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Understanding Sediment Management

Highly vulnerable to excessive erosion and sedimentation, the Koshi River Basin needs collaborative efforts at the regional level to address this challenge

Threats to the Koshi River Basin

Due to its hilly and mountainous topography and intense rainfall during the monsoon season, the Koshi River Basin (KRB) is prone to flood-induced erosion, sedimentation, and landslides every year. These problems consequently damage property and diminish productive soils, which impact agriculture and infrastructure.

The KRB is known to have an exceptionally high sediment carrying capacity. Although the KRB represents only nine percent of the Ganges river system, it contributes nearly 25 percent of its total sediment load – 100-135 million tonnes per year.

In the KRB, unsustainable agricultural and land management practices contribute to erosion, and the loss of top soils affects agricultural productivity. Moreover, the eroded materials can adversely affect the life span of reservoirs, agricultural lands, water quality, and aquatic ecosystems. In recent years, poorly developed infrastructure has intensified sediment flow to the rivers, particularly in the middle hills of Nepal, and especially during monsoon.

Sediment produced in the upstream reaches is transported and deposited downstream in the rivers and plains of southern Nepal and northern India. The high sediment load and riverbed aggradation lead to frequent flooding and bank erosion in the downstream reaches. Amplified bank erosion can heighten the risk of water-induced disaster during monsoon and increase the likelihood of rivers shifting course.

Figure 1: **The Koshi River basin spreads over three different countries: China, Nepal and India. While the uplands in China and Northern Nepal are characterized by high elevation terrain, the alluvial plain in Southern Nepal and India are flat and agriculture intensive**

Koshi River Basin

The transboundary Koshi River Basin (KRB) extends from the high altitude Tibetan Plateau of China through Nepal to the Gangetic plains of India. Rich in water, ecosystems, and biodiversity, the KRB is home to over 40 million people whose lives and livelihoods depend on the water and land resources provided by the basin. The total area of the basin is 87,481 km^2 of which 32% lies in China, 45% in Nepal, and 23% in India. As the KRB is characterized by steep topography, the basin ranges from some of the highest mountain systems in the world, including Mt Everest, to southern plains just 25 meters above sea level.

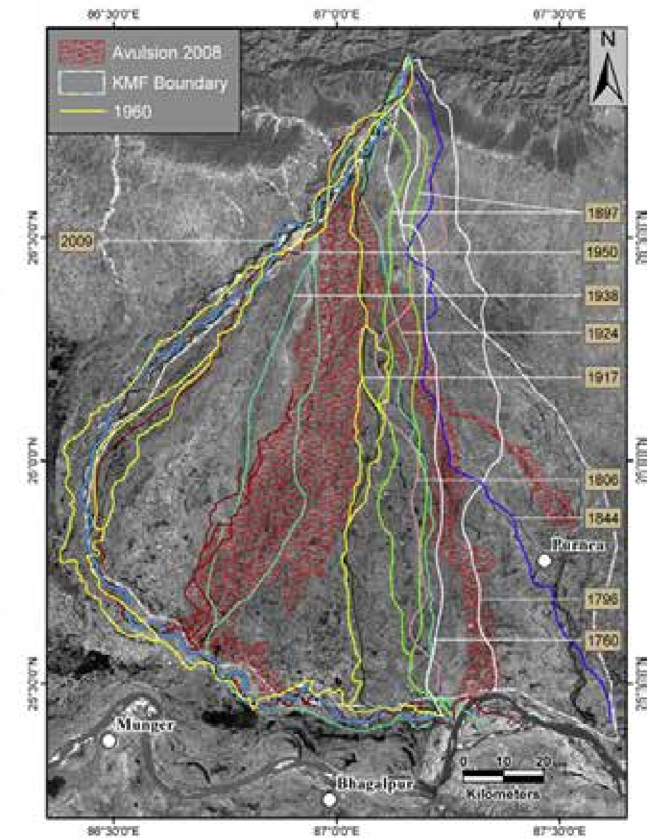
The alluvial fan of the Koshi River illustrates the dynamic nature of the river channel over the past two centuries during which time the Koshi River has moved more than 113 km across the Bihar Plains (Figure 2). Because the KRB is transboundary (like other several river basins in South Asia) soil erosion control and sediment management require a collaborative and integrated multi-disciplinary assessment and management from stakeholders across the region.

Critical issues

Land use and land cover (LULC) are considered the most important factors affecting the magnitude of surface runoff and related erosion processes. The main drivers of erosion in the KRB are natural (e.g., geology, topography, and climate) and anthropogenic (e.g., LULC change and management practices), particularly in the middle hills and high mountains.

