the arrow on the X-axis.

To ensure the accuracy of the measurements, velocity was recorded at three distinct points along the flow path - upstream, midstream, and downstream - for each trial. Then, the models were constructed using MS Rods, which were 10mm in thickness and 20.32 cm in length, and were welded together. An additional 4cm length was added to each member of the model to allow for embedding them into the simulated riverbed in the experimental channel. These models were used as a representation of the actual size porcupines and the efficacy of porcupine systems in controlling erosion and facilitating channelization in rivers. The bed materials were collected, air-dried and then evaluated for particle size distribution, in order to determine the relative percentages of fine and medium-grained sand, as well as fines present in the sample. Specific gravity of the sample was determined by using a pycnometer. To replicate the natural conditions of the river bed, the simulated river bed in the laboratory channel, which had a depth of 0.49 meters, was prepared by maintaining the same relative percentages of fine and medium sand that were present in the actual river bed material sample collected from the site.

By using three groynes with different angles, after placing single groynes at various angles we place multiple groynes i.e. three groynes at various angles like 90^{o},120^{o} and 135^{o}. Each groynes is placed at an interval of 1.3m from each other. Water is flown continuously for two hours and then the motor is shut to drain out the water. Depth of bank for silt deposition before and after flow of water and volume of erosion is measured using point gauge. It was observed that outer side of channel witnessed some deposition of sediments and inner side has comparatively less deposition of sediments after placing multiple groynes.

Overall, the river bank protection utilizing the combined system called as porcupine and groynes system to control the scouring and reduce the intensity flow of the river attack. Then the loam based sediment modeling and MS rod based model has been developed. Here loam means the combination of sand-silt-clay and MS rod means mild steel rod has been introduced to proper discharge, water depth and sediment concentration and the velocity of the flow and effective arrangement for minimizing the erosion. Thereby, it effectively reduces the velocity flow of river and control the scouring problem and the efficiency of sediment trapping.

IV. RESULT AND DISCUSSION

This section includes a thorough discussion of the system configuration, implementation results, dataset description as well as the performance of the proposed system and a comparison section to ensure that the proposed system is applicable for a River bank protection with porcupine and groynes system.

A. Simulated output of proposed model

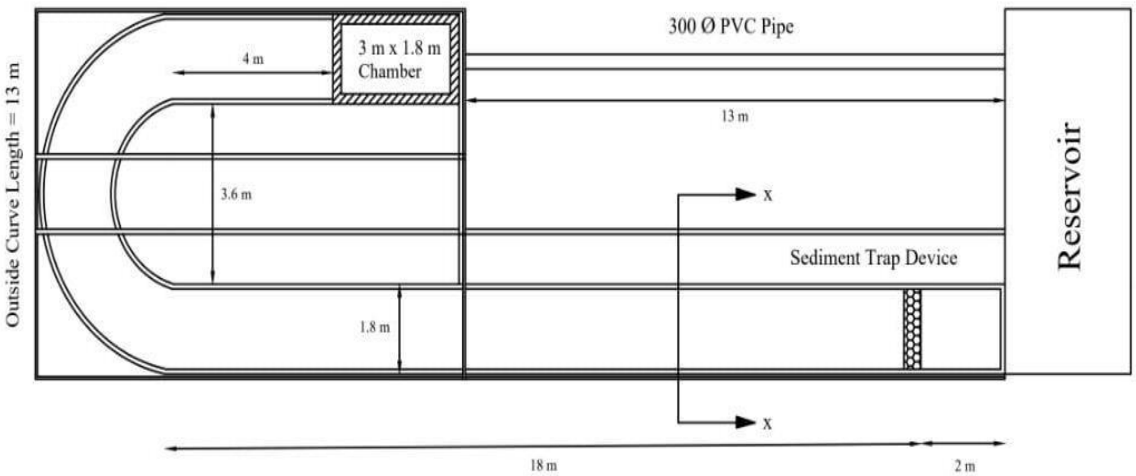

Figure 4: Plan View of the Channel

Figure 4 represents the width of the channel is 1.8 m and bed slope of 1:250 is provided. The channel wall is made up of 250 mm thick brickwork with 1:6 cement mortar. The straight portion of the channel is 18 m long and after that there is a sharp 180^o bend of outside curve length of 13 m. The total length of the channel is 40 m. The average thickness of the channel bed is about 750 mm above the concrete floor of the channel.

