STUDY OF MORPHOLOGICAL CHANGES AND EFFECTIVE COUNTERMEASURES BY USING SPUR DIKE FOR RIVER MANAGEMENT: A CASE STUDY AT INDUS RIVER SKARDU GILGIT-BALTISTAN

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ABSTRACT

The Indus River, which is heavily reliant on glacial melt, experiences an 80% increase in flow during summer, affecting Skardu City in Gilgit-Baltistan province of Pakistan. Settlements along its banks suffer from sediment deposition, and erosion of river banks owing to river channel changes, endangering agriculture, and vital infrastructure. This study aims to analyze river channel change using spur dikes as a countermeasure to assess flood mitigation measures. Using a 2D integrated model and satellite imagery, flow patterns, and erosion and deposition tendencies were simulated using various countermeasures in the Hoto and Sundus areas. Valuable insights have emerged, aiding proactive flood management to protect lives, livelihoods, and infrastructure while promoting sustainable development. This study serves as a vital resource for policymakers to make informed decisions and safeguard communities along the Indus River in the Hoto area of Skardu.

Keywords: Glacier melt, Food disaster, River channel change, Spur Dike, Sustainable development

INTRODUCTION

The upper Indus River basin spans Pakistan, China, and India, covering 322,000 sq km and is characterized by glaciers. Melting glaciers contribute 50-80% of the water of the Indus River. The river originates in China's Tibetan Plateau, flows through Ladakh, Gilgit-Baltistan, Punjab, and Sindh in Pakistan, and finally reaches the Arabian Sea. The study area was Skadru, in Gilgit-Baltistan, situated on the left bank of the Indus River, where one of its tributaries, the Shigar River, also meets the Indus.

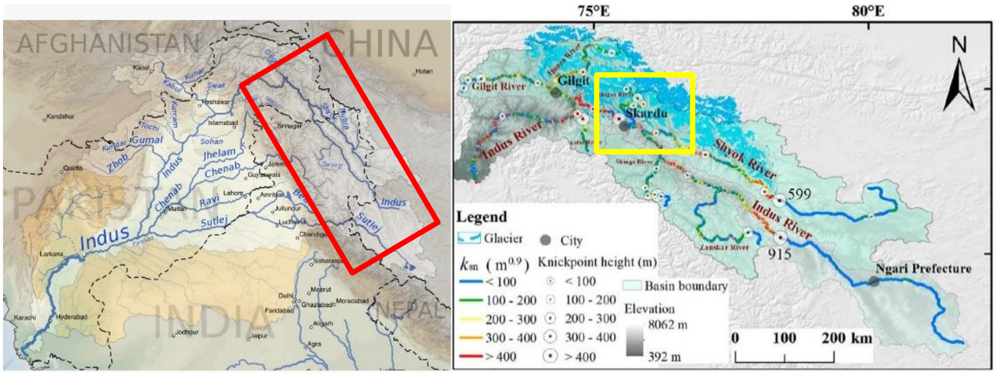

Figure 1: Study Area (Skardu, Upper Indus River Basin)

During the peak season, from June to August, the powerful Indus River experiences a significant increase in water flow, reaching approximately 8000 cubic meters per second. This surge poses a threat to vulnerable areas, such as Sundus and Hotto in Skardu, owing to changes in the river's path.

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This natural force causes severe damage to farmland, and infrastructure, and puts nearby residents at risk because of soil erosion along the left bank. Even important features, such as the Skardu International Airport and Juglot-Skardu Road, are endangered by the river's unpredictable shift along its left bank. Every year, on the left bank, the Indus River undergoes changes in shape and structure owing to the accumulation of large amounts of sediment in its middle. This leads to the formation of sandbars, that obstruct the flow of the river and alter its course, causing ongoing erosion. Understanding these processes is essential for developing effective solutions to protect the lives and property of the locals from this recurring problem.

This study aimed to understand how sandbars form and how the Indus River channel changes, with a particular focus on studying the impact of spur dikes as a countermeasure.

