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Spatio-Temporal Flood Dynamics and its impact on Kosi River Morphological Changes

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Abstract:

Despite extensive multi-generational flood mitigation efforts in the Kosi River basin, monsoon season flooding persists. Braided rivers, with their intricate patterns of small stones and sandy bed streams, undergo changes due to natural and anthropogenic activities, influencing river operation. This study analyzes spatial-temporal deviations in Kosi River channel geomorphology from 1988 to 2020 using historic Landsat-TM satellite imagery and GIS practices. Findings reveal a fragile riverbed, susceptible to heavy alluviation during flood events. Morphological parameters, including sinuosity and tortuosity indices, show a strong positive relation, indicating high rates of centerline and bank line shifting, modifying stream flow. Hydrodynamic modeling using HEC-RAS 6.0.2 assesses flood dynamics' impact on morphology, indicating a gradual channel shift. The right banking side experiences the most lateral channel shifting, necessitating engineering fortifications to protect the vulnerable adjacent area. The study's results, integrated with human intervention and climate change effects, suggest river restoration tactics and safety precautions for land planning and watershed management in the Kosi River region. Detailed knowledge of morphological responses is crucial for proposals integrating diverse needs and preserving natural ecological diversity.

Keyword:
Kosi river, morphology, avulsion, hydrodynamic, GIS.

Introduction:
The Kosi River, originating from the Central Himalayas, stands as the third-largest Himalayan River, shaped by the convergence of its primary tributaries: Sun Kosi, Arun Kosi, and Taimur Kosi. The river's journey, spanning approximately 233.040 kilometers, encompasses diverse terrains, from a deep gorge upstream to an expansive alluvial plain downstream. This technical brief explores the intricate relationship between the river's morphology, human interventions, and flood hazards over a span of three decades.

River Morphology and Human Interventions:
The Kosi River exhibits a dynamic nature, evident in its constant channel shifts attributed to sediment deposition. To curb these shifts and harness the river's potential for irrigation, a comprehensive scheme was implemented in 1954. This scheme included a barrage, a dam, upstream afflux bunds, and extensive flood embankments. Levees flanking the river, finished in 1959, guided the river's path within a range of 6 to 16 kilometers. Despite these measures, the river, flowing between stop banks, still faces challenges related to sediment transport capacity and potential channel migration.

Geographical Context and Alluvial Fan:
The Kosi River basin, bordered by major watersheds, witnesses the confluence of the three

largest tributaries at Triveni, forming Sapta Kosi or Seven Rivers. The expansive Kosi alluvial fan, stretching 180 kilometers in length and 150 kilometers in width, highlights the river's historic channel dislodgment of over 120 kilometers. Historical records indicate the river's westward shift from Purnia to its current course west of Saharsa.

Technological Advancements in Flood Inundation Models:

With increasing weather alterations and frequent flooding, the need for advanced flood inundation models has become imperative. Recent advancements, combining efficient numerical approaches and high-performance computing, have significantly enhanced the precision and reliability of flood predictions. Hydraulic models, utilizing 1D and 2D approaches, employ various numerical methods and advanced hydrodynamics, offering a comprehensive understanding of river systems at different resolutions.

Role of Remote Sensing and GIS:

The study integrates remote sensing (RS) and Geographic Information Systems (GIS) techniques to assess topographical characteristics, flood hazards, and the extent of the Kosi River and its surroundings. The Copernicus 30 m resolution Digital Elevation Model (DEM) emerges as a reliable tool, boasting vertical accuracy of 1-3m and a coefficient of determination of approximately 93 percent. The accurate depiction of watershed features using DEMs is crucial for estimating hydrodynamic parameters.

The research employs Landsat imageries for nine different years (1988-2020) to evaluate morphological indices. Hydrodynamic modeling, using HECRAS-2D, facilitates the assessment of flood scenarios, including variations in flood depth, velocity, duration, and inundation extent on the Kosi River geometry.

Research Objectives:

The study sets forth three primary objectives:

- **Morphological Changes Assessment**: Examine the evolution of morphological characteristics such as channel shifting, shoaling, and erosion from 1988 to 2020.
- **Flood Dynamics Parameter Analysis:** Analyze and estimate flood dynamics parameters influenced by changes in river morphology.
- **Flood Hazard Assessment:** Evaluate flood hazard scenarios resulting from morphological changes for various flood scenarios using hydrodynamic modeling.

Findings from the research address the critical questions surrounding the morphological changes in the Kosi River and their implications. The Copernicus 30 m resolution DEM emerges as a valuable tool for accurate representation of watershed features, influencing the precision of flood predictions.