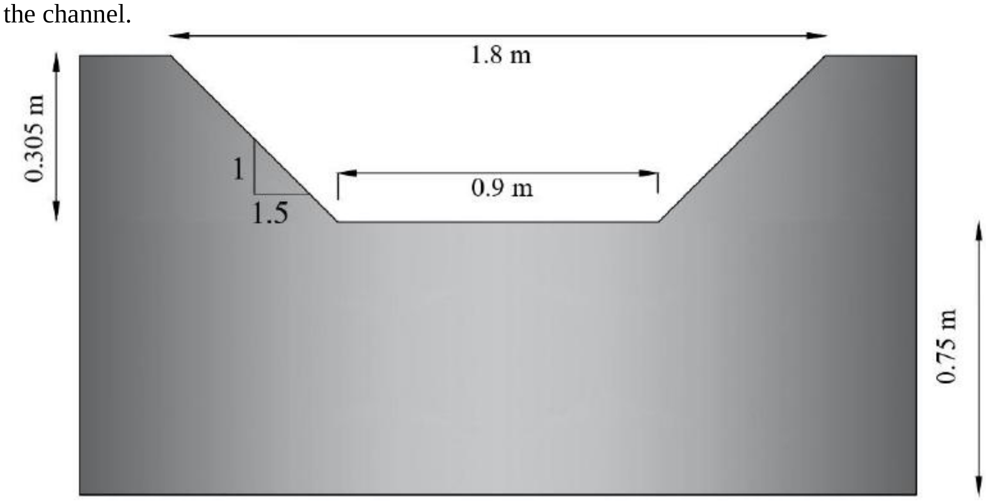

Figure 5: Cross-sectional view showing the waterway

Figure 5 represents a trapezoidal section of the channel features a 900 mm clear waterway between the two banks. The banks measure 450 mm in width and 300 mm in height.

B. Calculation of Sediment Deposition and Trap Efficiency for Each Trial

For 1st trial of groynes field model layout:

Table 1: Estimation of sediment deposition in the groynes field at section A for 1st trial

Distance along the length of the flume	Ripple Height, 'h'	Average ripple height, m	Area	Volume	Volume of sand taking porosity into consideration V' = V-33.73% V	Weight of sediment trapped (kg)
(m)	**(m)**	**(m)**	**(m^2)**	**(m^3)**	**(m^3)**	**∂= 2040.42 kg/m^3**
24.2	0.011	0.011	0.01	0.000110	0.000073	0.149
24.5	0.009					
24.8	0.009	0.009	0.0072	0.000065	0.000043	0.088
25.1	0.009					
25.4	0.007	0.007	0.01	0.000070	0.000046	0.095
25.7	0.007					
26	0.006	0.006	0.0088	0.000053	0.000035	0.071
26.3	0					
					Total weight =	0.402411

Table 2: Estimation of sediment deposition in the groynes field at section B for 1st trial

Distance along the length of the flume	Ripple Height, 'h'	Average ripple height,	Area	Volume	Volume of sand taking porosity into consideration V' = V-33.73% V	Weight of sediment trapped (kg)
(m)	**(m)**	**(m)**	**(m^2)**	**(m3)**	**(m^3)**	**∂= 2040.42 kg/m^3**
24.2	-0.002	-0.002	0.00002	-0.00000004	-0.00000003	-0.00005409
24.5	0.007					
24.8	0.006	0.006	0.00001	0.00000006	0.00000004	0.00008113
25.1	0.003					
25.4	0.002	0.002	0.000015	0.00000003	0.00000002	0.00004057
25.7	-0.003					
26	-0.003	-0.003	0.00002	-0.00000006	-0.00000004	-0.00008113
26.3	-0.001					
					Total weight =	-0.0000135

Total weight of sand deposited in the first trial
= Sand deposited at A + Sand deposited at B
= (0.402411 – 0.0000135) kg
= 0.402397 kg

Trap efficiency

$= \frac{Volume\ of\ sediment\ trappe}{Volume\ of\ incoming\ sedimen}$

$= \frac{Weight\ of\ sediment\ trapp}{Weight\ of\ incoming\ sedime}$ (since densities are equal)

$= \frac{0.402397}{5}$

= 8.05

For 2nd trial of groynes field model layout:

Table 3: Estimation of sediment deposition in the groynes field at section A for 2nd trial

