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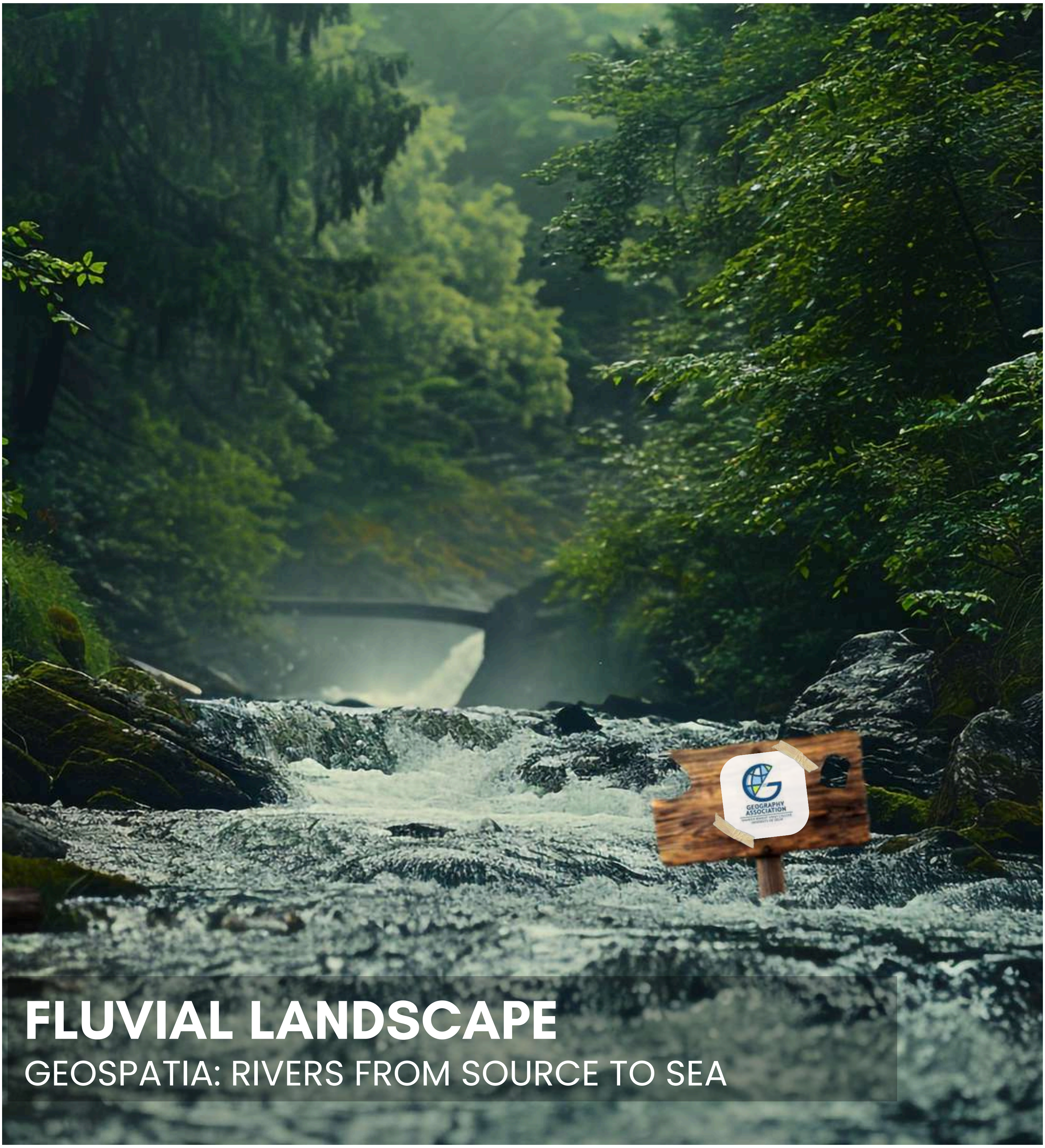
LANDSCAPE

A FORUM FOR YOUNG GEOGRAPHERS



FLUVIAL LANDSCAPE

GEOSPATIA: RIVERS FROM SOURCE TO SEA

PREFACE

Welcome to the latest edition of the "Landscape", the department's annual magazine. In this edition we embarked on an exciting journey through the fascinating world of rivers—from their humble beginnings at the source to their grand finale at the sea. This edition is dedicated to explore the critical role rivers play in shaping landscapes, sustaining ecosystems, and influencing human civilization.

The theme, "Geo-Spatia: Rivers from Source to Sea" takes us on an exploration of the journey of rivers through their various stages. We delve into the science and art of tracking their courses, understanding their intricate geospatial patterns, and examining the physical, environmental, and cultural significance of the waterways that define our planet. As we follow these rivers from their sources—whether in mountains, springs, or glaciers—through winding paths, valleys, and plains, we also focus on how technology, mapping, and geographic analysis help us gain insights into their behavior. The impact of rivers on urbanization, agriculture, and even climate is explored in depth, alongside the challenges posed to rivers by environmental change and human activity.

We invite you to engage with the research and illustrations in this issue, as they offer a glimpse into the dynamic and interconnected world of rivers, from their origin to their final destination in the seas. We hope this magazine inspires further curiosity, fostering a deeper understanding of the essential, yet often overlooked, rivers that sustain life across the globe.

Enjoy your journey from the source to the sea.

Prof. Arun Kumar Attree
Principal
Shaheed Bhagat Singh College
University of Delhi

I am glad to know that the Department of Geography, Shaheed Bhagat Singh College is publishing its Annual Magazine, Landscape on the theme “Geo-Spatia: Rivers from Source to Sea”.

Rivers are an important natural resource and a vital source of freshwater for human consumption, agriculture and industry. It supports a wide range of aquatic life and microorganisms.

Therefore, it is essential to gain an understanding and learn about rivers from their origin to their mouth, as well as how they impact human societies as well as how human actions affect them.

This magazine is a testament to the unwavering dedication and tireless hard work of the Geography Department. I would like to appreciate Dr. Amrita Bajaj, Teacher-in-charge, Dr. Nitin Punit, Staff Advisor, and Dr. Ashwani Kumar Agnihotri, Magazine Advisor, for their belief in the magazine and its spirit. I would also like to congratulate the editorial team for their hard work on this magazine, as well as the students who contributed significantly by submitting their entries and marking their valuable contributions.

Best Wishes!

Dr. Amrita Bajaj
Teacher-in-Charge
Department of Geography
Shaheed Bhagat Singh College
University of Delhi

Dear Students, Faculty, and Esteemed Readers,

It gives me immense pleasure to present the latest edition of our department's magazine, "Geo-Spatia: Rivers from Source to Sea". Like the rivers that flow through valleys, plains, and deltas—shaping landscapes and nurturing life—this magazine carries the collective creativity, knowledge, and passions of our vibrant college community.

The theme of this edition is deeply symbolic. A river's journey from its humble source to the vastness of the sea mirrors the journey of knowledge—starting from curiosity, meandering through exploration, and finally merging into the ocean of understanding. Similarly, the contributions within these pages reflect diverse perspectives, much like the river's changing course, gathering stories, experiences, and insights along the way.

This magazine is not just a collection of words and images; it's a testament to the intellectual curiosity and artistic expression that flow through the hearts and minds of students and faculty.

I extend my sincere appreciation to our Principal, the faculty members, the editorial board, and every student who has been part of this creative endeavor. Your hard work has created a edition that not only informs and inspires but also celebrates the beauty and complexity of geography in all its forms.

May this magazine inspire you to reflect on the rivers within your own journey—ever-flowing, ever-evolving, and always moving forward.

Dr. Ashwani Kumar Agnihotri
Magazine Advisor
Department of Geography
Shaheed Bhagat Singh College
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It is with immense pride and joy that our department's "Magazine Committee" presents this year's edition of Landscape magazine, themed "Geo-Spatia: Rivers from Source to Sea." This theme encapsulates the intricate journey of rivers, reflecting their significance in shaping landscapes, sustaining ecosystems, and nurturing civilizations. Rivers, the lifelines of our planet, are facing unprecedented challenges in the Anthropocene era—pollution, encroachment, climate change, and overexploitation threaten their very existence. The revival of rivers is not just an environmental necessity but a collective responsibility. As young geographers and environment enthusiasts many students have demonstrated remarkable academic rigor and intellectual curiosity in exploring these challenges. Through their research papers, they have critically analyzed riverine health, examined anthropogenic influences, and proposed sustainable solutions for river restoration.

Their work stands as a testament to the power of geographical knowledge in understanding and addressing real-world issues. By integrating remote sensing, G.I.S, hydrological modeling, and field-based studies, they have showcased the potential of geography in river revival efforts. I strongly believe that their insights will inspire further discourse on sustainable river management and conservation.
I extend my heartfelt congratulations to all the contributors for their dedication and scholarly contributions. I am also delighted to acknowledge the external funding received for the publication of this magazine—a recognition of the significance of our students' work and the value of their research in shaping sustainable river futures.

May this edition of Landscape serve as a platform to ignite awareness, foster innovation, and strengthen our commitment to reviving the rivers that sustain us. Wishing all the students who contributed a continued success in their academic and research endeavors!

Dr. Santosh Kumar
Magazine Co-Advisor
Department of Geography
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University of Delhi

It gives us immense joy and satisfaction to present the 2024-25 issue of our annual magazine ,i.e., “Landscape”. I congratulate the “Magazine Committee” and the contributors for their sincere efforts in bringing out the magazine on the theme “Geo-Spatia” Rivers from Source to Sea”.

A river is a naturally flowing body of water that originates from a source, it can be a spring, glacier, or snowfield and flows towards a mouth, typically another waterbody, such as an ocean, sea, lake, or another river. Rivers are dynamic systems that play a crucial role in shaping the surrounding landscape and support a wide range of ecosystems. They provide water for drinking, irrigation, and industry. They support transportation, fishing, and recreation and are a source of hydroelectric power. Recently, rivers have become vital assets for a country and its people. The construction of dams on these rivers generates kilowatts of hydroelectricity, which are used to drive the industrial growth of the nation.
However, humans are exploiting these pivotal rivers by polluting them with industrial, agricultural, and domestic waste, including plastics, chemicals, and sewage, threatening aquatic life and human health, while also altering natural flows and depleting water resources, exacerbating the crisis of water scarcity and ecosystem degradation. This emphasizes the urgent need to sustainably use, manage, and protect our rivers.