Significance and Roadmap for River Management:

The study's significance lies in its role as a roadmap for managing siltation and river migration hazards. Anthropogenic activities along the riverbanks impose strain on the river's stability, leading to continuous drifting and associated issues. Insights from the study, obtained through thoughtful application of remote sensing and GIS, provide valuable guidance for sustainable river management. The Kosi River, with its rich history of channel shifts and flooding events, presents a unique case for hydrodynamic modeling and morphological analysis. The study's comprehensive approach, leveraging technological advancements and multi-temporal geospatial data, contributes not only to understanding the river's complex dynamics but also offers practical insights for sustainable river management.

Future Implications:

The research sets the stage for ongoing monitoring of the Kosi River's morphology, emphasizing the social importance of understanding and managing its dynamic evolution. Future studies could delve deeper into specific anthropogenic impacts, integrating socio-economic considerations and proposing sustainable solutions for river management.

In conclusion, the Kosi River's complex interactions with natural processes and human interventions highlight the need for continuous monitoring and adaptive management strategies. This research, spanning over three decades, provides a foundation for future studies and policy decisions aimed at ensuring the resilience of the Kosi River basin against evolving environmental and anthropogenic challenges.

Literature Review

This article provides a comprehensive review of the role of remote sensing indices in assessing river morphology, exploring historical patterns, and addressing concerns related to erosion, deposition, and floods. Researchers worldwide have contributed to the understanding of river dynamics, with a focus on key studies such as Leopold and Wolman (1957), Schumm (1979, 1993), and others. The classification of alluvial rivers into straight, braided, or meandering patterns serves as a foundation for evaluating their features, and indices like the braiding index play a crucial role in quantifying the continuity of channel patterns. The study delves into specific cases, including the investigation of the braiding characteristics and migratory behavior of meandering rivers, illustrated by the case of the Teesta River and the Gazaldoba barrage. Satellite imagery and GIS analysis have become invaluable tools in quantifying river planform changes over time. The findings reveal the impact of human-induced alterations, shedding light on how rivers transition from small tangled patterns to highly interlaced configurations. A significant portion of the review focuses on the Ganges River system, particularly its transboundary section between India and Bangladesh. Geospatial tools have been employed over 40 years to measure stream characteristics, examine bank line shifts, and analyze denudation and sedimentation patterns. The Ganga River's geomorphic diversity methodology and the classification of reach types contribute to a better understanding of spatial variability.

The article discusses the geological processes involved in river morphology, emphasizing the influence of sediment load and the river's capacity to carry material. It explores how excessive sediment deposition leads to channel divergence, creating interconnected channels and impacting both habitable and agricultural land. The case study of the Kosi River mega fan and its delta island formation provides insights into the consequences of sedimentation and the dynamic nature of river behavior. Hydrological modeling is a key aspect of river morphology studies, dating back to the 1850s. The article highlights the evolution of hydrodynamic modeling tools, with a specific focus on HEC-RAS and its integration with GIS through HEC-GeoRAS. The benefits of numerical modeling in simulating real-world flood events are discussed, showcasing the advancements in flood risk assessment and emergency management.

The study emphasizes the significance of river sensitivity to disturbances, considering equilibrium forces, and explores the geomorphic factors influencing river morphology changes. A detailed examination of the stream evolution triangle and river evolution diagram helps identify primary determinants and drivers impacting morphological variations in response to flood events. The latter part of the review delves into flood hazard assessment, utilizing Copernicus DEM data, hydraulic models, and GIS analysis. Case studies, including the Kosi River in Bihar, demonstrate the effectiveness of combining hydrological and socio-economic methods to evaluate flood hazard index and potential threat locations.

Finally, the review provides insights into the history of losses caused by Kosi River floods, highlighting major flood events from 1954 to 2020. The economic and human impact of these floods underscores the importance of proactive measures in flood prediction and disaster management. The comprehensive review presented in this article elucidates the multifaceted aspects of river morphology assessment, emphasizing the pivotal role of remote sensing indices, hydrodynamic modeling, and GIS integration. Understanding the historical patterns, human-induced alterations, and the geomorphic factors influencing river behavior is crucial for effective flood prediction, risk assessment, and disaster management. The insights gained from this review contribute to the broader knowledge base, guiding future research endeavors and policy decisions aimed at mitigating the impact of river dynamics on vulnerable regions.

Study Area

In this research, the focus revolves around the study area, primarily the Kosi River, extending from the Kosi Barrage at Bhimnagar to the Kursela post rail bridge just before its confluence with the Ganga River, situated at approximately 86°55'41.57" E longitude and 26°31'31.39" N latitude, as depicted in Figure 3.1. The geographical range under investigation spans approximately 234 kilometers, categorized into three distinctive sections across the entirety of the Kosi River in India.

The delineation of the Kosi River into three sections is as follows:

- The higher reach, encompassing Birpur to Basua.
- The middle reach, spanning from Basua to Baltara.
- The lower reach, covering the area from the beginning of Baltara to the Kursela confluence with the Ganga.

The principal physical divisions of the Ganga basin are the northern mountains, including the Himalayan peaks and foothills, along with the snow-covered basins of the Himalayan Mountain and the Deccan plateau. The Kosi River is identified as a major tributary contributing its entire discharge to the Ganga basin. For the purpose of this project, the examination is focused on the river channel from Birpur to Kursela.