Distance along the length of the flume	Ripple Height, 'h'	Average ripple height,	Area	Volume	Volume of sand taking porosity into consideration V' = V-33.73% V	Weight of sediment trapped (kg)

(m)	**(m)**	**(m)**	**(m^2)**	**(m^3)**	**(m^3)**	**∂= 2040.42 kg/m^3**
24.2	0.01	0.01	0.01	0.000100	0.000066	0.135
24.5	0.009					
24.8	0.008	0.008	0.0072	0.000058	0.000038	0.078
25.1	0.009					
25.4	0.007	0.007	0.012	0.000084	0.000056	0.114
25.7	0.007					
26	0.006	0.006	0.0077	0.000046	0.000031	0.062
26.3	0					
					Total weight =	0.389

Table 4: Estimation of sediment deposition in the groynes field at section B for 2nd trial

Distance along the length of the flume	**Ripple Height, 'h'**	**Average ripple height,**	**Area**	**Volume**	**Volume of sand taking porosity into consideration V' = V-33.73% V**	**Weight of sediment trapped (kg)**
(m)	**(m)**	**(m)**	**(m^2)**	**(m^3)**	**(m^3)**	**∂= 2040.42 kg/m^3**
24.2	-0.002	-0.002	0.00004	-0.00000008	-0.00000005	-0.00010817
24.5	0.008					
24.8	0.006	0.006	0.00001	0.00000006	0.00000004	0.00008113
25.1	0.004					
25.4	0.002	0.002	0.00003	0.00000006	0.00000004	0.00008113
25.7	-0.003					
26	-0.004	-0.004	0.00002	-0.00000008	-0.00000005	-0.00010817
26.3	-0.008					
					Total weight =	-0.0000541

Total weight of sand deposited in the 2nd trial
= Sand deposited at A + Sand deposited at B
= (0.389 - 0.0000541) kg
= 0.389105 kg

Trap efficiency $= \frac{Volume\ of\ sediment\ trapped}{Volume\ of\ incoming\ sediments}$

$= \frac{Weight\ of\ sediment\ trapped}{Weight\ of\ incoming\ sediments}$ (since densities are equal)

$= \frac{0.389105}{5}$

= 7.78

For 3rd trial of groynes field model layout:

Table 5: Estimation of sediment deposition in the groynes field at section A for 3rd trial

Distance along the length of the flume	**Ripple Height, 'h'**	**Average ripple height,**	**Area**	**Volume**	**Volume of sand taking porosity into consideration V' = V-33.73% V**	**Weight of sediment trapped (kg)**
(m)	**(m)**	**(m)**	**(m^2)**	**(m^3)**	**(m^3)**	**∂= 2040.42 kg/m^3**
24.2	0.009	0.009	0.01	0.000090	0.000060	0.122

24.5	0.009					
24.8	0.007	0.007	0.0072	0.000050	0.000033	0.068
25.1	0.008					
25.4	0.007	0.007	0.012	0.000084	0.000056	0.114
25.7	0.006					
26	0.005	0.005	0.0077	0.000039	0.000026	0.052
26.3	0					
					Total weight =	0.355

Table 6: Estimation of sediment deposition in the groynes field at section B for 3rd trial

Distance along the length of the flume	Ripple Height, 'h'	Average ripple height,	Area	Volume	Volume of sand taking porosity into consideration V' = V-33.73% V	Weight of sediment trapped (kg)
(m)	(m)	(m)	(m^2)	(m^3)	(m^3)	∂= 2040.42 kg/m^3
24.2	-0.003	-0.003	0.00005	0.00000015	-0.0000001	-0.0002028
24.5	0.009					
24.8	0.007	0.007	0.00002	0.00000014	0.0000001	0.0001893
25.1	0.004					
25.4	0.003	0.003	0.00004	0.00000012	0.0000001	0.0001623
25.7	-0.002					
26	-0.004	-0.004	0.00002	0.00000008	-0.0000001	-0.0001082
26.3	-0.005					
					Total weight =	0.0000406

Total weight of sand deposited in the 3rd trial
= Sand deposited at A + Sand deposited at B
= (0.355 - 0.0000406) kg
= 0.3555304 kg

Trap efficiency

$= \frac{Volume\ of\ sediment\ trappe}{Volume\ of\ incoming\ sedimen}$

$= \frac{Weight\ of\ sediment\ trappe}{Weight\ of\ incoming\ sedime}$

(since densities are equal)

