

**REMOTE SENSING BASED MULTI-SCALE
GEOMORPHOLOGICAL STUDY OF LOWER KOSI RIVER
BASIN**

UNRAVELLING THE MYSTERIOUS KOSI

Vilakshna Parmar



**DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY DELHI**

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UNRAVELLING THE MYSTERIOUS KOSI

by

Vilakshna Parmar

Department of Civil Engineering

Submitted

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to the



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Dedicated to my family and my loving husband.

Certificate

This is to certify that the thesis, entitled “**Remote Sensing based Multi-Scale Geomorphological Study of lower Kosi Basin - Unravelling the mysterious Kosi**”, being submitted by **Ms Vilakshna Parmar** to the Indian Institute of Technology, Delhi, for the award of **Doctor of Philosophy**, is a record of bonafide research work carried out by her under our joint-supervision. The thesis work, in our opinion, has reached the standard, fulfilling the requirements for the said degree. Further, we certify that this submission is Ms Vilakshna ’s own work and that, to the best of our knowledge and belief, it contains no material previously published or written by another person which to a substantial extent has been accepted for the award of any other degree or diploma of any University or Institute, except where due acknowledgement has been made in the text.

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Professor,
Department of Civil Engineering
Indian Institute of Technology Delhi



Prof R Maheswaran
Assistant Professor,
Department of Civil Engineering
Indian Institute of Technology
Hyderabad

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Vilakshna Parmar

Abstract

The Himalayan rivers flowing in the Indo-Gangetic alluvial plains are highly dynamic, owing to the large volume of water and sediment generating from the mountain slopes of geologically young Himalayas. Kosi is one of the major and most dynamic Himalayan Rivers that drains the Indo-Gangetic plains. The river is notorious for its hyperkinesis which lends the river its characteristic course instability and frequent morphological avulsions. The river has shifted 120 km in 250 years progressively westward.

Many theories have been advanced to explain this aberrant but anomalous propensity to shift course. These may be grouped into two broad categories namely (i) Autocyclic processes, and (ii) Tectonics processes. Autocyclic processes allude to the natural phenomenology of upland and riverbank erosion and sediment deposition and arguably, the latter theory has been the more dominant viewpoint amongst researchers and other investigators in their quest to explain the observed migration of the Kosi. A serious drawback, however, has been its failure to explain the recorded preferential westward translation of the river.

This study presents a credible and an encompassing metaphysical hypothesis to explain the geomorphological evolution of Kosi's course and is supported by a detailed examination of available topographical maps, footprints of paleo-channels and historical literature. Critical review of traditional viewpoints with a plausible argument for the river migration is also presented. The author proposes that Kosi's migration and its geomorphological evolution may be a response to underlying multi-scale basin processes including neo-tectonic movements and causing a westward creeping, limited extent upheaval. The result is a transverse tilt in the river base that exaggerates its western bank cutting rate.

The study highlights the imperativeness for a better understanding of the complex morphodynamics of Kosi basin as an aid for implementing river training and/or management initiatives in the region. This study proposes a new perspective and framework for understanding the morphological characteristics of the dynamic Kosi River using the remote sensing and hydrodynamic techniques.

Kosi River is a prime subject to study fluvial geomorphology as it displays many of the fluvial morphometric features in its short journey to River Ganga. At reach scale, it creates various planforms such as braids, anabranches and meanders. Whereas, at the basin scale, it forms a

tributary river network as well as a distributary alluvial megafan. The study formulates an alternative approach for remote-sensing based geomorphological characterization of the large-dynamic rivers. The satellite imageries provide footprints of the evolution of river dynamics. These capture the morphometric features and position of the river in time, and thus variations in these features can be examined. These changes then can be analysed to understand the underlying dynamics.