Positioned to the north of the Kosi River is the Brahmaputra River, with the Ganges River to the south. The eastern ridge divides it from the Mahananda watershed, while the western ridge line separates it from the Gandak / Burhi Gandak catchment. Notably, there is an elevation dip of 87 meters over a distance of approximately 260 kilometers between the Chatra gorge and Kursela near the confluence with the Ganga River.

The extensive river basin of the Kosi spans 95,156 km2, with 20,376 km2 falling within India's borders, as per the Hydrological-Network-Details-of-Cwc (n.d.). The western edges of Bihar's plains witness the confluence of the Bhutahi Balan and Bagmati streams with the Kosi River.

Tibet and Nepal contribute to about 80% of the total catchment area of the Kosi, with tributaries like Bagmati, Kamla Balan, Trijuga, and Bhutahi Balan connecting to the Kosi River on the western side of Bihar's plains.

A comprehensive illustration of the distribution of the catchment area of the Kosi River system is presented in Table 1 and Figure 1.

Table1: Distribution of Catchment area of Kosi River system (Sinha et al. 2019)

	In India (km^2)	Outside India (km^2)	Total (km^2)
Kosi including Hill tributaries	11070	63430	74500
Kamla Balan	2980	2465	5445
Bagmati	6320	7080	13400
Trijuga	-	706	706
Bhutahi Balan	-	1105	1105
Total	20370	74786	95156

Moving on to the central highlands, located to the south of the Great Plains, the study aims to construct a hydrodynamic model for determining the potential inundated area along river banks using DEM-generated data. In India, accessing reliable geometric and hydrological data remains a significant challenge. The Kosi River, traversing Bihar's Biratnagar, Purnia, and Katihar blocks, as well as Nepal's Kathmandu, is a trans-boundary river. Notable rivers originating in Tibet, China's autonomous region, such as the Sun Kosi, Arun, and Bhote Kosi, contribute to the Kosi River System. Designated as "Bihar's Sorrow," the Kosi River is notorious for causing annual floods, leading to extensive damage. The study area spans from the Birpur Barrage to the Kursela post rail bridge, focusing on understanding the morphodynamics of the channel, flood depth, and inundation zones corresponding to discharges released from the Birpur Barrage.

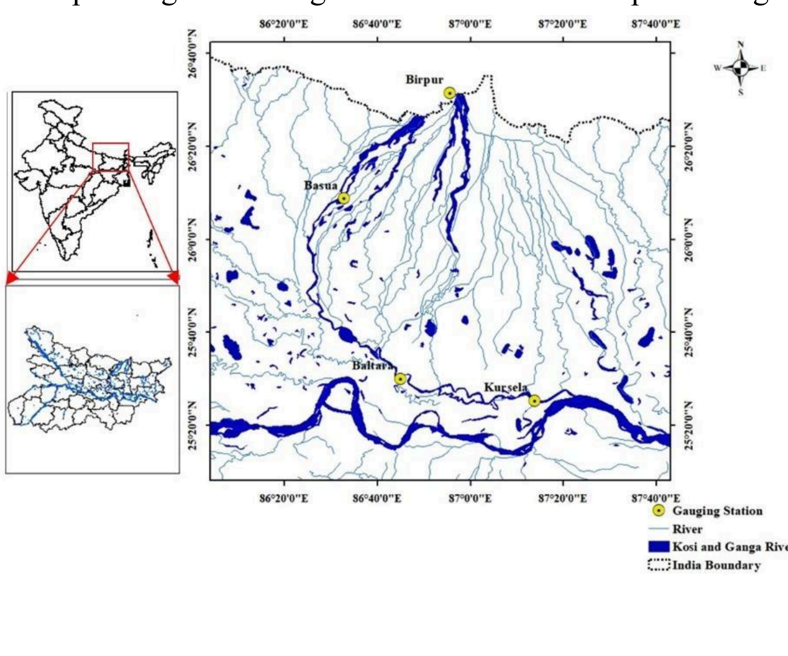

Figure 1: Plan showing study area

A significant flood event in 1954, with a discharge of 24,230 m^3/s, prompted the conceptualization of the Kosi project to mitigate the impact on North Bihar and Nepal. Levees were constructed on both sides of the river, along with a barrage near Bhimnagar, completed by 1963. However, observations over the years have indicated the inefficiency of levees in preventing river avulsion. Embankments on both banks, spurs, and afflux bundhs were constructed to channelize the flow of water and control the river's movement within specific reaches. These structures, known as spurs, serve to protect the embankment, and several spurs were constructed to redirect the primary flow of the river away from its banks, as illustrated in Figure 2 (Burele et al. 2014)