To better understand the high sediment flux of the KRB, we need to explore the main causes of erosion and the relative

Figure 2: **The shifting of the Koshi River channel since 1760 reconstructed from historical maps**



Source: Chakraborty et al., 2010
Note: KMF – Koshi Mega Fan

quantitative contribution to spatial erosion patterns including isolated large events of mass wasting and landslides. These sediments find their way into the river through another set of processes and then into the plains of north Bihar, building the largest alluvial fan in the world. In this regard, sediment dynamics including sediment transport and deposition, in the KRB must be examined carefully.

Excessive sediment flux in the Koshi River is a clear manifestation of large-scale erosional processes that in turn affect various utility structures downstream including hydroelectric power stations, barrages, and irrigation canals. In addition, eroded soil from the agricultural lands also carries pesticides and fertilizers, which degrade water quality downstream for local communities and affect the freshwater habitats for riverine animals.

Local sedimentalogical adjustments resulting from excessive sediment loads is one of them most common causes of channel instability of the Koshi River in the alluvial plains. The 2008 avulsion triggered by a breach in the Koshi River at Kusaha is the most recent example. More than three million people in Nepal and Bihar were affected by extensive flooding and sand deposition that converted a large tract of agricultural land into a sand sea. Many parts of the affected areas are yet to recover from this disaster.

Sand and sediment deposited across the landscape after an embankment breach in 2008. Five years later, in 2013, the land remained unsuitable for farming

Preliminary research findings from the Koshi Basin Programme

1. How much erosion is taking place?
   Using the Revised Universal Soil Loss Equation (RUSLE), the maximum soil loss rate is estimated at approximately 22 tonnes per hectare per year from barren land. Similarly, the estimated annual per hectare soil erosion in agriculture areas is 5.3 tonnes and grassland 5 tonnes per hectare per year. The minimum soil erosion rate observed in the forested areas was 0.5 tonnes per hectare per year (Uddin et al., 2016).

2. How are land use and land cover changing and how does this influence catchment erosion?
   At the catchment level, land cover alteration, either positive or negative, is a slow but continuous process, influenced by many factors, including poverty, migration, population pressure, governmental policies, illegal encroachment of land, and mismanagement of natural resources by surrounding communities. Between 1990 and 2010, the KRB lost approximately 205 km^2 forest area to other land covers.

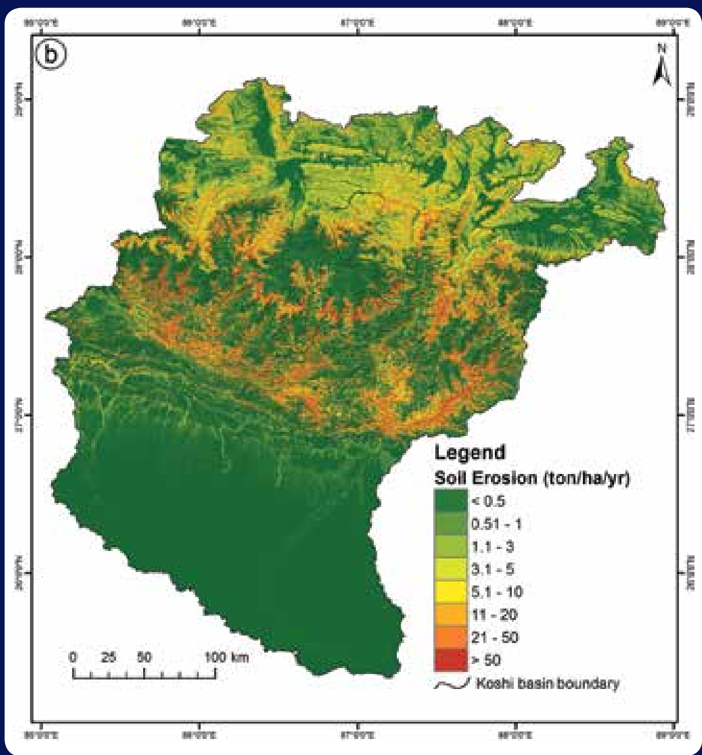
   Land cover changes influence soil erosion because it results in variations on surface roughness, the organic content of soil, the soil structure and infiltration rate, and the hydraulic connectivity within a catchment. Together these factors instigate spatial and temporal dynamics of hillslope hydrology and sediment production, and transport and delivery of sediments to rivers.