The study reclassifies the river-reaches on the basis of their planforms- (1) straight, (2) braided, (3) anabranching, and (4) meandering. The reaches in these planform zones have different evolution dynamics and thus, also have significant differences in terms of channel stability. The upper and lower reaches of the river, which lie in the straight and meandering zone respectively are morphologically stable. Whereas the middle reaches (braided and anabranching) are rapidly evolving and are critical. The study also presents the effect of anthropogenic intervention on the complex morphology of the Kosi Basin. In anabranching zone, the river has shown gradual westward movement and is skimming along the western embankments. The Kosi and Baghmata confluence also lies within this zone. The two rivers do not have a definite point of confluence but forms a looped network, which is continuously evolving.

The study also points out that unlike many other rivers, Kosi flood plains are not straightforward. The 2008 Kosi floods are the example of the same. The intuitive understanding of the floods is in proximity to the river. However, in Kosi River the nodal point of the flood plays a decisive role in mapping the flood inundated area. This can be alluded to the complex topography of the river.

The flood of 8th August 2008 is arguably amongst the severest in the history of the Bihar floods. Many investigators attribute this catastrophic event to a breach in the eastern embankment of Kosi near Kusaha, 12 km upstream of Kosi barrage. Following it, the river is said to have 'avulsed' back into one of its old historical courses. This study suggests an alternate understanding that Kosi's locally dynamic riverbed morphology may indeed have been a likely trigger for the aforementioned catastrophic event of 2008. Study suggests that changes in bed morphology may be attributable to development of critical sediment deposition patterns due to the natural interplay between fluvial dynamics and the hydrodynamic influence of Kosi Barrage. The phenomenological causality for this 2008 event has been established

based on inferences from 2D hydrodynamic simulation of flood flow propagation in Kosi for pre- and post-barrage bed morphological scenarios.

Apart from complex morphogenesis and morphodynamics, the Kosi River also poses a great challenge due to the extensive flooding caused by its waters, and, in its wake, the large-scale destruction and socio-economic disruption is common in North Bihar. Lower part of Kosi Basin (LKB), downstream of Chatra Gorge, has been a system of concern for the natives, water managers, Government of Bihar, and Government of India. The country witness annual episodes of flood and inundation lasting for many more months disturbing the life of the natives. The implicit assumption of stationarity is often overlooked while understanding the rivers, causing gross assumptions in the flood management and planning, which was clearly evident from the 2008 Kosi Floods.

In the present study, the paleochannels of Kosi are proposed as the flood channels for effective flood management of the non-stationary Kosi. The efficacy of the paleochannel system has been evaluated by employing the graph-theoretic approach. The paleochannel network was found to transfer nearly 35% of flood volume stress. Moreover, the paleo network system was found resilient to small perturbations further increasing the reliability of the flood management system. Thus, the study proposes and structures a non-invasive strategy to alleviate the flood problem of the region.

The present study offers a more comprehensive and rational understanding of the morphogenesis of Kosi River, which recognizes Kosi as a non-stationary system. The study provides a coherent tool for morphological study and characterization of rivers using remote sensing techniques, which can be implemented for large dynamic rivers. The paleochannel framework developed in the study will enable the decision makers for making a sustainable flood management strategy for the region.

Keywords: Non-Stationary Rivers, River Shifting, Avulsion, Course Instability, Fluvial Geomorphology, Kusaha Floods, Bed Morphology, Megafan, Morphodynamics, Paleochannels

सार

इंडो-गंगा के जलोढ़ मैदानों में बहने वाली हिमालय की नदियाँ युवा हिमालय के पहाड़ी ढलानों से बड़ी मात्रा में पानी और तलछट उत्पन्न होने के कारण अत्यधिक गत्यात्मक हैं। कोसी प्रमुख और सबसे गत्यात्मक हिमालयी नदियों में से एक है जो इंडो-गंगा के मैदानों में बहती है। यह नदी अपने विशिष्ट मार्ग अस्थिरता और हाइपरकिनेसिस के लिए कुख्यात है। कोसी नदी 250 वर्षों में उत्तरोत्तर पश्चिम की ओर 120 किलोमीटर स्थानांतरित हो गई है।