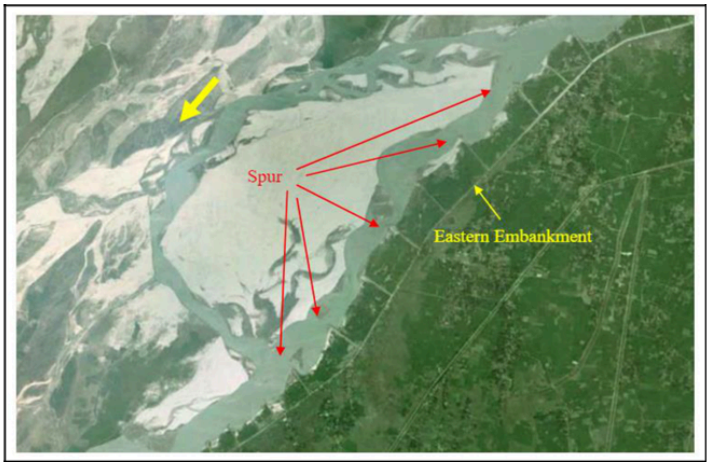

Figure 2: Series of Spurs on eastern embankments of Kosi River (Image from Google earth)

The river, previously shifting several kilometers annually, saw restricted movement due to the construction of retaining walls and spurs. The construction of embankments led to the compression of the river channel, and spurs were strategically placed to divert the main river flow away from the banks. A notable aspect is the river's morphology and the average bed slope of the Kosi River system in different reaches.

Focusing on Kosi floods, the river is recognized as "Bihar's Sorrow" due to its devastating impact, flooding the entire state annually. In non-monsoon seasons, the normal water flow in the Kosi River system is 2,166 cubic meters per second, increasing to eighteen times during floods. The largest recorded flood occurred on August 24, 1954, with a discharge of 24,200 m^3/s. The Kosi Barrage, constructed between 1959 and 1963 on the Indo-Nepal border, was engineered to withstand floods up to 27,014 cubic meters per second. The geographical extent of the Kosi sub-basin is illustrated in Figures 3.5a and 3.5b. The river drains a total catchment area of 95,456 km^2, with 31,726 km^2 in India and the remaining 63,730 km^2 in Tibet and Nepal.

In summary, the study encompasses a comprehensive analysis of the Kosi River, its morphology, historical floods, and the efforts undertaken for flood control and mitigation in the region.

Study Design

Estimation of Morphological Parameters in River Systems

The study area focused on a segment of the FCC (Flood Control Channel) where significant meandering of the river course was evident. A visual interpretation of satellite imageries was conducted using a simple magnifying system, and river courses were delineated on transparent overlays. The floodplains and boundaries of associated landforms were also traced using pattern recognition techniques. Separate overlays were created for different dates, and after superimposing multiple pairs of imageries, a comprehensive overlay depicting river courses and floodplains on different dates was generated (Thakur, 2014).

The study aims to accomplish the following tasks:

- Historical exploration of the river's deeper channel, left and right banks, reach by reach, estimating the battered/deposited expanse, and graphically representing the acquired shape, with a focus on studying river length.
- Analysis of variations in channel geometry, channel drifting magnitude, and potential locations of extreme occurrences.
- Detailed investigation of river migration using high-definition satellite images in crucial stretches.
- Reconnaissance study to examine geomorphologic deviations in the river before the construction of hydraulic structures, particularly around major structures and crucial stretches.

Sinuosity Ratio:

The planforms of rivers, classified as meandering, braided, or straight, can be characterized by their sinuosity. Sinuosity, the ratio of channel distance to valley extent, distinguishes between straight (sinuosity < 1.5) and meandering rivers (sinuosity ≥ 1.5). The research utilizes the modified sinuosity parameter, P, defined as $P = Lcmax / LR$, where Lcmax represents the stream length, and LR is the basin calculated in a straight line (Sinha, 2009).

Channel Width:

Two methods are employed to calculate the Kosi River's breadth. The dynamic channel's width is considered as the river girth in the first approach, while the distance between the river's extreme banks is used in the second approach. Channel breadth is crucial for displaying a channel's stage and evolution aspects, especially in areas with large sediment deposits or shoals.

Channel Length:

The temporal channel length of the Kosi River is assessed between both the left and right banks, covering the stretch from Birpur Barrage upstream to the confluence locations at Kursela. Additionally, the centerline length of river curves is measured to capture variations in morphological parameters.

Meander Geometry:

Meandering tendencies of the Kosi River are analyzed using parameters such as meandering amplitude (Ma), meander belt width (Mw), and meander length (Ml) for different years.

Radius of Curvature (Rc):

The radius of curvature quantifies the 'tightness' of a meander bend and is inversely proportional to sinuosity. It is calculated using the radius of a circle that fits the meandering arc from the bank-full channel's outside to the crossing point of two perpendicularly bisecting tangential lines of each meandered departure point.

