STUDY ON SEDIMENT RUNOFF AND MORPHOLOGICAL CHANGES IN THE SANGU RIVER BASIN, BANGLADESH

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Extended Summary

Introduction

The Sangu River, whose basin area is about 3600 km^2, is located in the southeastern hilly region of Bangladesh. It originates from the Arakan Hills, flows northward and finally empties into the Bay of Bengal. The longitudinal slope of the Sangu River is very mild in the middle and lower reaches. The bed materials of the river are predominantly sandy in the lower reach, gravel in the upper reach, and boulders in the uppermost reach. The river is an important source of drinking water, irrigation, navigation, fisheries, and biodiversity. In the upstream area, people generally plough the hillsides for cultivation. The continued practice of deforestation and topsoil cutting in the upstream hilly region is driven by the need to fulfill various human requirements, such as food production, human settlements, transportation infrastructure, brick manufacturing, and agricultural land preparation. During the monsoon season, floods due to heavy rainfall carry sediment from the upstream hilly area to the downstream low-lying area. As a result, the downstream part of the Sangu River faces siltation, which reduces the river's conveyance, increases flooding during the monsoon season, and decreases water availability during the dry season, resulting in navigability problems and scarcity of water uses, which have adverse impacts on the natural environment (BWDB, 2021). The downstream part of the Sangu River exhibits the characteristics of a low-lying meandering channel that is subject to the influence of tidal flow. Active channel changes occur in the lower reach, causing severe bank erosion where settlement is dense. Though the Bangladesh Water Development Board (BWDB) has implemented bank protection works at a number of locations, some of them require frequent repairs. In order to gain insight into the future behavior of the river, it is imperative to conduct a scientific study. Numerical modeling is a commonly employed method for comprehending the effects of tidal flows on river morphology. In order to address such issues and promote sustainable management, this study investigates the river's sediment runoff characteristics and morphological changes in the lower reach and proposes practical measures.

Methodology

In order to evaluate sediment runoff processes, a rainfall-sediment runoff (RSR) model was developed by integrating a rainfall-runoff-inundation (RRI) model with a sediment-runoff model based on the unit channel concept. The RRI model is a two-dimensional model that can simulate rainfall-runoff and flood inundation at the same time (Sayama et al., 2012). It can simulate land surface flows, river channel flows, and their interactions on a river-basin scale. The model calculates the flow on the slope grid cells with the 2D diffusive wave model and the flow in the channel with the 1D diffusive wave model. The unit channel concept is a rational and simple method for predicting the amount of sediment runoff at any point in the river basin from time to time and over the long term. In the RSR model, the section with two inflow points and one outflow point is defined as a unit channel. A basin channel network is formed with a series of unit channels. This model allows us to obtain storage-type governing equations, which facilitate the prediction of sediment runoff processes in complex river networks. This makes the model very stable and reduces computational time (Egashira & Matsuki, 2000). A drainage basin model was prepared for the Sangu River using 30 arc sec SRTM data. Using ground-based daily rainfall, the RRI model was calibrated and validated with observed discharge data. Several equations for sediment transport are available for both bed load and suspended load transportation. However, it is important to note that these equations are often tailored to specific sites and may not be universally applicable to all river basins. The estimation of suspended load is highly sensitive to the method used for sediment runoff processes, particularly in the case of suspended-load dominant rivers, such as the Sangu River. For this reason, calculations were done using two cases with different formulas for basin-scale studies. Case 1 uses a combination of the bed load transport formulas proposed by Ashida and Michiue (1972) and the suspended load formula proposed by Lane and Kalinske (1938), and case 2 uses a combination of the bed load transport formula proposed by Egashira et al. (1997) and the suspended load formula proposed by Harada et al. (2022).

In addition, a numerical model (iRIC-Nays2DH) was used to simulate the hydrodynamics and sediment transport of the lower reach (about 45 km) of the Sangu River under realistic tidal conditions using an entrainment model for calculating erosion rates proposed by Harada et al. (2022). This model computes two-dimensional flows using the depth-averaged momentum and continuity equations in a generalized curvilinear coordinate system. The study also focuses on the impacts of tidal conditions on sediment transport as well as morphological changes. The model computational domain was created using bathymetry data. The accuracy of this model was verified through comparison with field measurement data, specifically in relation to water level, velocity, and discharge for the flow field, as well as suspended sediment discharge for sediment transportation.