इस मार्ग अस्थिरता की असामान्य लेकिन विषम प्रवृत्ति की व्याख्या करने के लिए कई सिद्धांत विकसित किए गए। इन्हें दो व्यापक श्रेणियों में बांटा जा सकता है अर्थात् (i) ऑटोसाइक्लिक प्रक्रियाएं, और (ii) टेक्टोनिकस प्रक्रियाएं। ऑटोसाइक्लिक प्रक्रियाएं अपलैंड और रिवरबैंक अपरदन और अवसादन की प्राकृतिक घटनाओं की ओर इशारा करती हैं और यकीनन, यह सिद्धांत कोसी के देखे गए प्रवास की व्याख्या करने के लिए शोधकर्ताओं और अन्य जांचकर्ताओं के बीच अधिक प्रभावी दृष्टिकोण रहा है। हालाँकि यह सिद्धांत नदी के रिकॉर्ड किए गए अधिमान्य पश्चिम की ओर प्रवास करने की व्याख्या करने में विफल रहा है।

यह अध्ययन कोसी के मार्ग के भू-आकृतिक विकास की व्याख्या करने के लिए एक विश्वसनीय और व्यापक आध्यात्मिक परिकल्पना प्रस्तुत करता है और उपलब्ध स्थलाकृतिक मानचित्रों, पैलियो-चैनलों के निशान और ऐतिहासिक साहित्य की विस्तृत परीक्षा द्वारा समर्थित है। नदी प्रवास के लिए एक प्रशंसनीय तर्क के साथ पारंपरिक दृष्टिकोण की समीक्षा भी प्रस्तुत की गई है। लेखक का प्रस्ताव है कि कोसी का प्रवासन और इसका भू-आकृतिक विकास नव-विवर्तनिक आंदोलनों सहित अंतर्निहित बहु-स्तरीय बेसिन प्रक्रियाओं की प्रतिक्रिया हो सकता है और पश्चिम की ओर प्रवासन का कारण बन सकता है। परिणाम स्वरूप यह नदी के तल में एक अनुप्रस्थ झुकाव होने के कारण इसकी पश्चिमी तट की कटौती दर को बढ़ा देता है।

यह अध्ययन क्षेत्र में नदी प्रशिक्षण और/या प्रबंधन पहलों को लागू करने के लिए सहायता के रूप में कोसी बेसिन के जटिल आकारिकी की बेहतर समझ के लिए अनिवार्यता पर प्रकाश डालता है। यह अध्ययन रिमोट सेंसिंग और हाइड्रोडायनामिक तकनीकों का उपयोग करके गत्यात्मक कोसी नदी की आकृतिक विशेषताओं को समझने के लिए एक नए परिप्रेक्ष्य और रूपरेखा का प्रस्ताव रखता है।

कोसी नदी नदी के भू-आकृति विज्ञान का अध्ययन करने के लिए एक प्रमुख उदाहरण है क्योंकि यह गंगा नदी की अपनी छोटी यात्रा में कई फ़्लूवियल मॉर्फोमेट्रिक विशेषताओं को प्रदर्शित करती है। लघु-स्तर पर, यह विभिन्न प्रकार की प्लेनफोर्म बनाती है जैसे कि ब्रैड्स, एनाब्रांच और मेन्डर्स। जबकि, बेसिन-स्तर पर, यह एक अभिसारी नदी नेटवर्क के साथ-साथ एक अपसारी जलोढ़ मेगाफैन बनाता है। यह अध्ययन बड़ी गत्यात्मक नदियों को रिमोट-सेंसिंग आधारित भू-आकृति विज्ञान लक्षण वर्णन के लिए एक वैकल्पिक दृष्टिकोण तैयार करता है।

उपग्रह इमेजरी नदी की गत्यात्मकता के पदचिह्न प्रदान करते हैं। ये समय में नदी की आकृतिक विशेषताओं और स्थान को संग्रह कर लेते हैं, और इस प्रकार इन विशेषताओं में परिवर्तन की जांच की जा सकती है। इन परिवर्तनों का विश्लेषण अंतर्निहित प्रक्रियाओं को समझने के लिए किया जा सकता है।