$= \frac{0.3555304}{5}$

= 7.11

Table 7: Range of dimensional parameters for the trial porcupine field models

Trial No.	Length of Retards (L_r)	Spacing of Retards (L_s) (cm)	No. of compartment	Weight of sand injected (kg)	Length of compartment (L_c) (cm)	PFLF ($\frac{L_s}{L_c}$)	PCDI ($\frac{L_r}{L_c}$)	PFDI ($\frac{L_s}{L_c}$)
1	50	35	2	5	70	0.5	0.7	1.4
2	50	35	2	8	70	0.5	0.7	1.4
3	50	35	3	5	105	0.33	0.47	1.4
4	50	35	3	8	105	0.33	0.47	1.4
5	50	55	2	5	110	0.5	0.45	0.9
6	50	55	2	8	110	0.5	0.45	0.9
7	50	55	3	5	165	0.33	0.3	0.9
8	50	55	3	8	165	0.33	0.3	0.9
9	50	55	2	5	110	0.5	0.45	0.9
10	50	55	2	8	110	0.5	0.45	0.9

1. For 1st trial of porcupine field model layout, following values of the indices described above are adopted-
   Porcupine Field Density Index (PFDI) = L_r / L_s = 1.4
   Porcupine Compartment Density Index (PCDI) = L_r / L_c = 0.7
   Porcupine Field Length Factor (PFLF) = L_s / L_c = 0.5

Here 5 kg of sediment was injected

2. For 2nd trial of porcupine field model layout, following values of the indices described above are adopted-
   Porcupine Field Density Index (PFDI) = L_r / L_s = 1.4
   Porcupine Compartment Density Index (PCDI) = L_r / L_c = 0.7
   Porcupine Field Length Factor (PFLF) = L_s / L_c = 0.5
   Here 8 kg of sediment was injected.
3. For 3rd trial of porcupine field model layout, following values of the indices described above are adopted-
   Porcupine Field Density Index (PFDI) = L_r / L_s = 1.4
   Porcupine Compartment Density Index (PCDI) = L_r / L_c = 0.47
   Porcupine Field Length Factor (PFLF) = L_s / L_c = 0.33
   Here 5 kg of sediment was injected.

C. Variation of Scour Depths with Different Angles

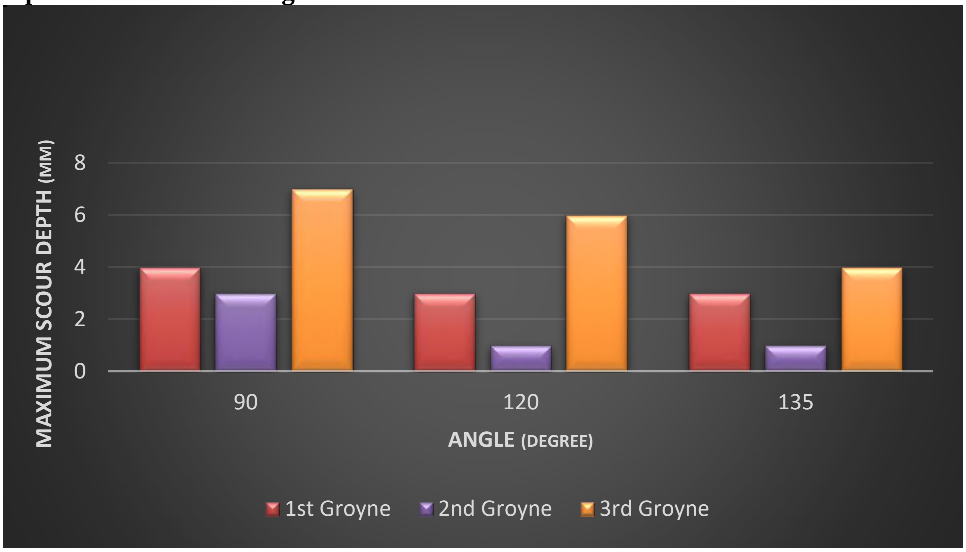

Figure 6: Plot of Maximum Scour Depths in the group of groynes

In case of multiple groynes, at a particular angle, different scour depths were observed from individual groynes in a group of groynes. When the angles of the groynes were changed, different scour depths were observed. Maximum Scour Depth was observed when the groynes was placed at an angle of 90^o near the third groynes and comparatively lesser in the first and second groynes. When the groynes was placed at higher angles, the scour depths decreased in all the groynes as compared to the groynes at 90^o.