Protecting rivers from pollution requires a multi-faceted approach. Techniques include wastewater treatment, sewage management, and industrial effluent control. River buffer zones, wetland restoration, and riverbank stabilization are also needed. Public education and awareness, regulatory frameworks, and regular monitoring are crucial. These efforts are essential to preserve the ecological balance. Billions of people depend upon these rivers for their survival. Hence, it is essential to have knowledge and understanding about it. We hope this magazine will be useful and knowledgeable for all the readers.

Dr. P. Thongkhanthang
Magazine Co-Advisor
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It is with great pleasure that I welcome you to the latest edition of our magazine, i.e., “Landscape” on the theme “Geo-Spatia: Rivers from Source to Sea”. I would like to appreciate the “Magazine Committee” for the efforts they have put into this magazine and all the contributors who contributed to this magazine with their valuable contributions.

Rivers are the lifeblood of our planet, shaping our environment and supporting life. The study of rivers encompasses various themes, including river morphology, fluvial landforms, and river ecology. Rivers have a profound impact on the landscape, creating valleys, canyons, and waterfalls, and supporting a wide range of plant and animal species. However, human actions, such as deforestation, urbanization, and pollution, harm rivers and their ecosystems. A popular example of that you can see with the Yamuna River in Delhi.

Hence, understanding these themes is essential for managing and conserving rivers, and ensuring the long-term health and sustainability of our planet. Rivers provide freshwater, food, and habitat for many species, and are a vital source of water for human consumption, agriculture, and industry. By studying rivers, we can better appreciate their importance and work to protect them for future generations. This knowledge is crucial for maintaining the health and biodiversity of our planet.

Our magazine is dedicated to delving into the intricacies of rivers and its related sub-themes. We hope this magazine brings a bright light to the following theme and be fruitful for all the readers.

Dr. Nitin Punit
Staff Advisor
Department of Geography
Shaheed Bhagat Singh College
University of Delhi

I am delighted to connect with you all with the 18th edition of our annual magazine, "Landscape", an edition that showcases the outstanding work of our department. I am thrilled to announce that our department is proud to present this year's magazine which is based on the theme “Geo-Spatia: Rivers from Source to Sea”.

Rivers from their source to the sea play a vital role in shaping the landscape, supporting life and influencing the environment. As they flow, rivers carve out valleys, create deltas, and deposit sediments. Moreover, they provide sustenance, habitat, and transportation for countless species, including humans, and serve as a lifeline for agriculture, industry, and urban centers. Therefore, it is essential to understand the morphology of rivers, including their channels, floodplains, and watersheds, as well as the complex dynamics that govern their behavior. Furthermore, it is crucial to address the negative impact of human actions on rivers, such as pollution, mining and deforestation which can have devastating consequences for aquatic ecosystems, human health, and the environment as a whole. By grasping the intricacies of river morphology and the far-reaching effects of human activities, we can work towards preserving the health, integrity, and resilience of these vital rivers which are an important source of freshwater and ensure a sustainable future for generations to come.

Last but not the least, I would like to acknowledge the “Magazine Committee” and everyone who contributed in this magazine for their unwavering efforts, hard work, and for its successful compilation. May this reading experience be informative and enriching for all readers!

Dr. Rahul Kumar
Staff Co-Advisor
Department of Geography
Shaheed Bhagat Singh College
University of Delhi

It gives me immense pleasure to announce the 18th volume of our department's magazine titled "Geo-Spatia: Rivers from Source to Sea". This magazine provides an in-depth exploration of the journey of rivers from their sources to their confluence with the sea.

Through the use of Geographic Information Systems (GIS), remote sensing, and spatial data analysis, the magazine examines how rivers influence landscapes, support biodiversity, and shape human civilizations. It aims to offer readers a comprehensive understanding of the dynamic nature of river systems, emphasizing both their environmental significance and the technological methods used to study them.

I appreciate the magazine committee for their dedication and efforts. Hope the readers enjoy reading the magazine.

Chetan Patnaik
Magazine Coordinator

It’s a pleasure to introduce this year’s department’s magazine, “Geo-Spatia: Rivers from Source to Sea”. This theme is more than just about rivers—it’s about the journeys, transformations, and how everything flows, just like life itself.

Many rivers start as tiny trickles in the mountains, full of energy and potential, much like all of us at the beginning of our journeys. As it moves forward, it carves its path, faces obstacles, nourishes the land, and gathers strength before finally merging with the vast ocean. Isn’t that exactly how we grow—learning, evolving, and making an impact along the way? Through this magazine, we celebrate not just rivers but stories—stories of change, resilience, and discovery.

A big thank you to everyone who contributed their time, creativity, and hard work to bring this edition to life. We hope you enjoy reading it as much as we enjoyed putting it together.

Happy reading, and may you always find your course, just like a river!

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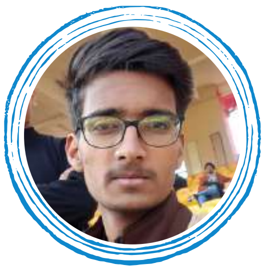

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ANNUAL REPORT
The Department of Geography
Shaheed Bhagat Singh College
University of Delhi

Events organized by Department of Geography

VASUNDHARA’24

Vasundhara is the annual geo-feat organized by the Department of Geography at Shaheed Bhagat Singh College. Each year, this event is conducted with great enthusiasm by the students and faculty of the department. For Vasundhara-2024, the chosen theme was "Earth in Pixels: Exploring GeoAI's Impact on Geography." A variety of activities were organized, including:

- Geoquorum: Debate Competition
- Intellectus: Quiz
- Geobiz: Business Plan Competition
- Globeshots: Photography Contest
- Geographikos: Poster Making

The event featured Prof. Tejbir Singh Rana from Shivaji College, University of Delhi, as the chief guest. The festival provided an enriching experience for all participants, fostering valuable interactions and creating lasting memories.

SEMESTER 6 (2023-24) FIELD TRIP TO GUJARAT

The Geography course students of semester VI had their educational trip to Gujarat for the discipline-specific practical course named DisasterManagement to have an understanding of the topic Assessing the Impact of the Biparjoy Cyclone in the Western Coastal Region Gujarat in the month of January 2024.

The journey embarked from New Delhi with the students and faculty members. The expedition was filled with experiences and exposures holistically. It helped in assessing the real-world effects of natural disasters by interviewing the locals and knowing their perspectives as survivors. The research and study of the topic on field enhanced the practical understanding about risks, vulnerabilities, consequences, mitigations, etc. and hence broadened our knowledge.

FAREWELL' 24

The Department of Geography had farewell for the third year students of session 2023-24. The event was organised on 10th May, 2024, filled with fun games and celebrations creating memories for life. As we move on to new horizons we carry with us new lessons, memories, and the friendship built here. It was such a mesmerizing time to get nostlagic about the very first day here to the last to cherish forever.

ORIENTATION CEREMONY

On August 29, 2024, the Geography Department at Shaheed Bhagat Singh College welcomed its new batch of students to the orientation ceremony. The event provided a comprehensive introduction to the department, its faculty, and its resources. The teachers, who were all present, took the opportunity to showcase the department's activities, opportunities, and facilities, and assured the students that they would receive the best possible education and great exposure. The Staff Advisor also briefed the students on the various co-curricular and extracurricular activities available, and the faculty members outlined the academic and personal support they would provide to help the students succeed throughout their time at the college. The session concluded with an engaging discussion between seniors and freshers, during which the newcomers had their questions answered. The ceremony wrapped up with wishes for all students to have a bright and healthy future.

SPEAKER SESSION

Session on the topic "Floodplains Hydromorphic Assessment Using Optical And Radar Remote Sensing Methods" The session was led by Dr. Manudeo Singh, a Newton International Fellow at Aberystwyth University, UK.

In the session, he discussed the creation of wetlands and applications of sustainable approaches for their conservation. The session was interesting and joined by students and various faculty members of the Department.

FIELD TRIP TO JOSHIMATH, UTTARAKHAND

Students from Semester V embarked on a field trip to Joshimath with the objective of studying the impact of land subsidence in the region. Through the use of questionnaires, the students engaged with local residents to gain insights into the issues and challenges they face as a result of this phenomenon. In addition to their research activities, the students participated in trekking excursions in Auli, which offered stunning vistas of the Garhwal Himalayas. This field visit served to enhance the educational experience, providing students with valuable opportunities for practical learning and engagement with the local community.

INTERNATIONAL CONFRENCE 2024

The Department of Geography organized an International conference on the 15th and 16th of November, 2024 on the theme **"Urban Development Missions, reconstructing of Spaces and Emergence of New Urbanism"**.

On the 1st day: The International conference includes a panel discussion on day 1, under the chairmanship of Dr. V.K. Tyagi, the chairman of D.D. College, Dehradun. Many experienced Panelist were present in this conference who provide invaluable insights into the various aspects of resilient and sustainable urbanization.

Cultural evening: A cultural evening was organized on the same day. The evening featured mesmerizing dance performances, soulful musical renditions, and engaging skits that reflected the rich cultural heritage of our institution. The lively atmosphere, enthusiastic participation, and an appreciative audience made the evening an unforgettable experience for all.

On the 2nd Day: On the Second day the Conference is chaired by Prof. B.W Pandey, Director, Centre for Himalayan studies, University of Delhi. Participants from various educational institutions participated in this panel discussion.

At the Valedictory Ceremony, The Chief guest was Prof. Heeraman Tiwari, Honorary Director, NRC- ICSSR, JNU, and guest of Honour Prof.Debolina Kundu.

The Session insights into the overall performance of the participants from across the world who have shared their valuable insights and perspectives regarding new Urbanism.