अध्ययन नदी-पहुंच को उनकी योजना के आधार पर पुनर्वर्गीकृत करता है- (1) सीधी, (2) ब्रैड्स, (3) एनाब्रांचिंग, और (4) मेन्डरिंग। इन प्लानफॉर्म ज़ोन में अलग-अलग विकास गतिकी हैं और इस प्रकार, चैनल स्थिरता में भी महत्वपूर्ण अंतर हैं। नदी की ऊपरी और निचली भाग, जो क्रमशः सीधे और मेन्डरिंग क्षेत्र में स्थित हैं, रूपात्मक रूप से स्थिर हैं। जबकि मध्य भाग (ब्रैड्स और एनाब्रांचिंग) तेजी से विकसित हो रहे हैं और संकटपूर्ण हैं। यह अध्ययन कोसी बेसिन के जटिल आकारिकी पर मानवजनित हस्तक्षेप के प्रभाव को भी प्रस्तुत करता है।

अनाब्रंचिंग क्षेत्र में, नदी ने धीरे-धीरे पश्चिम की ओर गति दिखाई है और पश्चिमी तटबंधों के साथ बह रही है। कोसी और बाघमती संगम भी इसी क्षेत्र में स्थित है। दोनों नदियों का संगम का कोई निश्चित बिंदु नहीं है, लेकिन एक लूप नेटवर्क है, जो लगातार विकसित हो रहा है।

यह अध्ययन यह भी बताता है कि कई अन्य नदियों के विपरीत, कोसी बाढ़ के मैदान सरल नहीं हैं। 2008 की कोसी बाढ़ उसी का उदाहरण है। बाढ़ की सहज समझ नदी के निकट है। हालांकि, कोसी नदी में बाढ़ का नोडल पॉइंट बाढ़ग्रस्त क्षेत्र के मानचित्रण में निर्णायक भूमिका निभाता है। इसका अंदाजा नदी की जटिल स्थलाकृति से लगाया जा सकता है।

8 अगस्त 2008 की बाढ़ बिहार की बाढ़ के इतिहास में सबसे भीषण बाढ़ है। कई जांचकर्ता इस विनाशकारी घटना का श्रेय कोसी बैराज से 12 किलोमीटर ऊपर कुसाहा के पास कोसी के पूर्वी तटबंध के टूटने को देते हैं। नदी के बारे में यह भी कहा जाता है कि वह अपने पुराने ऐतिहासिक मार्ग में से एक में वापस आ गई है। यह अध्ययन एक वैकल्पिक समझ का सुझाव देता है कि कोसी की स्थानीय बेड व चैनल मॉर्फोलॉजी वास्तव में 2008 की पूर्वोक्त विपत्तिपूर्ण घटना के लिए एक संभावित ट्रिगर हो सकता है। अध्ययन से पता चलता है कि बेड आकारिकी में परिवर्तन महत्वपूर्ण अवसादन पैटर्न के विकास के कारण हो सकता है, जो कि कोसी बैराज के जलगतिकी और जल-गतिकी प्रभाव के बीच प्राकृतिक परस्पर क्रिया के कारण हो सकता है। 2008 की इस घटना के लिए घटनात्मक कार्य-कारणता को कोसी में बाढ़ प्रवाह प्रसार के 2-डी हाइड्रोडायनामिक सिमुलेशन बैराज से पूर्व और बाद के बेड आकारिकी परिदृश्यों के अनुमानों के आधार पर स्थापित किया गया है।

जटिल रूपजनन और आकृति परिवर्तन के अलावा, कोसी नदी भी अपने जल के कारण व्यापक बाढ़ के कारण एक बड़ी चुनौती बन गई है, और इसके मद्देनजर, उत्तर बिहार में बड़े पैमाने पर विनाश और सामाजिक-आर्थिक व्यवधान आम है। लोअर कोसी बेसिन (एलकेबी), छतरा

गॉर्ज के नीचे, मूल निवासियों, जल प्रबंधकों, बिहार सरकार और भारत सरकार के लिए चिंता का विषय रहा है। क्षेत्र में बाढ़ की वार्षिक घटनाएँ देखी जाती हैं, जिससे मूल निवासियों का जीवन अस्त-व्यस्त हो जाता है।