Bend Tightness Index (BTI):

The Bend Tightness Index (BTI) assesses the 'tightness' of a bend by comparing the radius of curvature to the mean channel width. Lower BTI values indicate sloppy river bends, while higher values suggest powerful and abrupt bends.

Channel Centerline Migration:

The study evaluates the overall length of centerline migration from 1988 to 2020 and migration rates by cross-section to understand the river's shifting patterns.

Channel Bank Line Shifting:

As the river's centerline drifts, bank lines also tend to shift in parallel, emphasizing the fragility of bank lines to sedimentation and erosion.

Planform Change:

Rivers' planform changes, categorized as straight, meandering, or braided, are analyzed using a methodological flowchart to understand variations over time.

Hydrodynamic Modeling - HEC-RAS:

The HEC-RAS software, version 6.0.0, is employed for hydraulic modeling. This software allows for 1D and 2D simulations, enabling the assessment of flow characteristics, water level, velocity, and discharge at different locations in a watershed. The study primarily focuses on 2D modeling for floodplain assessments.

Schematization of Kosi River System / Model Reach and Data:

The Kosi River basin is modeled using HEC-RAS 6.0, covering a 20-kilometer radius of the major Kosi channel reach system. A terrain layer is generated using Copernicus DSM with a resolution of 30 meters, and the model includes both 1D and 2D computational grids.

Flow Data:

Real-time flood hydrograph data from Birpur Barrage is utilized, and water levels at gauging sites near Kosi River, including Basua, Baltara, and Kursela, are observed. The data are crucial for understanding flood scenarios, river morpho-dynamics, and variations in water levels. The Standard Modeling Approach. (Gibson et al. 2017) The approach is shown in Figure 3 and equations 3.1.

$$Z_2 + Y_2 + \frac{a_2 V_2^2}{2g} = Z_2 + Y_2 + \frac{a_1 V_1^2}{2g} + h_e$$

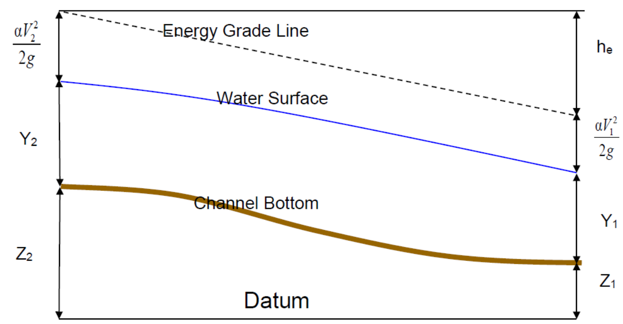

Figure 3: Representation of terms in energy equation(USACE 2016)

Moreover, since the terrain characteristics within a grid cell are identifiable, a connection can be established between the storage volume of the grid cell and the elevation of the water surface. This relationship is commonly known as a stage-storage curve, as described by Perry (1960) and the United States Army Corps of Engineers (USACE, 2016). The water surface elevation for each grid cell is computed at every timestamp, with the resolution and outcomes of the model being contingent on the dimensions of the grid cells.

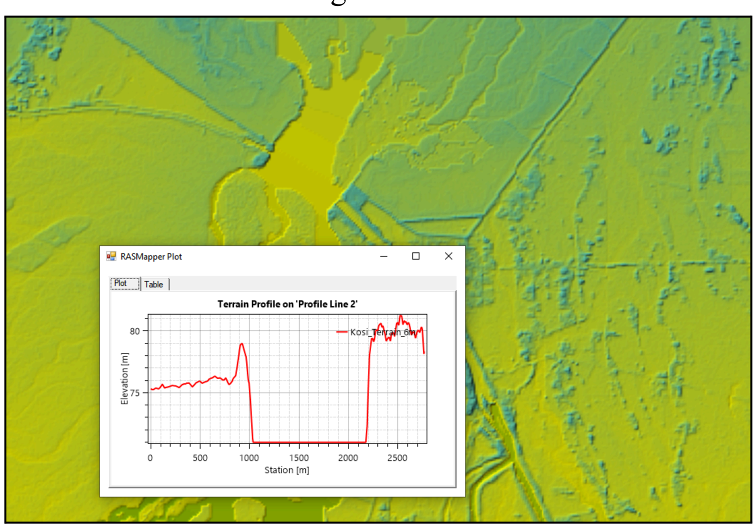

Figure 4: Unit Surface Layout.

The DSM (Digital Surface Model) and terrain layers are outcomes obtained from satellite imagery, specifically representing top surface elevation profiles. It is crucial to include elevation data for areas beneath water bodies, such as river bed elevations, to accurately simulate results. Figure 5 illustrates the Kosi floodplains, highlighting the presence of western and eastern embankments, which could influence flooding patterns and potential lateral breaches.