FIELD TRIP TO SHIMLA, SEMESTER 6

Students from Semester VI went on a field trip to Shimla, Himachal Pradesh with the objective of access the carrying capacity and landslide susceptibility of the city. Through the use of questionnaires, the students engaged with local residents to understand the situation, the issues and challenges they face as a result of this phenomenon. In addition to their research activities, the students engaged in a fruitful discussion with prominent geographers like Dr. B.R. Thakur, Dr. Ram Lal and Prof. D.D. Sharma of Himachal Pradesh University, which enhanced the students understand about landslide. Later, the students also had an interaction with Dr. Bharat Kohli at Chail Palace, a pioneer in the field of ecology, to understand how the vegetation cover could help to reduce the landslide. This field visit served to enhance the educational experience, providing students with valuable insights and information.

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DRAINING CHAMBAL: THE SILENT THREAT OF ILLEGAL SAND MINING

Anuj Mudgal

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1. Abstract

Rivers are vital lifelines that forms landscapes and sustain human communities. However, rampant human activity has disrupted their natural flow, resulting in ecological and environmental challenges. Illegal sand mining in the Chambal region has emerged as a significant environmental and socio-economic threat, severely impacting biodiversity, river ecology, and local livelihoods. This paper examines the impact of illegal sand mining on the Chambal River. Unregulated sand extraction has changed the river's hydrology, increased bank erosion, and is threatening endangered species like the gharial and river dolphin. Using secondary data sources- including government reports, published research, media coverage, Down to Earth reports, and credible websites- the study analyses the environmental degradation and socio-economic consequences of unregulated sand extraction from the Chambal River. The finding of this study reveals severe erosion, habitat destruction, and threats to endangered species such as gharial and river dolphin. High demand for construction material including sand and weakness of administration have fuelled this crisis. The study highlights need for stricter policy enforcement, community involvement, and sustainable alternatives to reduce the long-term impact of sand mining on river landscapes.

KEYWORDS: Illegal Sand Mining, Biodiversity, Ecology, Bank Erosion, Hydrology Change, Sustainable alternatives, policy enforcement, community involvement

2. Introduction

Rivers are systems that shapes landscapes, support biodiversity, and they provide resources for the local civilisation. They help in agriculture, fisheries and transportation. But growing human activities have changed the landscapes of these rivers. One of the most pressing concerns today is illegal sand mining, which is an unsustainable practice driven by increasing demand for sand in the construction and infrastructure sectors. Unregulated extraction of sand-by-sand mafias have caused destruction environment and gave rise to several socio-economic problems. Chambal River flows through the state of Madhya Pradesh, Rajasthan, Uttar Pradesh, have length of 1024 K.M, and it is known for its rich biodiversity, supporting endangered species such as gharial, dolphin, red crowned roofed turtle, Indian skimmer. However illegal extraction of sand from its riverbed has caused severe loss of habitat, increased bank erosion, disruption of natural flow, decrease in aquatic biodiversity.Illegal Sand Mining has severely affected the gharials in the National Chambal Sanctuary. Presence of powerful sand mining mafias, weak law enforcement, and the rising demand for sand have caused harm too. It threatens not only the river but also the livelihoods of people.

3. STUDY AREA

3.1 Location

Chambal River originates from the Bhadakla Falls in Janapav Hills on the northern slopes of the Vindhyan escarpment near Mandav, 67.5 kilometres (41.9 mi) South-West of Mhow in Indore District, Madhya Pradesh state, at an elevation of about 843 metres (2,766 ft). The length of the river is 1024 kilometres and it flows through the state of Madhya Pradesh, Rajasthan and Uttar Pradesh. It is a major tributary of the Yamuna River and it join river Yamuna in Etawah district, Uttar Pradesh. It is one of the cleanest rivers in India due to low industrial pollution but is now facing the risk of illegal sand mining. It is home to endangered species such as gharial (Gavialis gangeticus), gangetic dolphin (Platanista gangetica), indian skimmer(Rynchops albicollis), Red-crowned roofed turtle (Batagur kachuga) etc. Major tributaries of Chambal are: Banas, Mej, Kothari, Kali Sindh, Parbarti, Shipra along with some minor tributaries.

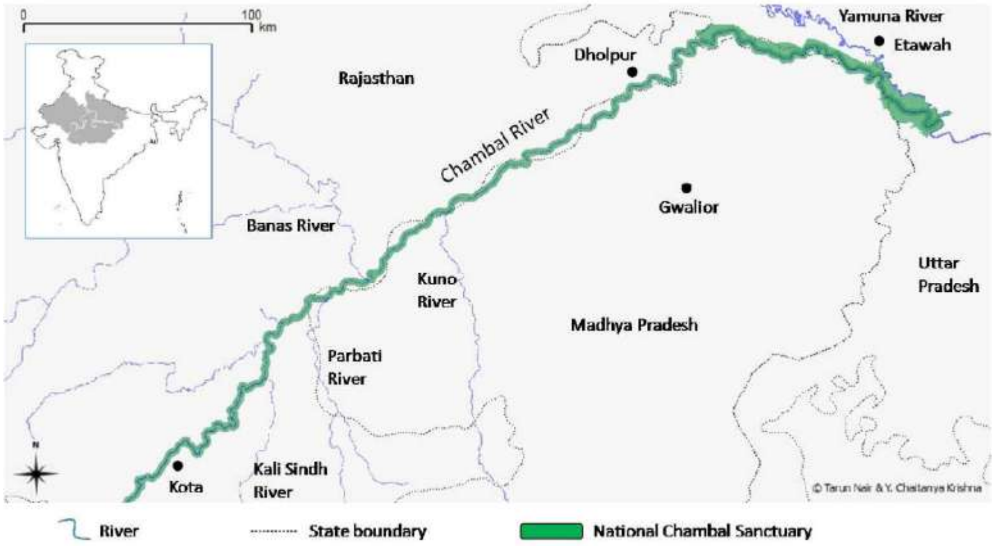

Figure 1-: Map showing the flow of Chambal River through Madhya Pradesh, Rajasthan and Uttar Pradesh, Source-: IAS Gyan

3.2 GEOLOGY AND CLIMATE

Chambal river has a semi-arid to sub humid climate. It has moderate climate with irregular rainfall. The annual rainfall is around 697mm. The majority of rainfall occurs during the monsoon months of June to September. The temperature remains very cold from November to February and hot from March to June. The mean maximum temperature is around 45°C. The Chambal River valley is part of the Vindhyan System, which includes sandstones, slate, and limestone. The river valley is characterized by hillocks, ravines, and gullies. The river has deep gorges and ravines, particularly in Madhya Pradesh and Rajasthan due to long term erosion, this terrain helps hiding the illegal mining activities from easy detection.

3.3 ECONOMY

The river basin is mainly rural with the economy relying on agriculture and livestock farming. The fertile plains support the cultivation of wheat, mustard, pulses, and sugarcane. The Rajasthan and Madhya Pradesh, the semi-arid conditions limit the scope for agriculture due to ravines and rugged terrain, making sand mining and quarrying contributor to local livelihoods. Illegal Sand Mining has given rise to an informal economy which provides employment to thousands but results in economic and environmental losses too. Thousands of labourers are dependent on illegal sand mining for daily wages however they work in unsafe conditions and are exploited by sand mining mafias.

Figure 2-: Illegal sand mining at Chambal Bridge, Dholpur , *Photo Credit-:* Sahil Zutshi

3.4 AREA AND POPULATION OF AFFECTED DISTRICTS

Illegal sand mining has affected the Chambal River basin, particularly in the districts of Morena, Bhind, Gwalior, Dholpur, Etawah.

State	District	Area (sq. km)	Riverbank Length (approx.)
Madhya Pradesh	Morena	4990	200 km
Madhya Pradesh	Bhind	4459	170 km
Rajasthan	Dholpur	3034	120
Uttar Pradesh	Etawah	2311	80

Table 1-: Area of affected districts and Riverbank length of Chambal (Created by author), *Source-:* Wikipedia

District	Population	Rural Population (%)	Urban Population (%)
Morena	19,65,970	80	20
Bhind	17,03,005	75	25

Dholpur	12,07,293	70	30
Etawah	15,81,810	65	35

Table 2-: Population and its rural-urban composition of affected districts of sand mining (Created by Author), Source-: Census of India

4. METHODS AND MATERIALS

The secondary data is information collected, processed, and analysed for purposes other than those originally intended by the original researcher or for other purposes. This kind of data is pre-existing data used to achieve a different analytical or research goal.

The secondary data for this report has been taken from various sources such as the Census of India 2011, reports by the Government of Madhya Pradesh, Central Pollution Control Board, articles from Down to Earth, authorised newspapers and credible websites, analysis of regulations and enforcements mechanisms available on government portals.

A case study has been given by the author as he visited a village in Morena, Madhya Pradesh. Case study shows the experience of an old man in Dimni Village, Morena, Madhya Pradesh.

The study follows a descriptive research design to examine the environmental, economic and social impacts of illegal sand mining in the Chambal River Basin.

4.1 Status of Sand Mining

Sand is considered as an essential material as it is used for making concrete, building sites, filling roads, making bricks, making glass, sandpapers etc.

According to UNEP, sand mining (extraction) is the removal of primary natural sand and sand resources from the natural environment to extract valuable minerals for subsequent processing.

Sand is classified as a "Minor Mineral", under The Mines and Minerals (Development and Regulations), Act, 1957(MMDR Act) and administrative control over minor minerals is in the hands of state Government. Rivers and coastal regions are the primary sources of sand, and its demands has increased in recent years owing to the increasing demand for housing and infrastructure.

The Ministry of Environment, Forests and Climate Change (MoEFCC) has issued "Sustainable Sand Mining Management Guidelines 2016" to promote scientific sand mining and environmentally friendly management practices.

4.2 Uses of Sand

Construction (40%): Sand is a primary component of concrete, asphalt, and bricks, making it the largest consumer

Land Reclamation (20%): There are many coastal and urban expansion projects which requires massive amounts of sand.

Glass Manufacturing: It is a key raw material for making glass for windows, bottles and screens.