नदियों को समझते समय स्थिरता की अंतर्निहित धारणा को अक्सर अनदेखा कर दिया जाता है, जिससे बाढ़ प्रबंधन और योजना में गलत धारणाएँ पैदा होती हैं, जो 2008 कोसी बाढ़ से स्पष्ट रूप से स्पष्ट थी।

इस अध्ययन में, कोसी के पैलियोचैनल को नॉन-स्टेशनरी कोसी के प्रभावी बाढ़ प्रबंधन के लिए बाढ़ चैनलों के रूप में प्रस्तावित किया गया है। पैलियोचैनल नेटवर्क की प्रभावकारिता का मूल्यांकन ग्राफ-सैद्धांतिक दृष्टिकोण से किया गया है। पैलियोचैनल नेटवर्क लगभग 35% बाढ़ मात्रा तनाव को स्थानांतरित करने के लिए पाया गया। इसके अलावा, पैलियो नेटवर्क सिस्टम को छोटी-छोटी बाधाओं के लिए रेसिलिएंट पाया गया, जिससे बाढ़ प्रबंधन व्यवस्था की विश्वसनीयता और बढ़ गई। इस प्रकार, अध्ययन क्षेत्र की बाढ़ की समस्या को कम करने के लिए एक नवीन रणनीति का प्रस्ताव और संरचना करता है।

वर्तमान अध्ययन कोसी नदी के मॉर्फोजेनेसिस की व्यापक और तर्कसंगत समझ प्रदान करता है, जो कोसी को एक नॉन-स्टेशनरी नदी के रूप में मान्यता देता है। अध्ययन रिमोट-सेंसिंग तकनीकों का उपयोग करते हुए नदियों के मॉर्फोलॉजिकल अध्ययन और लक्षण वर्णन के लिए एक सुसंगत उपकरण प्रदान करता है, जिसे बड़ी गत्यात्मक नदियों के लिए लागू किया जा सकता है। अध्ययन में विकसित पैलियोचैनल ढांचा क्षेत्र के लिए एक स्थायी बाढ़ प्रबंधन रणनीति बनाने के लिए निर्णय निर्माताओं को सक्षम करता है।

कीवर्ड्स: नॉन-स्टेशनरी नदियाँ, रिवर शिफ्टिंग, एवल्शन, कोर्स अस्थिरता, फ्लुवियल जियोमॉर्फोलॉजी, कुसाहा फ्लड, बेड मॉर्फोलॉजी, मेगाफैन, मॉर्फोडायनामिक्स, पैलियोचैनल्स

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Acronyms and Abbreviations

1D	One dimensional
2D	Two dimensional
3D	Three dimensional
AHP	Analytical Hierarchical Process
DEM	Digital Elevation Model
DWT	Discrete Wavelet Transform
EE	Earth Explorer
EPSG	European Petroleum Survey Group
ESA	European Space Agency
ETM+	Enhanced Thematic Mapper plus
E-W	East West
GIS	Geographic Information System
GOI	Government of India
KMf	Kosi Megafan
KRB	Kosi River Basin
LiDAR	Light Detection and Ranging
LKB	Lower Kosi Basin
MFT	Main Frontal Thrust
ML	Machine Learning
MNDWI	Modified Normalized Difference Water Index
M-S ridge	Munger-Saharsa
MSI	Multispectral Imager
MSS	Multi-Spectral Scanner
NDWI	Normalized Difference Water Index
NNE	North North-East
NNW	North North-West
NRSC	National Remote Sensing Centre
N-S	North South
OBIA	Object-Based Image Analysis

OLI	Operation Land Imager
PWD	Public Works Department
QGIS	Quantum Geographic information system
QSWAT	Quantum Soil and Water Assessment Tool
RS	Remote Sensing
SOI	Survey of India
SRTM	Shuttle Radar Topography Mission
SSE	South South-East
SSW	South South-West
TIRS	Thermal Infrared Sensor
TM	Thematic Mapper
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WGS	World Geodetic System