D. Performance metrics of the proposed model:

In this section, a detailed explanation of the effectiveness of the suggested technique and the result is provided.

Figure 7: Liquid limit of the bank material

The Liquid Limit of the bank material is determined using Cone Penetration Method. From the above figure 7 the liquid limit of the bank material is 36.49%. It is determined using loam based sediment model by considering the liquid limit and plastic limit of the loam.

Plastic limit of the bank material is 19.26%.

Therefore, Plasticity Index = Liquid Limit – Plastic Limit
= 36.49 - 19.26
= 17.23%

From the above graph, conclude that the soil is Intermediate Compressible (CI). It is determined using loam based sediment model by considering the liquid limit and plastic limit of the loam.

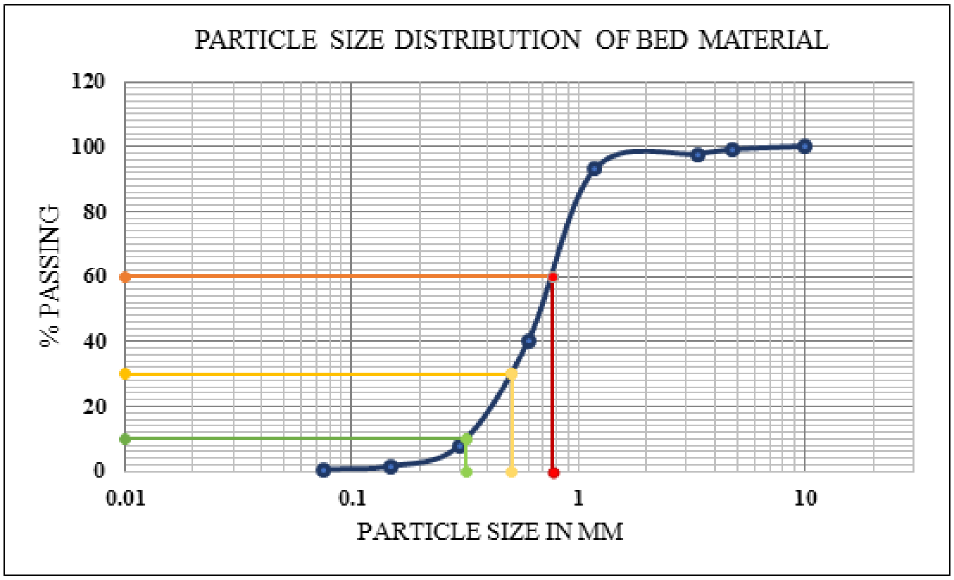

Figure 8: Particle size distribution of bed material

Figure 8 represents the particle size distribution graph. From the sieve analysis data, following results were obtained. From the above graph of percentage finer and particle size, the values of D10, D30, D50, D60, Cu and Cc were determined by using porcupine's system, the bed materials were collected, air-dried and then evaluated for particle size distribution, in order to determine the relative percentages of fine and medium-grained sand.