Industrial Use: Foundry casting, hydraulic fracturing, filtration processes use sand.

Recreation: Sand is also used in beaches, golf courses, and playgrounds.

Agriculture: It is also used for soil conditioning and horticulture.

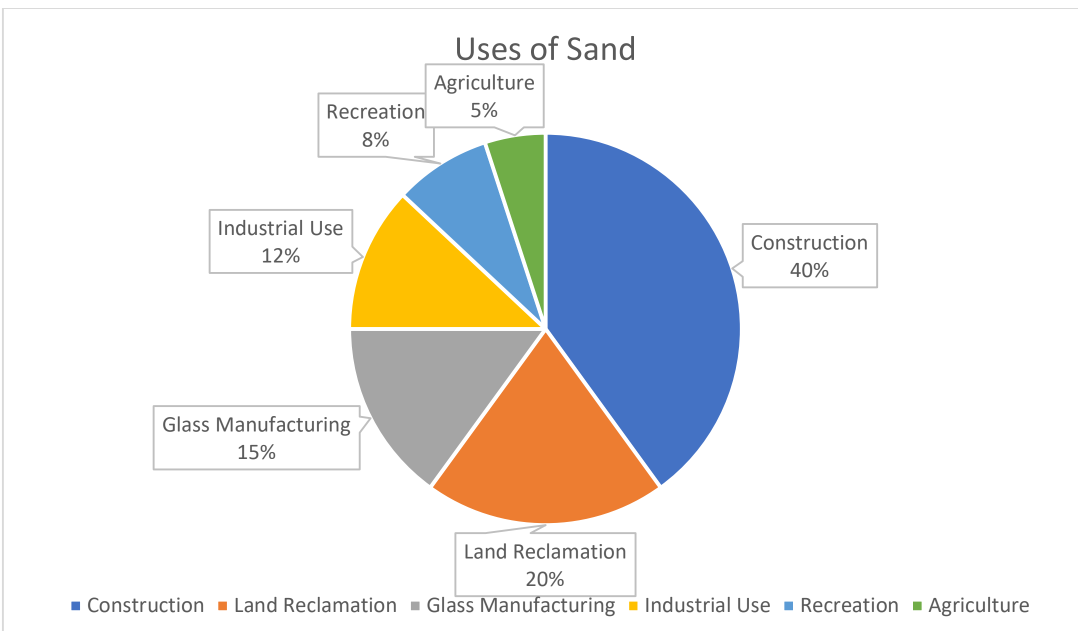

Figure 3-: Different Uses of Sand (Created by Author), Data Source-: Statista.com

4.3 Reasons for Illegal Mining of Sand

High demand for sand: Increasing urbanisation and infrastructure growth have led to the rampant demand for sand in construction, real estate, and road development. Sand is a non-renewable resource, making its extraction profitable.

Limited Legal Supply: Limited legal mining permits fail to meet the rising demand. Often the sand is more expensive if extracted and sold legally in the market.

Black Market Operations: It is a highly lucrative business with low investment and high profit margins.

Weak Law Enforcement: Illegal miners are operating freely due to lack of strictness from the authorities. Corruption among local authorities is also fuelling this crisis.

Poor Implementation of Laws: There are several laws regulating the sand mining in the country but those are poor implemented at the ground level, leading to rampant illegal sand mining in the Chambal River.

Employment Issues and Literacy: The area affected by illegal mining activities in Chambal River has low literacy rates. People are not educated to understand the ecological and long-term consequences of illegal sand mining. They have limited options to find employment in the rugged and ravines of Chambal. So, they sought to sand mining as an employment option.

Political and Bureaucratic Issues: There are various media reports which claim that illegal sand mining could not flourish in the region without the support from political parties and politicians. Authorities have their own vested interests.

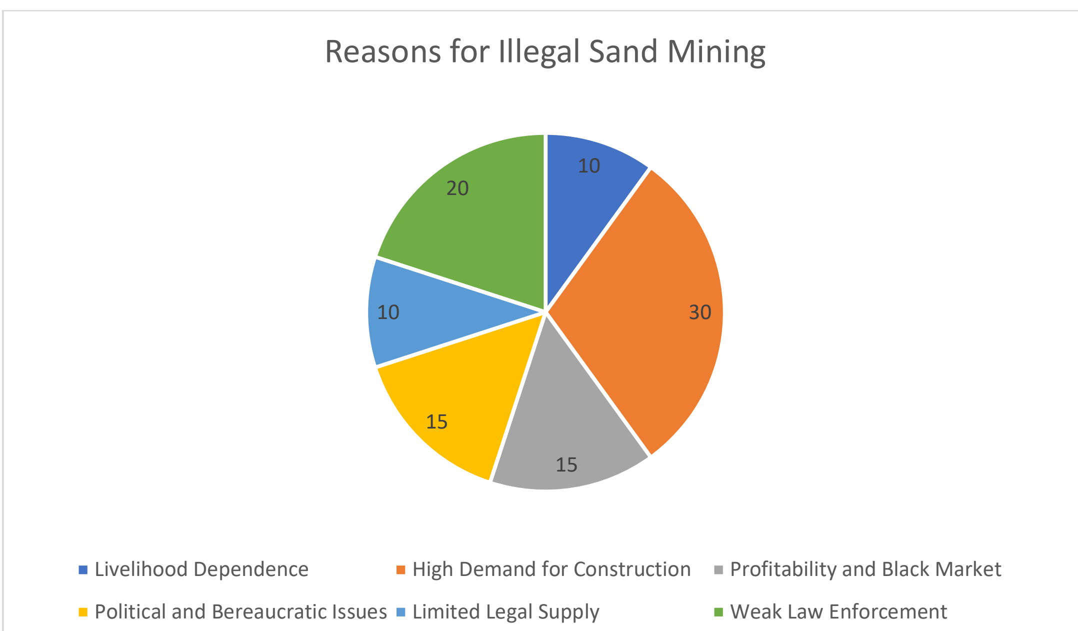

Figure 4-: Reasons of Illegal Sand Mining in Chambal River (Created by Author)

5. RESULTS AND DISCUSSION

5.1 Extent of Illegal Sand Mining in Key Districts

State	District	Estimated Illegal Mining Sites	Annual Sand Extraction (Million Tonnes)
Madhya Pradesh	Bhind	38	2.0
Madhya Pradesh	Morena	45	2.5
Rajasthan	Dholpur	30	2.1
Uttar Pradesh	Etawah	20	1.5

Table 3: Illegal Sand Mining in Bhind, Morena, Dholpur and Etawah, Source: Mining Department of respective state

Morena and Dholpur have the highest levels of extraction, making them the hotspots for illegal sand mining. This unsustainable exploitation is due to the rapid increase in construction works, inadequate law enforcements, and the influence of organised sand mafias.

5.2 IMPACT OF ILLEGAL SAND MINING

Illegal sand mining along the Chambal River has caused severe environmental, socio-economic and legal issues.

Riverbank Erosion: Due to excessive sand extraction from the banks of the river, there is rampant erosion along the riverbank.

Change of Natural Flow: Extraction of sand from riverbeds have the natural course of flow of river. Sand acts as a natural buffer, which maintains the equilibrium of the river flow. Excessive sand removal reduces the availability of sediment, which leads to increased water velocity, erosion, and channel deepening. According to various studies, rivers which experience illegal sand mining, they show a 20-30% increase in erosion rates.

Illegal sand mining often creates deep pits in the riverbeds, which forces the rivers to eventually change its course. A study using remote sensing data revealed that area which experience intense sand mining along the Chambal River, the river’s width has reduced by nearly 15-20%, which eventually increases the risk of flash floods.

Biodiversity loss: Chambal is the home of various species including critically endangered gharial (*Gavialis gangeticus*), gangetic dolphin (*Platanista gangetica*), red crowned roofed turtle and Indian skimmer bird. Illegal mining in the region has led to the destruction of nesting sites of gharials and turtles. Due the increased noise pollution from the machines used for sand mining, the dolphin population is also facing severe threat.

Lowering of Groundwater Table: Percolation capacity refers to the ability of soil or rock to absorb and allow water to pass through it. It determines how quickly water infiltrates into the ground.

Sand basically acts as a natural filter which allows rainwater and river water to seep into underground aquifers. It helps in groundwater recharge by maintaining percolation capacity. Due to illegal sand mining in the region, there is the problem of rapid groundwater depletion in the nearby areas.

District	**Pre-Monsoon Water Table (metres below ground level)**	**Post-Monsoon Water Table (metres below ground level**	**Annual Depletion Rate (cm per year)**
Morena (MP)	9.5	7.8	10-15cm
Bhind (MP)	11.2	9.3	12-18cm
Dholpur (Rajasthan)	8.7	6.9	8-12cm
Etawah (Uttar Pradesh)	10.4	8.6	9-14cm

Table 4-: Data on Groundwater Depletion in Chambal River Basin (table created by author*),*
Source-: Hydrogeological Atlas of Rajasthan: Chambal River Basin

There is significant decline in water table in areas of Morena and Bhind district in Madhya Pradesh (areas most severely affected by illegal sand mining). The table shows the higher depletion rate of water table in areas where sand mining in rampant, which shows its direct impact. Post monsoon recovery is limited which proves that groundwater recharge is disrupted. If we compare the non-mining areas of Rajasthan and Madhya Pradesh, they report an annual groundwater depletion of 3-5cm, compared to 10-20cm in illegal sand mining zones. Satellite imagery from ISRO shows a 30-40% reduction in water retention capacity of the Chambal floodplain. Reduced groundwater level directly impacts the poor farmers of this region dependent on wells and tubewells for irrigating their agricultural fields. This also results in lower crop yields.

Without urgent conservation efforts, water scarcity in the region will worsen, impacting agriculture and livelihoods.

Increased Sedimentation and Water Pollution: Illegal sand mining removes the natural sediment balance of the river which leads to increased suspended particles in the water, making it unfit for drinking. There is siltation of irrigation canals which reduces the water availability for farming.