THEORY AND METHODOLOGY

Observation and analysis of satellite imagery: Over the course of 30 years (1985-2015), the study area experienced dynamic changes in its watercourse due to multiple floods. By analyzing a series of satellite images from Sundus to Kachura along the Indus River, we observed these significant alterations.

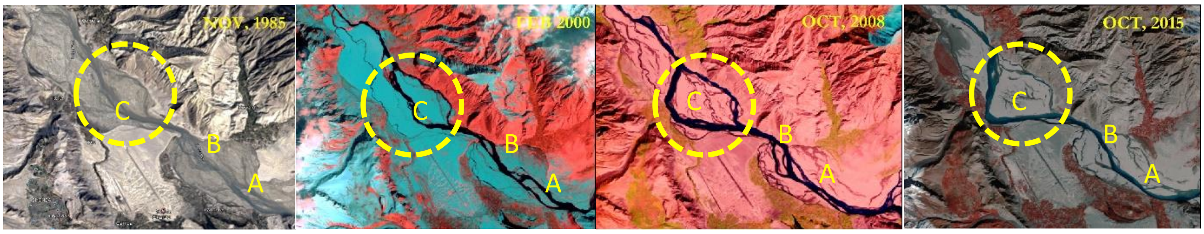


Figure 2: Satellite Imagery of Indus River channel change

Until 2000, no significant changes, in the channel were observed. However, since then, multiple substantial channel alterations have occurred owing to severe flood events. Notably, at location C, the river's bank line shifted approximately 2 km towards the left bank.

Numerical Evaluation: In the numerical simulation, we employed a two-dimensional (2D) depth-averaged governing equation. This encompasses the mass and momentum conservation equations for water flow, the mass conservation equations for suspended sediment and bed load, and appropriate erosion and deposition formulas. Specifically, we utilized the Ashida and Michiue formula for the bed load, and the Lane-Kalinske formula for the suspended load.

Computational Condition: The computational domain in the Nyas2DH solver of the iRIC was developed to understand the bathymetry of the study area. Owing to a lack of actual ground survey data, we used the digital elevation model (DEM) SRTM data with a resolution of 30m x 30m for our simulation and analysis of various results. The table below shows the calculation conditions;

Table-1: Simulation calculation conditions

Size of the calculation domain	Length = 44 km, width = 100 m to 3.5 km
Number of rows and columns	801 x 101 = 80901
Calculation time step	0.1 s
Upstream discharge	Unsteady
Sediment type	Uniform
Downstream condition	Uniform flow

Methodology: This methodology comprised two main steps. Firstly, we analyzed satellite images to observe the fan alluvial and channel changes. We then developed a 2-D depth-averaged numerical model and studied the temporal watercourse change using spur dikes as a countermeasure. To verify the proposed model, we compared it with satellite images. Next, we discuss the observed results of river course changes and conduct bed deformation analysis for different sets of countermeasures at different locations. Finally, we propose suitable countermeasures to stabilize the discharge conditions and protect riverbanks from erosion.

DATA

Topographic Data: SRTM DEM data of September 2007, obtained from the USGS was utilized, to assess topographic characteristics in the study area. Covering a 44 km reach downstream from Thorgu to Sordas, the data provides a resolution of 30 meters, enabling analysis of slopes, drainage patterns, and landforms, crucial for understanding hydrological processes. While ground survey data is preferred, SRTM DEM data serves as a valuable substitute, forming the foundation for further analysis in the study area.