Finally, the RSR model was revised and updated to include structural countermeasures for sediment management within the river basin. Several suitable sites were identified for the installation of check dams with the aim of promoting sustainable management of the river. In addition, field conditions were also observed in terms of sediment size distributions and topography changes.

Results and Discussion

The RSR model was prepared for the Sangu River basin, and one-year numerical simulations were conducted with two different cases. The results were validated in terms of suspended sediment concentration and confirmed that the Sangu River is a suspended-load dominant river and annually transports about 7.5×10^5 m^3 to 9.0×10^5 m^3 of sediment to the Bay of Bengal. In addition, finding a clear longitudinal sediment sorting in case 2 but not in case 1, we concluded that the difference between the two cases could be explained by the difference in the erosion rate of the suspended sediment formula. In case 1, the erosion rate of suspended sediment depends on sediment size, indicating that fine sediment is entrained into the water flow while coarse sediment is not entrained as much. Hence, most of the suspended sediment that is transported is very fine sediment. On the other hand, in case 2, the erosion rate depends the fraction of particle class rather than particle size, indicating that both coarse sediment and fine sediment are entrained into the water. In this way, since finer particles are transported farther with the flow while coarser ones are not, longitudinal sediment sorting is likely to occur in case 2. The field investigation revealed the same scenario as simulated in case 2. Sediment sorting significantly affects the results of the basin-scale sediment transport analysis. According to the findings from the model computations, a significant amount of sediment is transported from the upstream hilly region through different tributaries and then deposited in the middle and lower reaches, resulting in the formation of sand bars. The field survey confirmed that a significant number of sandbars were visible during the dry season in the middle and lower sections. These characteristics of the river are the primary contributors to flooding, bank erosion, and navigability issues.

The results from the analysis of the area within 45 km from the river mouth using the 2D depth-averaged model demonstrate that both river discharge and tides have an impact on the flow of a macro tidal channel, such as the Sangu River. In the Sangu River, the flow downstream is mostly influenced by tidal motions, whereas the flow upstream is influenced primarily by freshwater flows, which has a considerable impact. The bulk amount of sediment transportation occurs during spring tides near the river mouth. During a tidal cycle, the ebb tide is crucial for the transportation of sediment. Freshwater flows associated with high tidal fluctuations mainly control the morphology of the lower reach of the Sangu River.

Therefore, it is essential to control sedimentation effectively in the Sangu River basin in order to handle problems with flooding, erosion, deposition, navigation, and ecosystems. Excess inflow sediment produced by tributaries should be controlled by taking soft and hard measures. Check dams are considered to be one of the most effective and widely utilized soil conservation measures for mitigating soil erosion and sedimentation. Check dam construction in combination with land use changes can reduce sediment yield to an optimal level (Zhao et al., 2017). This analysis identified some potential sites for check dam installation. The findings suggest that check dams can serve as effective measures for controlling sediment, and regular maintenance of check dams by removing sediment can be a sustainable solution for sediment management. The potential removal of trapped sediment presents an opportunity to generate revenue for the government through its sale, given the significant demand for sediment in the region.

Conclusion

In this study, I conducted basin-scale numerical simulations to assess sediment transport processes for sustainable river sediment management, considering structural measures in the Sangu River. The simulation results show that sediment deposition occurs in most parts of the lower and middle reaches. As a result of the 2D computation for the area around the river mouth, the channel changes are strongly influenced by tidal motions, particularly in the downstream part, and within this area, the spring tide is the main cause of the channel changes. Therefore, it is essential to control sedimentation effectively in the Sangu River basin in order to handle problems with flooding, erosion, deposition, navigation, and ecosystems. According to the research, check dams can be useful tools for managing sedimentation, and regular maintenance of check dams by sediment removal can be a long-term solution.

Therefore, in addition to land use regulations in the upstream hilly area, check dam construction would be an effective countermeasure.

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