   The differences in erosion intensity among the northern, central, and southern parts of the KRB are due largely to topography. For example, the highest average soil loss per hectare occurs at elevations between 1,000 and 2,000 masl and the lowest at elevations between 70 and 100 masl.

3. How do stream power and sediment connectivity influence sediment dynamics?
   To quantify sediment fluxes from the upstream, we have applied integrated approaches including stream power computation, sediment transport capacity modeling, and hydro-dynamic modelling (HEC-RAS). Stream power (energy available for sediment transport, computed as a function of slope and discharge volume) distribution shows a close proximity with the spatial variability in slope data and provides a good proxy for sediment erosion. Significant spatio-temporal variability in sediment yield at the sub-basin scale has been documented using this approach.

Overall, our results indicate that the middle region (i.e., higher and lower Himalaya and the Siwalik region) has higher soil erosion, and a higher Sediment Delivery Ratio (SDR) compared to the upper (Tibetan region) and lower (alluvial region) reaches. While the Tamor and Bhote Koshi have exceptionally high SDR, the Sun Koshi and Tama Koshi have comparatively less SDR than other middle sub-basins. Overall, the Tamor, Dudh Koshi, Likhu and Bhote Koshi show very high SDR suggesting high sediment connectivity between source and sink.

Figure 3: **The rate of estimated annual soil erosion in the Koshi basin.**



Source: Uddin et al., 2016

4. How much is the in-channel aggradation?
   Sediment budgeting based on measured suspended sediment loads at different stations shows that the estimated sediment load downstream (at Birpur – 81 million tonnes/year) is lower than the sediment load upstream (at Chatara – 101 million tonnes/year). This suggests that 20 million tonnes of sediments are deposited between Birpur and Chatara per year. Sediment load at downstream Baltara reduces to 43 million tonnes/year partly due to the trapping of sediment upstream of the Birpur barrage and the low longitudinal slope (0.01°- 8.4°), indicating sediments deposition between Birpur and Baltara is 38 million tonnes/year.

5. How do we identify the hotspots of aggradation and degradation?
   Temporal analysis of planform morphology of the Koshi River in the alluvial reaches has helped us to characterize the morphodynamics of the river and to map specific reaches of aggradation or degradation over a period of 3-4 decades. This information has proved to be useful for identifying hotspots of aggradation that should be monitored closely for flood risk.

Recommendations

1. Identify areas of excessive erosion in the upstream and manage land and vegetation as appropriate.
   It is important to determine priority areas for promoting soil and water conservation practices in the entire basin. Spatial erosion rates and changes in erosion risk should be considered to indicate priority areas. A higher priority should be assigned to areas with a high risk of erosion, high levels of estimated soil loss, and areas with a high sediment delivery ratio. Suitable land cover management approaches as appropriate to the specific region should be considered. These approaches include gully plugging, afforestation of degraded land, crop management for vegetation cover, and constructing pits to improve infiltration.

2. Establish more stations for measuring sediment load.
   Additional measuring stations, located based on hot spot identification should be operationalized for more complete and robust data. Monitoring should employ the most current methods and technology.

3. Conduct integrated assessments of land cover changes, erosion, and sedimentation at the transboundary level.
   Land degradation, erosion and sedimentation are interrelated processes and their cause and effect relationship is exacerbated by inappropriate management practices and other environmental changes. In the KRB, these processes are transboundary in origin and require an integrated approach of multi-disciplinary assessment of stakeholders across the national borders. Similarly, data and information should be shared at transboundary level for timely and coordinated efforts. Stakeholders also need to cooperate on matters of monitoring and analysis.

4. Conduct strategic dredging of downstream stretches and consider innovative approaches for using dredged silt.
   Dredging channels to remove silt and to improve the conveyance of water flow are viable options but they require careful planning. Strategic locations for dredging need to be identified through scientific analysis with an objective to maintain the natural equilibrium profile of the river so that the inherent processes are not significantly affected. Potential dredging sites must also be examined for the amount of silt to be removed. Considering the large potential amounts of silt that can be dredged in the KRB, this material can be utilized as a potential resource for road construction, brick construction, and agricultural uses. River managers and stakeholders should plan accordingly.

5. Encourage greater transboundary cooperation.
   Erosion and sedimentation have transboundary impacts. Data and information should be shared at transboundary level for timely and coordinated efforts. Stakeholders also need to cooperate for monitoring and analysis.

Further reading

Chakraborty, T., Kar, R., Ghosh, P., & Basu, S. (2010). Kosi megafan: Historical records, geomorphology and the recent avulsion of the Kosi River. *Quaternary International*, 227(2), 143-160.

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