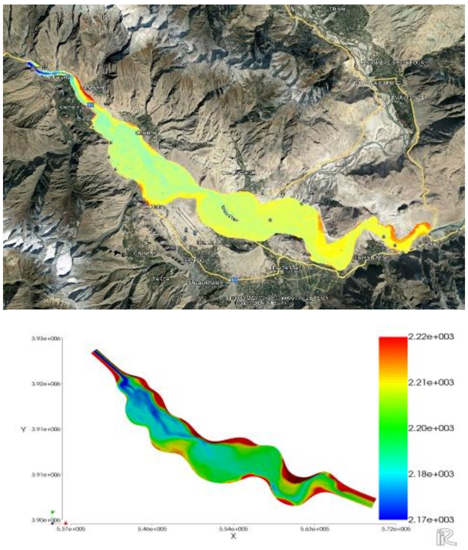


Figure 3: SRTM Sept 2007

Hydrological Data: WAPDA Pakistan provided crucial hydrological data, including discharge from the Kachura station, vital for studying the area's hydrological dynamics. The observed time series discharge from the 2008 and 2010 floods served as an input for numerical simulations, accurately representing flow characteristics during flood events. This incorporated hydrograph allowed effective analysis of the hydrological response, assessing flood risks, and understanding potential impacts on the study area. Reliable and observed data enhances the accuracy and validity of numerical simulations, ensuring better-informed decision-making in hydrology.

Suspended Sediment Concentration*:* The figure shows the average concentration of suspended sediments at Kachura station in 2010 provided by WAPDA Pakistan. During the peak season (May to September), the concentration exceeded 1000 mg/l, indicating a substantial presence of suspended particles in the water. This suggests high levels of sediment transport and potentially elevated turbidity within the river during this period.

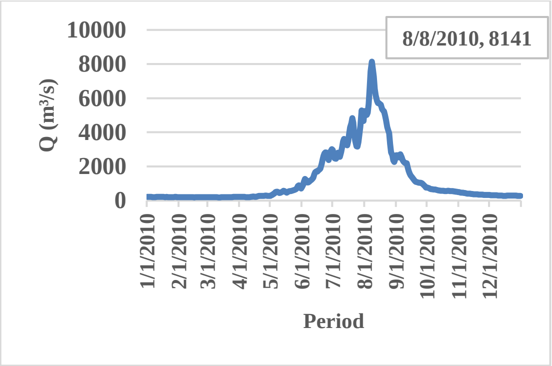


Figure 4: Hydrograph 2010

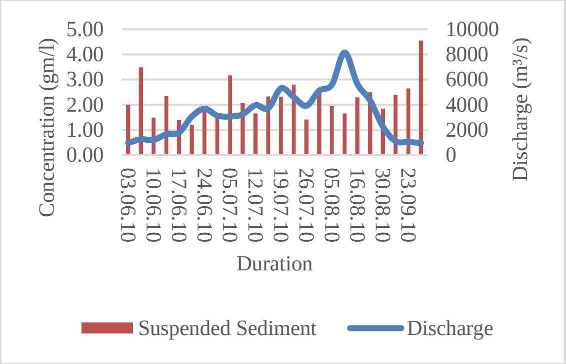


Figure 5: The grain distribution of suspended material

RESULTS AND DISCUSSION

Verification of Model*:* The model was set up with the initial morphology developed using the SRTM data of September 2007 and the model was simulated using unsteady flow of the hydrograph of 2008 (July-August) for 5 days of flood and steady flow of maximum discharge of 7000 m³/s for 18 days flood. The accuracy of the simulation results was verified by comparing various simulation cases with the corresponding 2008 (after-flood) satellite image. The flow and sediment deposition patterns from the 5 and 18-day numerical simulations were compared to validate the performance of the model.