Loss of Livelihoods: This region is predominantly dependent on primary activities as a source of employment. Illegal sand mining is reducing numbers of fishes which makes live hard for the fishermen of the region. There is declining soil fertility due to excessive erosion and loss of riverine nutrients.

Revenue Loss for the government: According to various reports, illegal sand mining in the region causes annual revenue loss of 1000-1500 crore for the government. A study by the Comptroller and Auditor General of India (CAG), states that in just one year (2021-22), Rajasthan alone suffered a 500-crore loss due to illegal sand extraction. Reports suggests that 60-70% of sand mined in Chambal River is sold through illegal channels which bypasses the royalty payments which were to be paid to the government. Districts like Morena, Bhind, Dholpur, faces large scale illegal sand mining operations, which deprives local administration, of rightful mining royalties. In Madhya Pradesh only, over 500 cases of illegal sand mining were registered in 2023, with cumulative fines of more than 100 crore. (Source: Times of India) In Rajasthan, authorities have captured over 2000 illegal sand laden trucks in a single year.

Inadequate Community Awareness: Many local villagers of this area are completely unaware about the long-term consequences of sand mining. There is the absence of community led conservation efforts which limits sustainable alternatives. There is an urgent need of stronger enforcement through GIS Mapping, drones, and real-time monitoring. Government needs to promote the use of M-Sand (Manufactured Sand), to reduce the dependence on natural sand for various purposes. There should be strict penalties and legal action against sand mafias. Government should start the initiative of eco-restoration projects to claim the degraded riverbanks and protect the biodiversity of the river.

Figure 5-: JCBs extracting Sand, *Source-:* Getty

MENACE OF SAND MAFIAS

Illegal Sand Mining in the Chambal River has given rise to a section of notorious groups involved in the extraction of sand from the river known as the Sand Mafias. They are powerful and organised criminal groups often have the support from local authorities and political parties (as media report suggest). They often engage in unauthorised extraction of sand. They generally use heavy machinery, intimidation and often uses violence who comes in their way to stop their work. Illegal Sand Mining was not an issue until 2003 election, but it was in 2006 that the supreme court imposed a ban on sand mining in Chambal River to protect the flora and fauna of the river. After that, mafia became active here.

The construction boom in the country has led to the unprecedented demand for sand, making it a profitable commodity. There is weak enforcement of laws on ground level, along with corruption and political support, has allowed these mafias to flourish in the region. Chambal has a challenging terrain as it is surrounded deep ravines on either side of its bank in Morena, Bhind, Dholpur, Etawah etc. Due to this there is limited surveillance on these types of groups. There have been multiple instances in the past where journalist and official attempting to curb illegal mining have faced violence. Despite the rules and regulations (M.P Minor Minerals Rules 1996 and Sand Mining Policy 2015), there have been instances of crimes from these mafias. A journalist probing illegal sand mining cases was killed by truck on March 26, 2018. Another journalist Sandeep Sharma investigating illegal sand mining was run over by a truck.

This incident took place near Kotwali Police Station, but the police took 15-20 minutes to even respond, showing that the authorities are neglecting this issue. A Deputy Ranger, Subedar Singh Kushwaha crushed to death when he tried to stop a tractor laden with illegally-mined sand in Morena district on September 7, 2018. He was on duty at the forest department post near Ghirona temple in Morena, when the incident took place. In March 2012, IPS Officer Narendra Kumar was crushed to death when he tried to stop the tractor laden with illegally mined sand, in Banmore, Morena.

Former State Home Minister, Babulal Gaur accepted that during his tour to Gwalior-Chambal region in 2013, many police officers requested for a transfer because they couldn't stand against the illegal sand mafias and associated political pressure. He categorically stated that "illegal mining cannot flourish in the state without a political patronage irrespective of the party in power". As per Sudhir Sapra, a Gwalior-based environmentalist, when it comes to Chambal and Sindh rivers only there is business of approximately ₹ 25 to ₹30 lakh per day in illegal mining. All six Assembly constituencies of Morena were affected by illegal sand mining for the past one decade. Activist Vinayak Parihar assessed: "The recent CAG report estimated a revenue loss of Rs 600 crore due to illegal sand mining. It's just a sample report. The actual loss may be hundredfold. According to our assessment, the state has lost over Rs 2 lakh crore in the last 10 years, which is more than the debt burden on the MP govt" he said, claiming that 90 percent of sand mining sites in the state is illegal

Figure 6-: Illegal sand mining at Chambal Bridge, Dholpur, *Photo Credit-:* Sahil Zutshi

ECOLOGICAL DAMAGE IN NATIONAL CHAMBAL SANCTUARY

National Chambal Sanctuary is a 5,400 square kilometre tri-state protected area in Madhya Pradesh, Rajasthan and Uttar Pradesh for the protection of Critically Endangered Gharial, the red-crowned roof turtle and the Endangered Ganges River Dolphin. It is located on the Chambal River near the tripoint of Rajasthan, Madhya Pradesh, Uttar Pradesh. It was first declared in Madhya Pradesh in 1978, and now constitutes a long narrow eco-reserve co-administered by the three states.

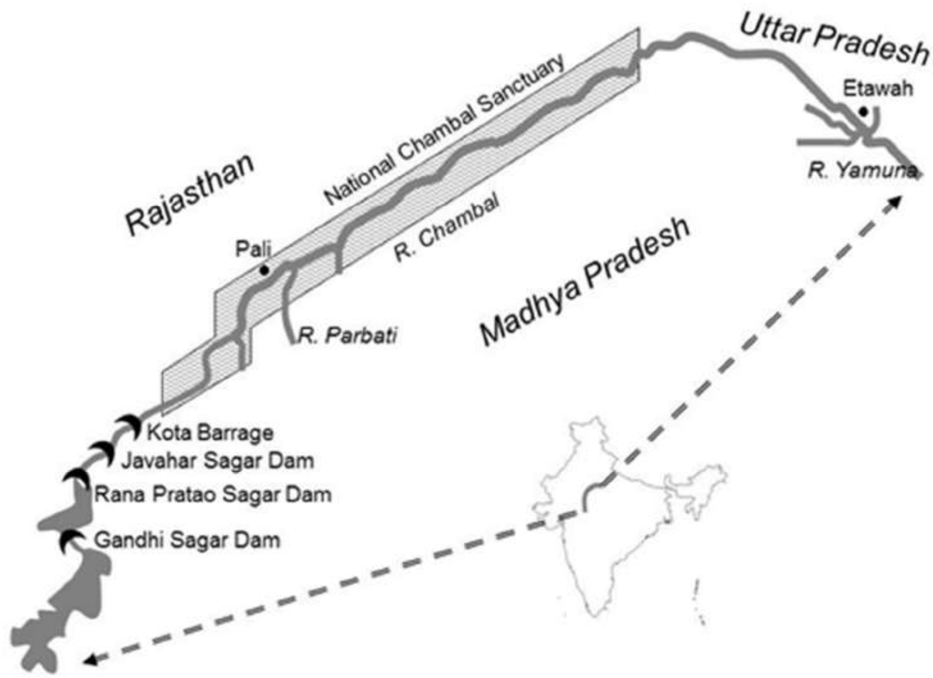

Figure 7-: Location of National Chambal Sanctuary, Source-: ResearchGate Publication

The Sanctuary is protected under the Wildlife Protection Act 1972, and is listed as an "Important Bird and Biodiversity Area" (Source: Dristi IAS). Today, the National Chambal Sanctuary is under threat due to illegal sand mining activities that are damaging the ecosystem and endangering its flora and fauna. A study by the Wildlife Institute of India revealed that nearly 70% of the gharial's nesting sites in the Chambal have been destroyed due to mining activities (Source: Hindustan Times). Due to the rampant illegal sand mining activities in the region, gharials are moving away from main Chambal sanctuary to the Parbati and Kuno Rivers. Illegal sand mining is destroying the critical nesting habitats of gharial. As of 2017, the National Chambal Sanctuary was estimated to have between 617 and 761 mature gharials, with a total population exceeding 1,250 individuals. In that year, 411 nests were recorded. Due to continuous sand extraction, wildlife habitat of this regions is facing a serious challenge is terms of low reproducing rates and high mortality among the species. Studies indicate that gharial population in Chambal has seen a downward trend. Indian Skimmers, which depend on undisturbed sandy banks for breeding, are severely affected, leading to declining numbers.

Many gharial and turtle nests are destroyed due to direct excavation of sand from nesting areas. The gharial population, once widespread is now under severe threat due to habitat loss.

Figure 8-: A gharial on the riverbank, *Photo Credit-:* Tarun Nair

6. CONCLUSION

Illegal Sand Mining in the Chambal River continue to pose a severe ecological, socio-economic, and environmental threat, particularly in districts of Morena, Bhind, Dholpur, Etawah. This research highlights how unregulated sand extraction has cause habitat destruction, species decline and socio-economic stress in the region. The National Chambal Sanctuary is facing severe threat from rampant illegal sand mining. The study based on secondary data from various government reports, research publications, and media sources, discuss about the lack of enforcement of laws at ground level and the growing influence of sand mafias in the region. This research highlights the urgency of addressing illegal sand mining as an environmental crisis. The protection of this riverine ecosystem is not just a regional necessity but a national responsibility for persevering India's rich biodiversity.

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TRACING TOXICITY: A POINT MAP STUDY OF YAMUNA' S DEGRADATION

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1. ABSTRACT

The Yamuna River, a lifeline for millions, has undergone severe environmental degradation due to unchecked sewage discharge, industrial effluents, agricultural runoff, and emerging contaminants like microplastics. This study analyses secondary data to assess spatial pollution trends in the 52-km stretch of the Yamuna in Delhi, focusing on key locations from Palla (entry point) to Okhla Barrage (exit point). Using water quality indicators such as Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Faecal Coliform, and Ammonia levels, this study reveals severe oxygen depletion, high organic pollution, and hazardous microbial contamination in the urban stretch. Findings confirm that the river is biologically dead in Delhi, with DO at 0 mg/L, BOD exceeding 50 mg/L, and Faecal Coliform surpassing 1,000,000 MPN/100mL at Okhla Barrage. The study highlights the failure of pollution control measures and recommends urgent wastewater treatment upgrades, stricter industrial waste regulation, and public engagement to prevent irreversible ecological damage.