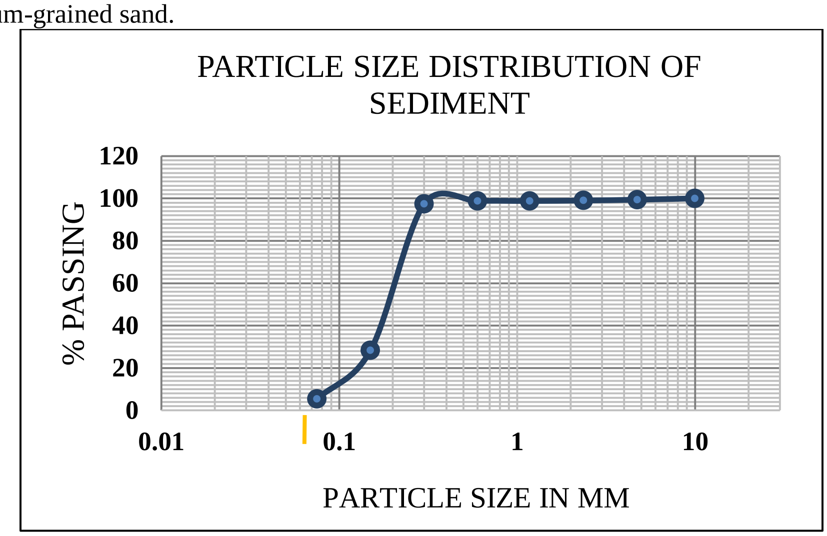

Figure 9: Particle size distribution of sediment

Figure 9 represents the particle size distribution graph, From the sieve analysis data, following results were obtained. From the graph of percentage finer and particle size, the values of D_{10}, D_{30}, D_{60}, Cu and Cc were determined. by using porcupine's system, the bed materials were collected, air-dried and then evaluated for particle size distribution, in order to determine the relative percentages of fine and medium-grained sand.

E. Comparison of Proposed model with Previous Models

This section emphasizes the effectiveness of the proposed model by comparing it with the outcomes of existing methodologies and illustrating their outcomes based on several metrics. The comparisons are made from the previous techniques with the various trap efficiency of velocity index, trap efficiency of different angle, trap efficiency of PFDI, trap efficiency of PFLF. Comparisons are made with the existing techniques such as single groyne arrangement, multiple groyne arrangement, qs-300, qs-600, PFLF 0.33, series 1, series 2 [28].

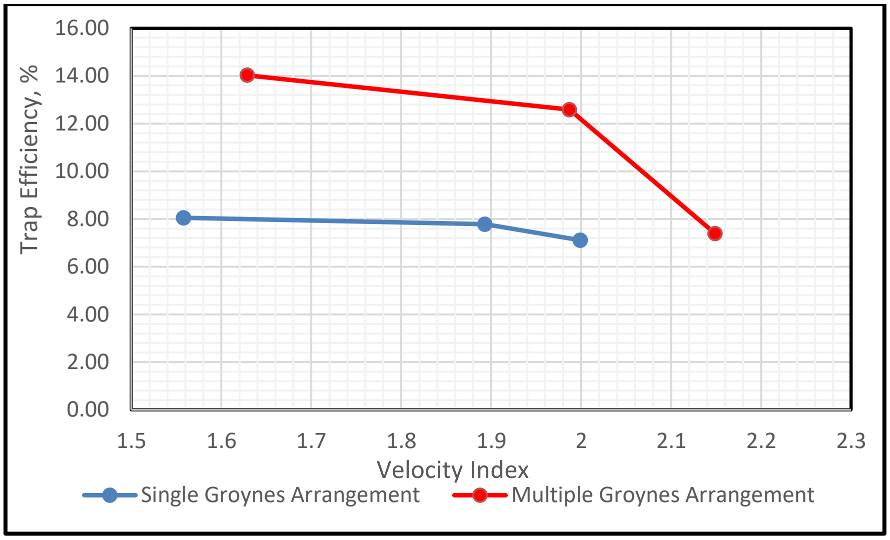

Figure 10: Plot of Trap efficiency versus Velocity Index

Figure 10 represents, in case of single arrangement of groynes, there is slight or very negligible decrease in the trap efficiency with the increase in velocity index. In case of multiple arrangement of groynes, there is significant decrease in the trap efficiency with the increase in velocity index. From the above two cases, it can be concluded that trap efficiency is inversely proportional to the velocity index.

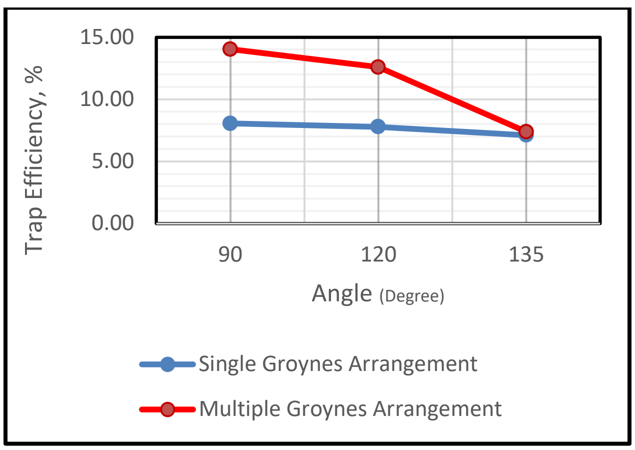

Figure 11: Plot of Trap efficiency versus Different angles of groynes

Figure 11 represents, in case of single arrangement of groynes, there is slight or very negligible decrease in the trap efficiency as the groynes were placed at greater angles. In case of multiple arrangement of groynes, there is significant decrease in the trap efficiency as the groynes were placed at greater angles. From the above two cases, it can be concluded that trap efficiency is inversely proportional to the angle of placement of groynes.