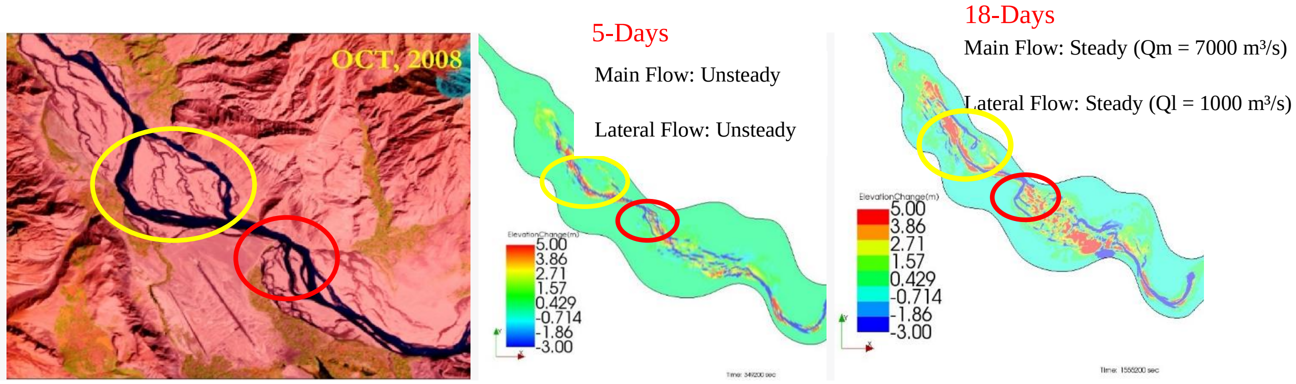


Figure 6: Comparison of simulated results with satellite imagery

Figure 6 shows how the model output matches the satellite image. The flow and sandbar patterns from the model closely resembled those in the satellite image, as indicated by the red and yellow circles, respectively.

Flow Pattern

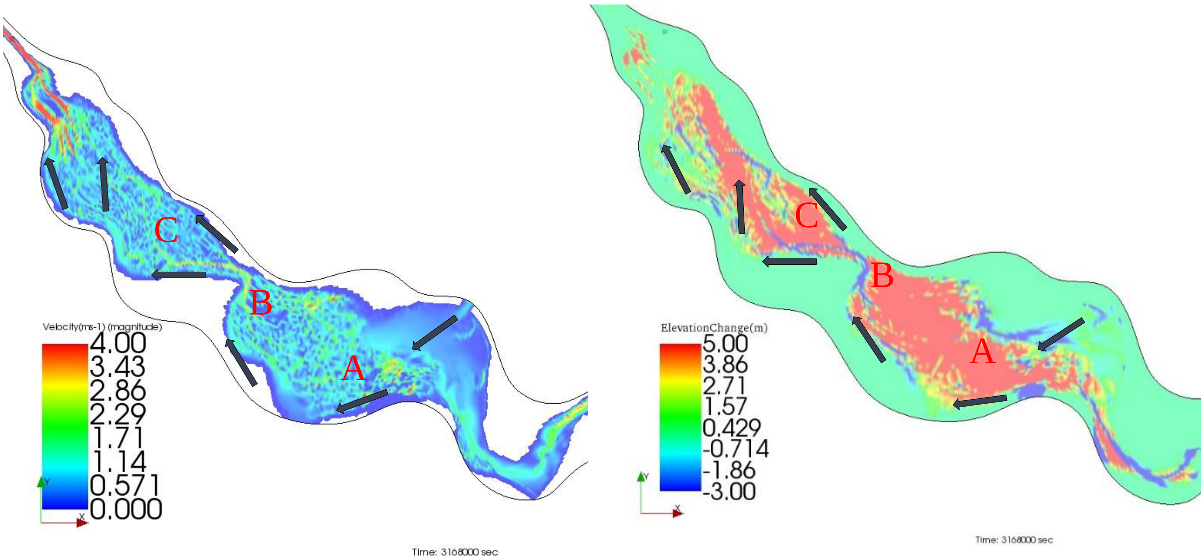


Figure 7a: Flow Pattern

Figures 7a & 7b provides a comprehensive depiction of the morphological changes resulting from a simulated flood case. The bed provide deformation initiates a surge in discharge. At locations A and B, sand bars emerge on the right bank and the middle of the river, causing the entire flow to concentrate on the left bank. Consequently, there is significant erosion on the left side, with the flow consistently impacting the left river bank. Upon reaching location C, the flow divides into two parts due to the formation of a sand bar in the river's middle area. The majority of the flow is directed towards the left bank, leading to impacts on the bank's stability and causing bank erosion.