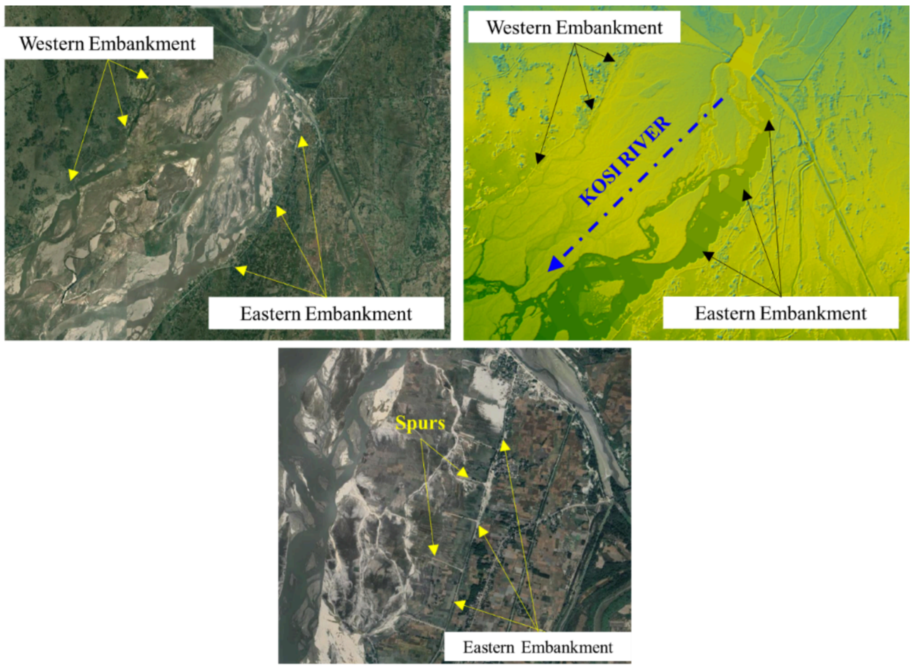

Figure 5: A portion of Kosi River, showing existing structures and floodplain.

Flood Hazard Assessment:

The flood hazard assessment is based on a methodology proposed by Wade et al. (2005), incorporating flood depth and velocity maps generated from hydrodynamic modeling. The Flood Hazard Rating (HR) is calculated using the equation HR = d * (V + 0.5) + DF, considering depth (d), velocity (V), and debris factor (DF). The hazard rating map is classified into warning, low, moderate, significant, and extreme degrees of flood hazard.

Table 2.: Flood Hazard classification according to (Wade et al. 2005)

Hazard Rating	Degree of Flood Hazard
<0.75	Warning
0.75-1.5	Low
1.5-2.5	Moderate
2.5-3.75	Significant
>3.75	Extreme

In conclusion, this comprehensive study integrates remote sensing, morphological analysis, and hydrodynamic modeling to provide a detailed understanding of the Kosi River system's behavior, offering valuable insights into potential flood hazards and changes in river morphology.

To examine the dynamics of the river channel, the alterations in the channel configuration from 1988 to 2017 were examined. The river channel consistently undergoes significant changes in its flow path throughout the entire stretch. Oscillation zones, identified based on the Planform Index, point bars, and other elements of river classifications, exhibit frequent variations in magnitude. It's important to note that this study focuses on estimating only a limited set of parameters for the Kosi River. The ground observed data and CWC published data records, which was received was used to evaluate the model results. The inundation boundary computed by HEC-RAS was compared to the satellite image of the flood extent for the year 2018, 2019 and 2020. For better stability of 2D Kosi model with manning's value 0.020, 0.022, 0.2 for Channel, Floodplains and urban areas respectively were assessed.

Between the 13th and 23rd of July 2020 (over an 8-day period), extensive flooding significantly impacted around 11 districts in north Bihar, covering an estimated area of approximately 16,837 square kilometers. This was primarily a result of heavy rainfall in these regions. In the year 2019, around the 20th of July, a flood affected approximately 4,799 square kilometers across a total of 11 districts. Additionally, during this period, the floodwaters receded, leading to the filling of drains and streams, and the riverine areas remained inundated. Figure 6 illustrates the Land Use and Land Cover (LULC) map indicating the flood-affected areas across various districts of Bihar. The analysis is based on SAR images from July 26, 2020. The affected districts include a total of 11 regions: Begusarai, Samastipur, Khagaria, Madhepura, Darbhanga, Saharsa, Bhagalpur, Khagaria, Munger, Supaul, and Madhubani.