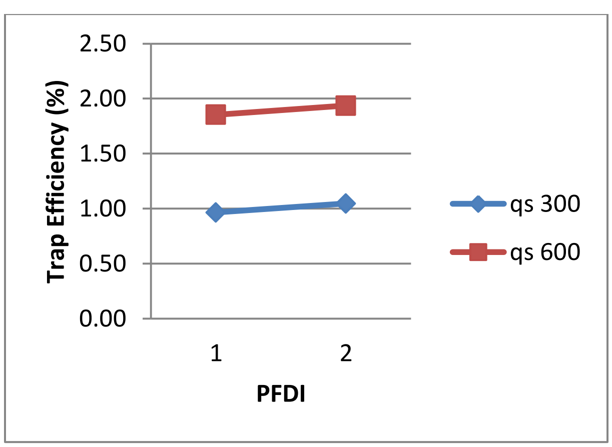

Figure 12: Plot of Trap efficiency versus PFDI

From figure 12 represent that there is more deposition of sediment for more sediment concentration and vice-versa. This means that trap efficiency increases with increase in sediment concentration, i.e. trap efficiency is directly proportional to sediment concentration**.** Series 1 represents plot of trap efficiency versus PFDI for q_s = 300 ppm. Series 2 represents plot of trap efficiency versus PFDI for q_s = 600 ppm.

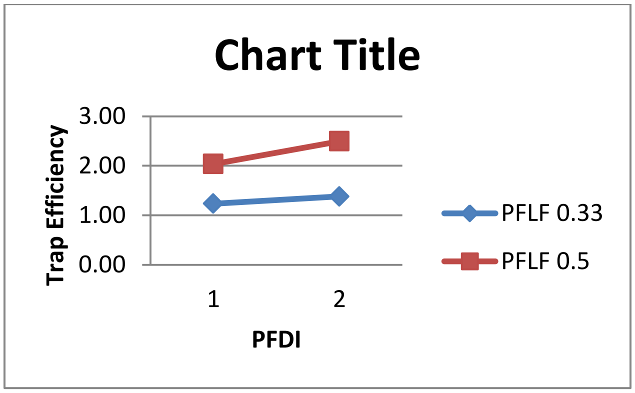

Figure 13: PFDI versus Trap efficiency for PFLF = 0.5 and PFLF = 0.33, when 6 kg of sediment

From figure 13 represents that trap efficiency decreases with increase in PFLF i.e., trap efficiency is inversely proportional to PFLF. Series 1 represents plot of trap efficiency versus PFDI for PFLF = 0.5, when 8 kg of sediment was injected. Series 2 represents plot of trap efficiency versus PFDI for PFLF = 0.33, when 8 kg of sediment was injected.

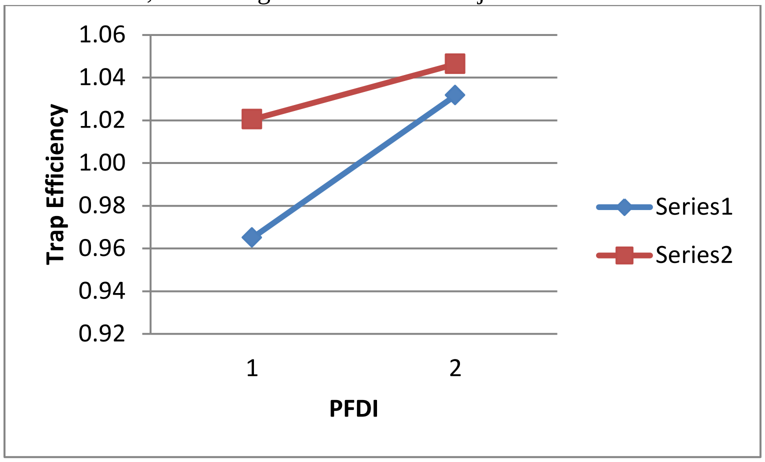

Figure 14: PFDI versus Trap efficiency for PFLF = 0.5 and PFLF = 0.33, when 3 kg of sediment was injected

Figure 14 represents that trap efficiency decreases with increase in PFLF i.e., trap efficiency is inversely proportional to PFLF. Series 1 represents plot of trap efficiency versus PFDI for PFLF = 0.5, when 5 kg of sediment was injected. Series 2 represents plot of trap efficiency versus PFDI for PFLF = 0.33, when 5 kg of sediment was injected.