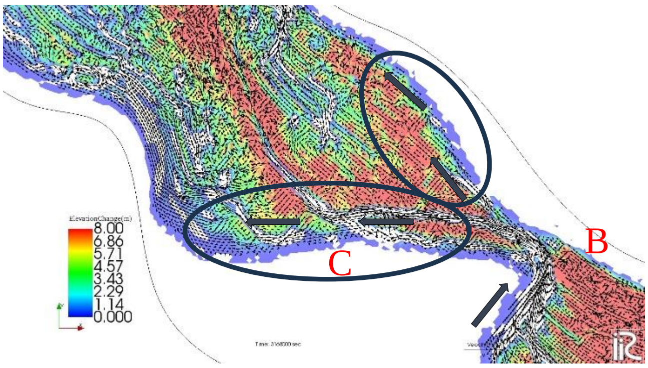
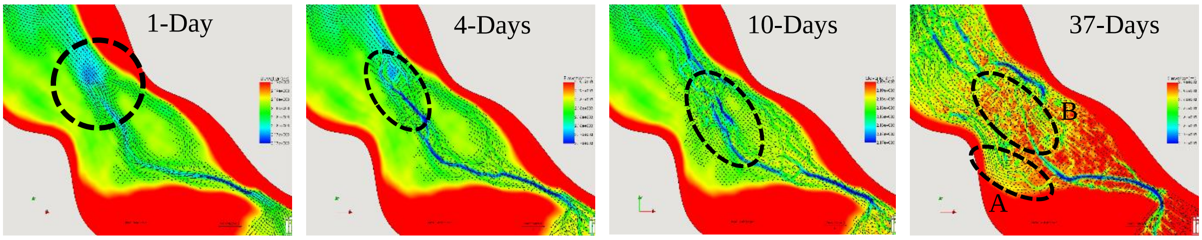


Figure 7b: Flow Pattern



The flow starts to divert because siltation occurs in the main channel.

The flow starts to rotate and divert. The main channel is becoming wider.

The channel changes its shape and shifts towards the left bank.

The main channel keeps changing due to the formation of a sand bar in the main channel. The main channel is silted up around area B, and now it is changing the path shifting towards the left bank as shown in circle A.

Figure 8: Flow Pattern and Channel Change

Sediment Deposition

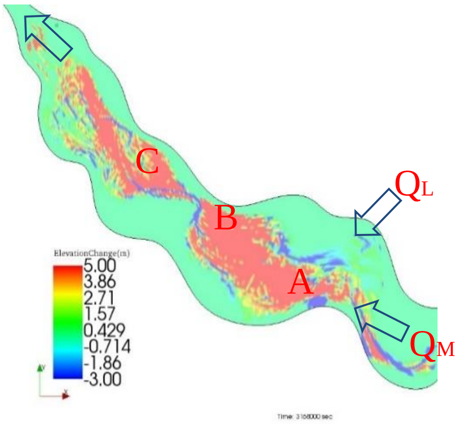


Figure 9: Sediment Deposition

Figure 9 illustrates the morphological transformations observed in the study area. As the discharge increases, there is a noticeable increase in sediment deposition and bed erosion. During the 37-day simulation period, sediment deposition reached up to 15 meters. Notably, in areas A and B, sediment deposition is most pronounced on the right side of the river, leading to a diversion of the flow towards the left bank. Additionally, sediments from the lateral flow of a tributary river also contribute to the deposition in this region. At location C, sediment accumulation occurs predominantly in the middle, resulting in the formation of a substantial sand bar. This sand bar, in turn, diverts the flow into two separate channels. The study area experiences significant morphological changes, driven by variations in discharge and sediment deposition patterns.

Effect of Countermeasures: The position, angle, shape, and size of the super dike are important for diverting the flow and changing the channel according to our requirements. To protect the left bank of the Indus River at the Hoto area location C from erosion, we applied a spur dike as a countermeasure with various options and observed the flow pattern and sediment deposition after the 11th day of the simulation. Figure 10 shows the deposition of sediments around the spur dikes and their overall effect on channel changes.