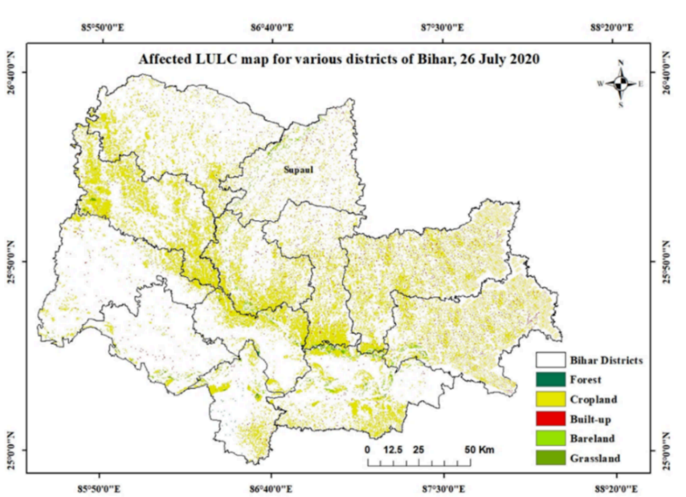

Figure 6: Affected LULC map for various districts of Bihar based on analysis of SAR images of 26 July 2020

Similarly, Figure 7 presents the LULC map showcasing flood inundation across multiple districts in Bihar. This analysis is based on SAR images from July 20, 2019, affecting a total of 11 districts: Begusarai, Samastipur, Khagaria, Madhepura, Darbhanga, Saharsa, Bhagalpur, Khagaria, Munger, Supaul, and Madhubani.

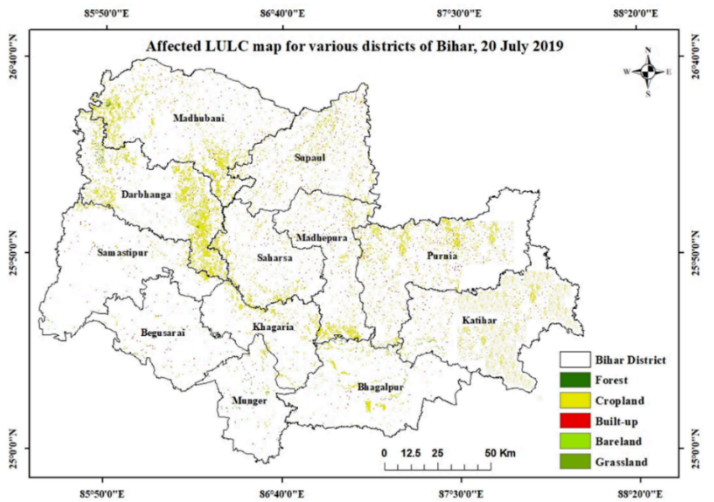

Figure 7: Affected LULC map for various districts of Bihar based on analysis of SAR images of 20 July 2019

Flood Velocity

The 2D modeling method also provides crucial information on flood velocity. The maximum velocity is determined for each cell within the computation meshes throughout the entire 31-day simulation period, irrespective of when it occurred. However, flood velocity might not pose the primary threat to developed areas in various scenarios. Therefore, it is imperative for relevant authorities to prioritize the maintenance of flood mitigation infrastructure in both urban and peri-urban regions.

Flood Inundation Depth

The flood inundation depth is determined through the 2D modeling approach, considering wet cells at any point during the 31-day simulation period, regardless of the specific timing of the maximum depth recorded. In Fig. 6.37 and Fig. 6.38, locations such as Bhaptyahi, Dagmara, Nirmali, Kishanpur villages, Kusaha chowk, and Simrahi villages could experience flooding with depths exceeding one meter. Additionally, when water levels in the Supaul district reach the height of protective levees, urban and peri-urban areas in the Biraul blocks are prone to inundation.

Flood Hazard Assessment

The evaluation of flood hazards is grounded in hydrodynamic factors, reflecting the risks posed during monsoons to urban areas (Australian Disaster Resilience Guideline 7-3, 2014). Flood extent, depth, and velocity derived from the HEC-RAS 2D scenarios were utilized in this analysis to classify and evaluate flood hazards.

The flood hazard maps, generated for the 2019 and 2020 flood events in the Kosi River, Bihar, were analyzed. These maps clearly highlight the hazard levels concerning land use, including settlements, agriculture, and roads. Each pixel's flood hazard score was categorized into five classes, ranging from 1 (least hazard) to 5 (maximum hazard), based on the severity of the hazard. High degree of hazard index at villages Gobargada, Kusaha chowk, Ganpatganj, Bhaptiyahi, Pirahipatti, Murus etc. It can also be observed that the braidedness of river is not affecting the degree of hazard index, which is serious situation of extreme flood disaster.

Supaul, Madhubani, Saharsa, Darbhanga, Madhepura, and Purnia exhibited significant impact, with flood inundation areas of approximately 11091 km^2, 13549 km^2, 20729 km^2, 22174 km^2, 22636 km^2, and 33535 km^2, respectively. On July 26, 2020. Meanwhile, in Figure 9, during July 20, 2019, districts Supaul, Madhubani, Darbhanga, Madhepura, Bhagalpur, and Purnia showed notable effects, with inundation areas measuring 6226 km^2, 7736 km^2, 8229 km^2, 5529 km^2, 3224 km^2, and 10195 km^2, respectively, among other districts in Bihar.