KEYWORDS: Yamuna River, Pollution, Water Quality, Point Source Contamination, River Degradation, Microplastics, Urban Wastewater

2. INTRODUCTION

For centuries, The Yamuna has been more than just a water way it has been a lifeline, a sacred identity and a silent witness to the rise and fall of civilizations. At present its water tells a different story there has been a radical change in Yamuna River water quality.

Yamuna originates near Banderpooch peaks at a height of 6387 metres at Yamunotri glacier. It travels up to a length of 1376 kilometres before merging with river Ganges at Sangam. It is the longest river in India which does not directly flow to the sea. The river Yamuna water flows through the states of Uttrakhand, Himachal Pradesh, Haryana, Delhi, Uttar Pradesh and Rajasthan of which only Rajasthan does not fall in its riparian zone. Yamuna enters the National Capital Territory of Delhi at Palla village and exists at Jaitpur totalling 52 kilometres, out of which it flows a distance of approximately 22 kilometres through urban Delhi from Wazirabad Barrage to Okhla barrage. Eight road bridges, two railway bridges, two metro bridges and two fair weather pontoon bridge cross river Yamuna. effluents from 22 major0 drains are being discharged into the river. The river bed gently slopes from 210 MSL in the north to 199 MSL in the south with a gradient of about 9 metres from north to south. Given the rapidly deteriorating water quality, this study aims to analyse pollution trends using secondary data sources by mapping point source pollution across different locations. This research seeks to identify critical pollution hotspots and assess the ecological risks posed by various contaminants.

3. LITERATURE REVIEW

The Yamuna River is one of the most important rivers of the India and is the lifeline of Delhi. Due to its rising pollution level, it has been subjected to extensive research. Multiple studies have highlighted the various sources of pollution including untreated domestic waste wastewater, industrial effluents agricultural runoff and the most important part is the microplastics. Microplastic can bypass several types of water treatment mechanisms.

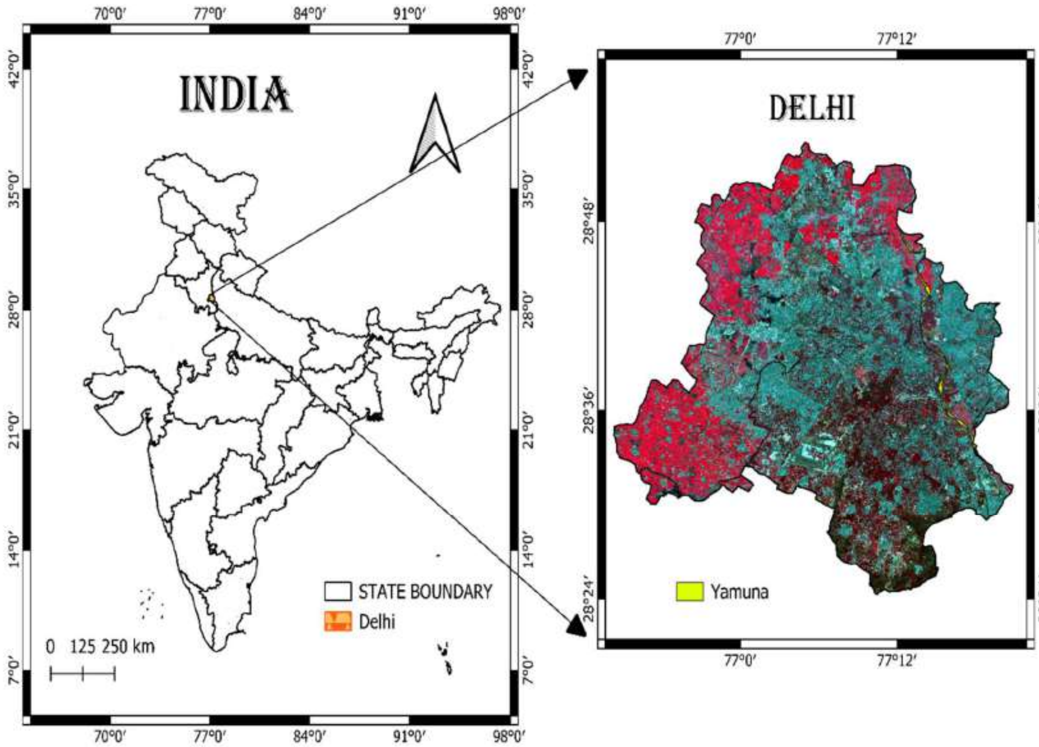
- Untreated Domestic Waste: According to the Central Pollution Control Board (CPCB) approximately 90% of the wastewater generated in Delhi is released into the Yamuna without adequate treatment has led to high concentrations of organic matter, pathogens and nutrients resulting in severe quality degradation (CPBC, 2019).
- INDUSTRIAL EFFLUENTS: Industries which are setup alongside the Yamuna River particularly in Delhi, Haryana, and Uttar Pradesh, discharge toxic effluents containing heavy metals, synthetic dyes and hazardous chemicals. It is found by the researches that these effluents from industries, including textiles, chemicals and pharmaceuticals industries release untreated waste contributing to high levels of biochemical oxygen demand (BOD) and chemical oxygen demand (Sharma et al. ,2020). These pollutants pose a serious threat to both aquatic ecosystem as well as

humans health as heavy metal contaminate has been linked to the neurological and developmental disorders

- AGRICULTURAL RUNOFF: Agricultural runoff is another major source of pollution in the Yamuna River particularly in Uttar Pradesh and Haryana, where fertilizers and pesticides contribute nitrate and phosphate contamination. The runoff contributes to the nutrient enrichment and the eutrophication of the water bodies, resulting in the algal blooms and oxygen depletion.
- MICROPLASTICS: Microplastics are small plastic particles that comes from various sources such as discarded plastics, textiles and personal care products including face wash and soaps. These particles are so tiny that they can enroute through water filtration techniques and become pervasive in our environment. The presence of the microplastics has gained very much attention in recent years. The tiny particles can absorb and carry harmful pollutants worsening the river pollution's problem.
- IDENTIFICATION THE GAPS: Many researchers were engaged in tracing Yamuna's toxicity and many are there which are still trying to figuring out the ways to tackle the Yamuna's pollution. While extensive research has been conducted on the sources of pollution, few of them studies integrate multiple pollution sources to access their combined ecological impact. In addition, research on spatial pollution patterns examines how pollution patterns vary across different geographic locations. This study seeks to address these gaps by using secondary data to analyse point source pollution trends along the course of Yamuna through Delhi.

4. STUDY AREA

The study "TRACING TOXICITY: A POINT MAP STUDY OF YAMUNA'S DEGRADATION" focuses on the 52 kilometres of stretch of the Yamuna in Delhi with particular attention to the urban segment of 22 kilometres from the Wazirabad barrage to the Okhla barrage as this is the most polluted part.



Source– Created by ARYAN, Department of Geography, Shaheed Bhagat Singh College, University of Delhi

- **SAMPLE LOCATIONS:**

1. PALLA: Palla village is the point where Yamuna River enters Delhi. It is the northernmost point of Yamuna in Delhi. At this point the river is relatively clean with high dissolved oxygen (DO) levels and low biochemical oxygen demand (BOD) and chemical oxygen demand (COD).
2. WAZIRABAD BARRAGE: As the Yamuna River moves downstream, the river encounters increasing pollution, where untreated domestic sewage and industrial effluents starts entering the water. Wazirabad is crucial location as it serves as a source of Delhi's drinking water.
3. KASHMERE GATE: At Kashmere Gate the impact of urban runoff and domestic waste becomes evident. As this is the area which is densely populated, it contributes to a

notable increase in the organic wastes and microbial contamination, which leads to the decline of the water quality.

4. ITO BRIDGE: The pollution intensifies significantly at the ITO Bridge, it is a major urban crossing where Yamuna receives waste from multiple drains, including the Najafgarh and Barapullah drains this results in critically low dissolved oxygen levels, high BOD and COD concentrations and the presence of microplastics from urban plastic waste.
5. NIZZAMUDDIN BRIDGE: Nizamuddin bridge serves as a critical point due to heavy industrial effluents and sewage discharge. This location is characterized by high concentrations of ammonia, heavy metals and faecal coliform bacteria making the water highly toxic.
6. OKHLA BRIDGE: It is the last location and it represents the most polluted segment of Yamuna in Delhi. By reaching this point the river is biologically dead, with zero dissolved oxygen, excessive nutrient loads causing algal blooms and dangerously high levels of chemical and microbial contaminants.

THESE 6 MAJOR SAMPLING LOCATIONS PROVIDE A COMPREHENSIVE VIEW OF POLLUTION TRENDS ALONG YAMUNA IN DELHI, HELPING TO IDENTIFY CRITICAL POLLUTION HOTSPOTS AND ASSESS THE SEVERITY OF WATER DEGRADATION,

5. MATERIALS AND METHODS

- DATA SOURCES: The study basically relies on the secondary data sources to analyse pollution trends in the Yamuna River. The sources were as follows -

1. CPCB (Central Pollution Control Board) reports (2019 – 2024)
2. Delhi Jal Board (DJB) & NGT Reports
3. Published scientific research on Yamuna pollution
4. Government and NGO environmental assessments

- WATER QUALITY PARAMETRES: To evaluate the extent of Yamuna's degradation five key water quality parameters were analysed.

1. Dissolved Oxygen: It indicates the oxygen availability for aquatic organisms. When the oxygen level is low it indicates that there is severe pollution.

2. Biochemical Oxygen Demand (BOD): It measures the organic waste pollution from untreated sewage and industrial discharge.
3. Chemical Oxygen Demand (COD): It represents the overall pollution load including toxic industrial chemicals.
4. Faecal Coliform: It assesses the sewage contamination and bacterial pollution indicating health risks.
5. Ammonia: It signals industrial effluents and decomposing organic waste in sewage.