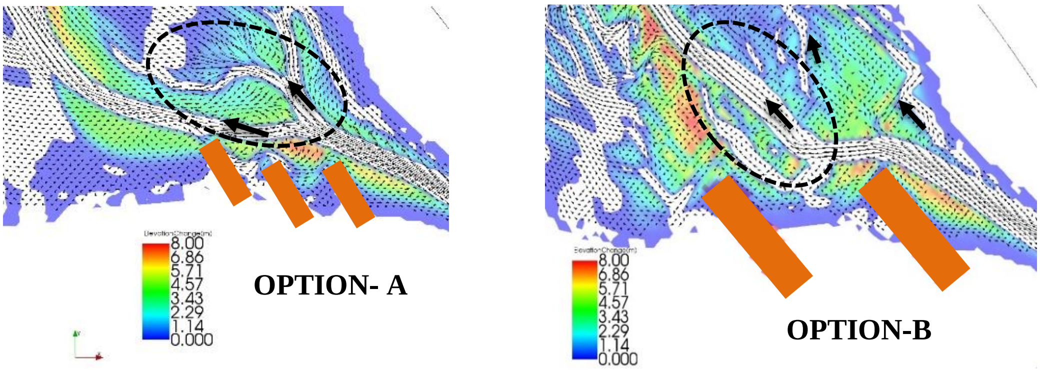


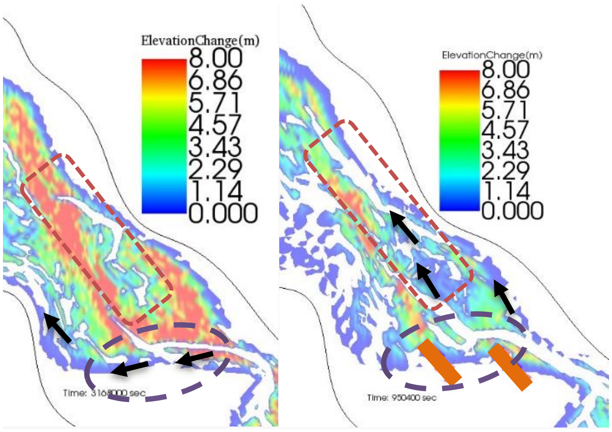
Figure 10: Effect of Countermeasures

Option-A: Applied 03 attracting spur dikes having 450 meters each angled downstream at 60º on the left bank at Hoto Area C. The flow pattern in between dikes is circulated. Positive bed elevation changes are seen between those dikes. Flow calculation is also stable. The current is also shifting away from the left bank towards the right bank.

Figure 11 shows the simulation results of bed deformation (elevation change) at location C Hoto area, with countermeasures option B in comparison to that without countermeasure case. The comparison of the results shows that there is a positive change in elevation around the spur dikes which is shown in a dotted blue circle.

The flow started concentrating on the right bank area and a deep channel is created on the right bank as shown in the dotted red rectangle.

Option-B: Applied 02 repelling spur dikes having a length of 600 meters each angled downstream at 30º on the left bank at Hoto Area C. The flow pattern in between dykes is circulated. Positive bed elevation changes can be seen around those dykes. Flow calculation is also stable. Channel change is observed towards the right bank of the river, protecting the left bank from erosion.



Without Countermeasure **With Countermeasure**

Figure 11: Comparison of sediment deposition height with and without countermeasures

RECOMMENDATIONS

This study investigated watercourse changes in the Indus River in Skardu, where the left bank erosion occurs owing to continuous channel shifts. By analyzing satellite images, we observed sediment deposition and flow shifting towards the left bank, forming sandbars. To address this issue, we proposed and evaluated countermeasures, such as spur dike, and redirecting the flow toward the stable right bank, which proved effective. Our findings highlight the impact of sandbar formation and flow patterns in the Hoto area C and the spur dike with option B was the most effective. We recommend implementing spur dikes at certain locations and directions as a countermeasure to mitigate the impact of sediment deposition on the left bank of the river. However, limited resources, such as the absence of ground survey data and upstream sediment supply information, pose study limitations. Future research should utilize actual bathymetry, sediment supply data, and discharge distribution in channels to obtain more accurate results regarding the morphological changes during each flood event.

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