Proposal

A) River Protection Area:
   a. construction on sides of the river should be strictly prohibited
   b. resilience space of the river channel should be reserved
   c. Installation of Velocity dampeners in the unprotected reaches

B) Ecological restoration area
   a. Scale of agricultural land should be strictly controlled
   b. farmland and fruit forest should be retreated to restore the natural community
   c. avoid soil erosion and water pollution
   d. protect diverse habitats and increase biodiversity

C) Town Connection Area
   a. illegal buildings occupying the river should be retreated
   b. Transform single-channel to a multi-channel river
   c. main channel should be used for flood discharge
   d. tributary should be used to improve sediment transport capacity and the quality of habitat
   e. Beautification of ghats
   f. Recreational zonal demarcations

Global Framework:

1. Action on Climate (ACT)
2. Asia Foundation - Gorakhpur Environmental Action Group - Centre for Policy Research in India, and with ISET–Nepal and Policy Entrepreneurs Inc. in Nepal
3. Sendai Framework for Disaster Risk Reduction 2015–2030
4. Other initiatives

5. “Cooperation Across Borders for Strengthened Capacity and Action” UNDRR’s Global Platform 2022

Institutional policy frameworks for planning and monitoring:

- FMISC : Flood Management Information System (FMIS) with technical assistance from the World Bank
- CWC : field unit of the River Management, Planning, Monitoring etc.
- NDMA: to promote a national resolve to mitigate the damage and destruction caused by natural and man-made disasters
- KVK: aims at assessment of location specific technology modules in agriculture and allied enterprises, through technology assessment, refinement and demonstrations
- BSDMA : State level measures focused on Disaster Risk Reduction (DRR) and mitigation.
- NHP: to strengthen the capacity of targeted water resources management institutions in India.
- National River Policy: will ensure that the rivers can be rejuvenated through participation of communities at all levels.
- WDC-PMKSY : “Neeranchal” integrated Watershed program

CONCLUSION

The core concept of morpho-dynamic changes and hazards in the Kosi River has been thoroughly examined, quantified, and integrated spatially for morphological studies. Utilizing 2D hydrodynamic modeling, the study delves into the spatial-temporal patterns of depth, duration, inundation extent, and velocity, contributing to hazard assessment and identification of the Kosi River's behavior and drifting pattern.

A notable occurrence of active channel drifting is observed predominantly at Piparihatti village, extending to Bapitti villages along the Kosi River. The assessment of temporal statistics reveals a shifting pattern, with the upstream reach drifting southeastward and the downstream reach drifting southwestward.

A comprehensive comparison of the meander pattern of the Kosi River is developed for the years 1988, 1992, 1999, 2001, 2008, 2011, 2015, and 2017. This methodology highlights the emergence of new curvy bends in recent years, leading to silting up of the river bed and the formation of cut-offs from the previous geometry. This situation results in a dampening of velocity in specific areas, causing waterlogging in villages like Dadpur, Murla, and Dhamra Ghat for more than 29 days.

Satellite-based observations indicate that the existence of the Birpur barrage has no significant impact on river morphology change. Noteworthy changes occur in the shifting of the main river course at Bhaptiyahi-Nirmali and Basua, approximately 47 km and 60 km downstream of the barrage.

River training structures such as embankments, spurs, and guide bunds act as velocity dampeners, transforming floodplains into new shoals/islands, and river bed erosions are detected in areas with steep bed gradients over time. During flood events, levees have been overtopped/breached at some locations, potentially due to an elevated Kosi River bed, resulting in inundation in Supaul district villages. Changes in the river's carrying capacity are observed through cross-section analysis in areas such as Pirahipatti, Kaleanpur, Tharbitia, Dharah, and Baspitti villages from DEM.

Among the twenty-four observation locations, villages near the Kosi River, including Hanuman Nagar, Nirmali, Supaul, Kishanpur, Biraul, Kusheshwar Asthan, Dhamra Ghat, Naugchhiya, Sonbarsa, and Nauhata, fall under an extremely high flood hazard zone. The flood hazard map, based on flood depth and velocity, classifies reaches 0-50 km, 75-100 km, and 160-230 km as extreme threat locations.

The study's outcomes provide valuable insights for future planning, river training management, and the selection of adaptation strategies for the region.

Conclusion

The paper attempts to understand river and its importance in social, economic, environmental and sustainable context and how this its importance is impacting the river and its floodplain. To study that various hydrological, hydraulic and water quality measures are considered before, during, and after the interventions are proposed to be conducted in the study. The pilgrimage events, encroaching the flood plains and illegal agriculture practices inside the flood plain operates as an external source of human disturbance, rendering the floodplain lively. As a result, the study aims to give the greatest service to agriculture and propose new eco-friendly and sustainable river training works while minimizing environmental impact. Create long-term opportunities for river-dependent communities to sustain the river's landscape and people's livelihoods by developing a river zone that has a lower environmental impact and encourages river-based interventions mentioned above.

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Conflict of Interest

Authors has no conflict of interest to declare.

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