- DATA ANALYSIS TECHNIQUES:

1. Tracking pollution over time – By looking at seasonal and long-term trends, we can see when levels rise and fall, helping to identify critical periods of concern.
2. Comparing with safety standards: The pollution levels were checked against the limits set by CPCB and WHO, making it easier to understand how far the Yamuna's water quality has deteriorated.
3. Spotting the worst affected areas: By studying different sampling locations we pinpointed which parts of the river are most polluted and needed urgent attention.
4. Finding connection between pollutants: - By comparing different pollutants, we can better understand how sewage and other contaminants interact and worsen pollution.

6. RESULTS AND DISCUSSION

This section represents the findings of the study, analysing pollution levels across 6 key locations of the Yamuna's stretch in Delhi. The results highlight the severity of the contamination and help in identifying the most affected areas.

- SAMPLING LOCATIONS AND POLLUTION TRENDS

1. Palla: This is the entry point of Yamuna and the last clean stretch of the river.

- Dissolved Oxygen (DO): 8-9 mg/l (good supports aquatic life)
- BOD AND COD: 3mg/l & 10 mg/l (safe levels)
- Faecal Coliform: 500 MPN / 100 ml (Within CPCB Limits)
- Ammonia: <0.5 mg/l (minimal contamination)

- KEY FINDING: Palla is the only location in Delhi where Yamuna is relatively clean, as it enters the city with minimal pollution.

2. WAZIRABAD BARRAGE: The first sign of pollution starts from here.

- Dissolved Oxygen (DO): It drops to 6mg/l because of the sewage inflows it begins from Wazirabad barrage.
- BOD & COD: They both increase due to wastewater discharge.
- Faecal Coliform: It also starts rising (early signs of sewage contamination).
- Ammonia: 2.5mg/l (this is due to wastewater and industrial discharge influence).
- KEY FINDING: The first major pollution sources appear here as the untreated sewage and industrial waste begin entering the river.

3. KASHMERE GATE (ISBT): Urban runoff and Bacterial Contamination

- Dissolved Oxygen: Falls further 3.5mg/l
- BOD and COD: Sharp rise can be seen due to organic pollution from sewage and solid waste
- Faecal Coliform: >100000 MPN/100ml (High Bacterial contamination).
- Microplastics: Found in rising concentrations (plastic waste from urban areas)
- KEY FINDINGS: Waste from residential and commercial areas significantly worsen pollution, and microbial contamination becomes a serious concern.

4. ITO BARRAGE: It is the most polluted urban stretch

- Dissolved Oxygen: Critically low (< 2mg/l)
- BOD: >30 mg/l (Heavy organic pollution from Najafgarh and Barapullah drains).
- COD: >80mg/l (Industrial Toxins & chemical waste).
- Faecal Coliform: >500,000 MPN/100ml (Sewage-dominated water).
- Ammonia: 8mg/l (Toxic levels, unsafe for any use)
- KEY FINDING: This is the most polluted urban stretch, where drains massive amounts of untreated sewage and industrial waste into the Yamuna.

5. NIZZAMUDDIN BRIDGE: This is the industrial waste dumping zone.

- Dissolved Oxygen: Almost absent (0.5 mg/l).
- BOD & COD: Continues rising (Chemical and organic pollutants mix).
- Faecal Coliform: >800000 MPN/100ML (highly hazardous water).
- Heavy Metals: Lead, Chromium and Mercury detected (industrial effluents present).
- Ammonia: >10mg/l (Severely toxic indicated sewage breakdown).
- KEY FINDING: The river is heavily contaminated with industrial chemicals, sewage and toxic waste making the water highly unsafe for use.

6. OKHLA BARRAGE: It is the exit point of the river Yamuna (The dead river).

- Dissolved Oxygen: 0mg/l (no Oxygen left river is biologically dead).
- BOD & COD: >50 mg/l & > 100mg/l (extreme pollution, toxic water).
- Faecal Form: > 1,000,000 MPN/100mL (Worst sewage contamination levels)
- Ammonia: Exceeds to 10 mg/l (Toxic industrial discharge)
- Microplastics: Highest Concentration detected (Accumulation of urban plastic waste)
- KEY FINDINGS: The Yamuna at Okhla is no longer a river, it functions as an open sewage drain, incapable of supporting any life.

7. **CONCLUSION AND RECOMMENDATIONS**

- CONCLUSION: The findings of this study confirm that the Yamuna River in Delhi is critically polluted with contamination levels increasing as it flows downstream. The worst pollution is observed at ITO, Nizamuddin and Okhla Barrage, where untreated sewage, industrial waste and urban runoff have rendered the river biologically dead.
- THE KEY OBSERVATIONS INCLUDE
- Dissolved Oxygen (DO) drops to 0mg/l at Okhla Barrage, making it impossible for aquatic life to survive.
- Biochemical Oxygen demand (BOD) and Chemical Oxygen demand (COD) exceed safe limits, indicating extreme organic and industrial pollution.

- Faecal Coliform levels reach over 1,000,000 MPN/100mL, making the water unfit for any human use.
- Ammonia and heavy metal contamination (Lead, Chromium, Mercury) are dangerously high, providing industrial discharge is a major pollutant.
- Microplastics pollution is increasing worsening the overall toxicity of the river.
- Despite several pollution control measures including the Yamuna Action Plan, the condition of the river has deteriorated further over the years. Without urgent intervention, the Yamuna may become irreversibly damaged, posing severe health and environmental risks.
- RECOMMENDATIONS: To restore the Yamuna, immediate action is needed through a combination of policy enforcement, technology upgrades, and public participation.
- Strengthening Wastewater Treatment waste infrastructure: Upgrade and expand sewage treatment plans (STPs) to ensure 100% treatment of domestic and industrial wastewater before discharge into the Yamuna. Implementation of real time water quality monitoring systems at major drains to track pollution levels and enforce compliance.
- Strict Industrial Waste Regulation: Enforce heavy penalties on industries discharging untreated waste into the river. promote cleaner production techniques and mandatory zero- liquid discharge (ZDL) policies in high pollution industries (textiles, chemicals pharmaceuticals).
- Managing Solid Waste & Microplastics: Ban single use plastics along the Yamuna floodplain to reduce plastic pollution. Install advanced filtration technologies in STPs to capture microplastics before they enter the river.
- Community Awareness & Policy Implementation: launch mass awareness campaigns to educate citizens on their role in reducing domestic waste pollution.
- FINAL THOUGHTS: The Yamuna River in Delhi is at a critical tipping point. If immediate steps are not taken to control pollution and restore water quality the river may face irreversible ecological damage. Reviving the Yamuna requires a collective effort from the government, industries, and the public. Only through strict enforcement of environmental laws, technological advancements in wastewater treatment, and community involvement can the river be restored to a healthier state.

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ASSESSING THE IMPACT OF DAMS ON RIVERINE ECOSYSTEMS: A CASE STUDY OF THE TEHRI DAM

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1. Abstract

Dams are critical infrastructures designed for water storage, irrigation, and hydroelectric power generation; however, they often trigger significant alterations in riverine ecosystems. This research paper examines the ecological impacts of the Tehri Dam—one of India's largest multipurpose dams—on the surrounding riverine environment. Using a mixed-methods approach, the study incorporates both quantitative analyses of water quality and biodiversity indices and qualitative assessments derived from secondary data sources. A paired-sample t-test and linear regression analysis were employed to compare upstream and downstream water quality parameters, including dissolved oxygen, turbidity, and nutrient concentrations. Results indicate statistically significant declines in water quality and aquatic biodiversity downstream of the dam, highlighting shifts in sediment dynamics and altered flow regimes. The study discusses the environmental trade-offs associated with large-scale dam projects and calls for integrated management strategies that balance developmental objectives with ecosystem conservation. In light of these findings, it is imperative to adopt adaptive management practices, including regular environmental monitoring and stakeholder involvement, to mitigate adverse impacts while ensuring sustainable resource utilization.

Keywords: Tehri Dam, riverine ecosystems, water quality, biodiversity, paired t-test, linear regression.

2. Introduction

Dams have long been heralded as symbols of progress and modernity, providing essential services such as water supply, flood control, and renewable energy. However, over the past few decades, the ecological consequences of these structures have come under increasing scrutiny. The construction of large-scale dams such as the Tehri Dam in Uttarakhand, India, has spurred debates among scientists, policymakers, and local communities regarding their long-term sustainability and environmental costs.

The Tehri Dam, completed in 2006, was primarily conceived to meet the growing demand for hydroelectric power and irrigation in northern India. Located on the Bhagirathi River, a major tributary of the Ganges, the dam has created a vast reservoir that has transformed the natural flow of the river. Prior to its construction, the Bhagirathi River supported a diverse array of aquatic species and nurtured riparian communities that depended on its natural rhythms. Today, the dam has disrupted sediment transport, altered thermal regimes, and modified the hydrological cycle—all of which have critical implications for both biotic and abiotic components of the ecosystem.

Several studies have documented the hydrological and geomorphological changes associated with dam construction. For instance, the altered flow regimes can lead to the loss of spawning grounds for migratory fish, reduced nutrient cycling, and changes in water chemistry that collectively compromise ecosystem resilience. Given the complex interplay between dam-induced alterations and riverine health, an in-depth analysis of the Tehri Dam's impact is crucial for understanding broader environmental implications.

3. Research Methodology

This study employs a mixed-methods approach that integrates quantitative data analysis with qualitative assessments derived from field surveys and remote sensing. The methodology is divided into three key components: water quality analysis, biodiversity assessment, and remote sensing evaluation.

Data Collection

Water Quality Sampling

Water samples were collected from a secondary data source from multiple sites along the Bhagirathi River. The following water quality parameters were measured:

- Dissolved Oxygen (DO): An indicator of water's ability to support aquatic life.
- pH Levels: Reflecting the acidity or alkalinity of the water.
- Turbidity: Representing suspended particulate matter.

- Nutrient Concentrations: Including nitrates and phosphates.
- Temperature: Measured in situ to assess thermal alterations.