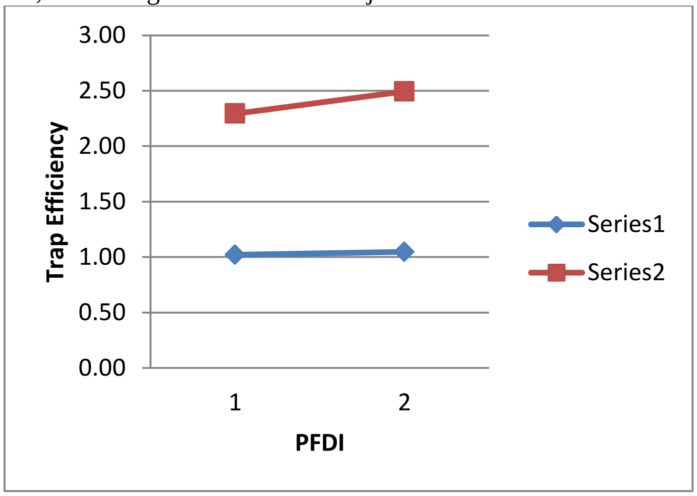

Figure 15: PFDI versus Trap efficiency for PFLF = 0.5, when 5 kg and 8 kg of sediment was injected

Figure 15 represents that trap efficiency increases with increase in amount of sediment injected i.e., trap efficiency is directly proportional to amount of sediment injected. Series 1 represents plot of trap efficiency versus PFDI for PFLF = 0.5, when 5 kg of sediment was injected. Series 2 represents plot of trap efficiency versus PFDI for PFLF = 0.5, when 8 kg of sediment was injected.

In the result area from the proposed methodology, a comparison is made with the previous study, and the techniques were explained using graphs. Overall, the comparisons are made from the previous techniques with the various trap efficiency of velocity index of 7%, trap efficiency of different angle of 7.2%, trap efficiency of PFDI of 1.02% and 1.9%, trap efficiency of PFLF of 1.4% and 2.50% when 6 kg of sediment was injected, trap efficiency of PFLF of 1.3% and 1.5% when 3 kg of sediment was injected, trap efficiency of PFLF of 1.02% and 2.50% when 5 kg and 8 kg of sediment was injected. Comparisons are made with the existing techniques such as single groyne arrangement, multiple groyne arrangement, qs-300, qs-600, PFLF 0.33, series 1, series 2.

V. CONCLUSION

To analyze and evaluate the different porcupine field configurations on sediment deposition and sediment trapping efficiency also to control the scouring of the river bed and bank by using River bank protection with porcupine and groynes system is introduced. Also, the loam based sediment modeling and MS rod based model has been introduced to evaluate the efficiency of various porcupine field models in terms of their sediment trapping efficiency with the proper discharge, water depth and sediment concentration and the velocity of the flow. A total of six experimental trials have been conducted in the channel with varying angles and depths. The velocity of each trial was measured using an instrument called ADV (Acoustic Doppler Velocimeter) in groynes and in porcupine's factors on sediment deposition patterns, including the length and spacing of retards, sediment concentration, water depth, and the inclination angle of porcupines towards the upstream direction was analyzed. The sediment deposition patterns were calculated and visualized using contour plots created with Surfer software. The velocity was measured using the Acoustic Doppler Velocimeter (ADV) and the results were analyzed to determine the relationship between different indices and trap efficiency. Overall, the comparisons are made from the previous techniques with the various trap efficiency of velocity index of 7%, trap efficiency of different angle of 7.2%, trap efficiency of PFDI of 1.02% and 1.9%, trap efficiency of PFLF of 1.4% and 2.50% when 6 kg of sediment was injected, trap efficiency of PFLF of 1.3% and 1.5% when 3 kg of sediment was injected, trap efficiency of PFLF of 1.02% and 2.50% when 5 kg and 8 kg of sediment was injected. Thus, the proposed model outperforms existing techniques such as single groyne arrangement, multiple groyne arrangement, qs-300, qs-600, PFLF 0.33, series 1, series 2.

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