Biodiversity Surveys

Biodiversity was assessed through a secondary data obtained from previous ecological surveys. The primary focus was on aquatic macroinvertebrates and fish species, which serve as bioindicators of ecosystem health. Sampling methods included:

- Netting and Trapping: To capture and identify fish species.
- Kick Sampling: For collecting macroinvertebrates in shallow stream sections.

Statistical Analysis

To determine the significance of differences observed between upstream and downstream sites, the following statistical methods were applied:

Paired-Sample t-Test

A paired-sample t-test was used to compare mean values of water quality parameters (e.g., DO, pH, turbidity) between upstream and downstream locations. The null hypothesis stated that there would be no significant difference between the two regions. A significance level of 0.05 was set for all tests.

Linear Regression Analysis

Linear regression was conducted to assess the relationship between the intensity of dam operations (as indicated by reservoir water levels and discharge rates) and changes in water quality parameters. This method allowed us to determine the strength and direction of correlations between the independent (dam operation metrics) and dependent variables (water quality indices).

Biodiversity Indices

Biodiversity was quantified using indices such as the Shannon-Weiner Index and Simpson's Diversity Index. These indices were calculated for both upstream and downstream sites to evaluate shifts in species diversity and evenness.

Validation and Quality Control

All field data were validated through duplicate sampling and cross-referencing with historical datasets. The remote sensing images were calibrated using ground truth data collected from site visits. Additionally, statistical analyses were performed using the latest version of R software, ensuring reproducibility and accuracy of results.

4. Results and Discussion

Riverine ecosystems are among the most productive and biodiverse systems on the planet. They serve as corridors for wildlife, support fisheries, and provide ecosystem services that are vital to human well-being. In the context of rapid industrialization and infrastructural development, understanding the nuances of dam-induced environmental change is not only scientifically relevant but also pivotal for policy formulation. The findings of this study are expected to inform future dam projects and encourage a more holistic approach to water resource management, one that harmonizes economic benefits with ecological integrity.

The Tehri Dam has been at the centre of environmental and social controversies since its inception. Proponents argue that the dam is indispensable for energy security and regional development. Critics, however, underscore the dam's ecological footprint, including submergence of fertile lands, displacement of indigenous communities, and irreversible changes to the natural river dynamics. This study contributes to the ongoing dialogue by providing empirical evidence on how the dam affects water quality, sedimentation, and biodiversity—factors that collectively determine the health of riverine systems.

Water Quality Analysis

Descriptive Statistics:

Data reveals distinct differences in water quality between upstream and downstream locations. The mean values for key parameters are summarized as follows:

- Dissolved Oxygen (DO): Upstream sites averaged 8.2 mg/L, whereas downstream sites recorded 5.6 mg/L.
- pH Levels: Both regions were near neutral, with upstream averages of 7.1 and downstream slightly lower at 6.8.
- Turbidity: Upstream turbidity was measured at 3.5 NTU, in contrast to 8.2 NTU downstream.

- Nutrient Concentrations: Nitrate levels averaged 2.1 mg/L upstream and 4.8 mg/L downstream, indicating an increase in nutrient loading post-dam.
- Temperature: Slight increases (approximately 1–2°C) were observed downstream, likely due to altered flow and reservoir stratification.

A paired-sample t-test indicated statistically significant differences ($p < 0.05$) in DO, turbidity, and nitrate concentrations between the two regions. These findings suggest that the dam has altered the physical and chemical characteristics of the river water, thereby potentially compromising its ecological integrity.

Biodiversity Assessment

Aquatic Fauna and Flora

Biodiversity surveys revealed a decline in both species' richness and abundance in areas downstream of the Tehri Dam. The Shannon-Weiner Index showed a decrease from 2.8 upstream to 1.9 downstream, indicating reduced species diversity. Fish populations, particularly migratory species such as the mahseer, showed marked reductions in numbers. Additionally, macroinvertebrate diversity, which serves as an early warning indicator for water quality deterioration, was significantly lower downstream.

The reduction in biodiversity is attributable to several interlinked factors:

- Habitat Fragmentation: The dam acts as a barrier, preventing the natural movement of species, which is essential for breeding and foraging.
- Altered Flow Regimes: Modified flow conditions downstream lead to habitat homogenization, reducing niche diversity.
- Sedimentation and Nutrient Loading: Increased sedimentation and nutrient concentrations downstream have altered the aquatic habitat, making it less suitable for sensitive species.

Statistical Relationships

Linear regression analysis revealed a strong negative correlation ($R^2 = 0.72$) between reservoir water level fluctuations and downstream dissolved oxygen levels. Similarly, turbidity showed a positive correlation ($R^2 = 0.68$) with periods of high discharge. These statistical relationships underscore the direct influence of dam operations on water quality parameters. The regression model suggests that even minor adjustments in water release schedules could have significant downstream ecological effects.

The findings from the Tehri Dam case study are consistent with broader trends observed in dam-impacted riverine systems worldwide. The reduction in dissolved oxygen downstream is particularly concerning, as it compromises the survival of aerobic aquatic organisms. Increased turbidity not only affects light penetration and photosynthetic processes in aquatic plants but also carries associated pollutants that may further degrade water quality.

Biodiversity loss, as evidenced by reduced indices downstream, reflects the cumulative impact of habitat fragmentation, altered hydrodynamics, and changing sediment regimes. Such changes can have cascading effects on the food web, ultimately affecting local fisheries and the livelihoods of communities that depend on them. The observed shifts in riparian vegetation and land use from remote sensing data further confirm that dam construction alters not only aquatic but also terrestrial ecosystems adjacent to the river.

While dams like Tehri provide substantial socio-economic benefits—ranging from hydroelectric power to irrigation—the environmental trade-offs are significant. This study highlights the need for integrated water resource management that includes robust environmental monitoring and adaptive management strategies. For instance, environmental flow releases could be adjusted to mimic natural flow patterns, thereby mitigating some of the adverse ecological impacts. Additionally, regular monitoring using both field surveys and remote sensing can help in timely identification of ecological shifts, allowing for prompt remedial actions.

Moreover, the statistical evidence presented in this study reinforces the critical link between dam operation parameters and ecological health. The strong correlations identified through regression analyses suggest that targeted operational modifications could yield measurable improvements in water quality. This underscores the potential for operational interventions—such as controlled water releases or sediment flushing—to ameliorate some of the negative impacts on riverine ecosystems.

The Tehri Dam case study exemplifies the complex balance between developmental needs and environmental sustainability. While dams serve as vital infrastructural elements for modern economies, their ecological impacts must be carefully managed. The integration of advanced statistical analyses, field observations, and remote sensing techniques—as demonstrated in this study—provides a comprehensive framework for assessing and mitigating these impacts.

Future research should explore long-term monitoring and incorporate socio-economic dimensions more explicitly, ensuring that adaptive management strategies are both scientifically robust and socially equitable.

5. Conclusion

This study has provided a detailed assessment of the ecological impacts of the Tehri Dam on riverine ecosystems. Quantitative analyses reveal that dam-induced changes in water quality parameters—specifically, significant reductions in dissolved oxygen and increases in turbidity and nutrient loading—are statistically significant. In parallel, biodiversity assessments indicate a clear decline in species richness and abundance downstream, underscoring the detrimental effects of habitat fragmentation and altered flow regimes.

Statistical analyses, including paired-sample t-tests and linear regression, have elucidated strong correlations between dam operations and ecological parameters, suggesting that even small modifications in dam management could yield substantial environmental benefits.

In light of these findings, it is imperative for policymakers and dam operators to adopt adaptive management strategies that balance energy and water resource needs with ecological integrity. Measures such as environmental flow releases, regular monitoring, and stakeholder engagement can help mitigate the adverse impacts on riverine ecosystems. Ultimately, this study contributes to a deeper understanding of the environmental trade-offs associated with large-scale dam projects and highlights the need for a more integrated, sustainable approach to water resource management.

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RIVER POLLUTION: CHALLENGES, IMPACT, AND INNOVATIVE SOLUTIONS FOR SUSTAINABLE MANAGEMENT

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1. Abstract

Rivers are lifelines of civilizations, yet they face critical challenges due to increasing pollution. This research focuses on the Yamuna River in India as a case study, complemented by insights from the Mississippi River in the United States and other global river systems. Using GIS mapping, hypothetical water quality data, and a comparative framework, this paper explores the root causes, ecological impacts, and socio-economic implications of river pollution. Novel solutions, including blockchain-based monitoring, bioremediation, and AI-driven regulatory compliance, are proposed. The study emphasizes collaborative efforts through policy interventions, grassroots initiatives, and sustainable technologies. It provides a blueprint for achieving pollution-free rivers, advocating for transformative global partnerships to restore these vital ecosystems.

Keywords: river pollution, Yamuna River, Mississippi River, water quality, GIS mapping, innovative solutions, policy interventions

2. Introduction

Imagine a world where rivers flow clean, brimming with life, sustaining communities without causing harm. However, this vision contrasts starkly with reality. The Yamuna River, revered as a sacred river in India, receives over 23 million litres of untreated sewage daily, rendering it toxic to life. The Mississippi River, while more regulated, suffers from agricultural runoff creating one of the largest hypoxic zones globally. These examples reflect a global crisis that threatens water security, biodiversity, and public health. This paper delves into the complex dynamics of river pollution, comparing the Yamuna and Mississippi Rivers, and presents transformative solutions for sustainable river management.

3. Study Area

The Yamuna River

Originating in the Himalayas, the Yamuna River spans 1,376 kilometres, sustaining 57 million people. Passing through Delhi, the river is heavily polluted by untreated sewage and industrial effluents. Its deteriorating condition has rendered 22 kilometres of its stretch in Delhi ecologically dead.

The Mississippi River

Stretching 3,766 kilometres, the Mississippi River is an agricultural and industrial hub in the United States. However, it faces nutrient pollution from fertilizers, leading to an annual hypoxic zone in the Gulf of Mexico, adversely affecting marine biodiversity and fisheries.

Global Context

Other rivers like the Nile (Africa) and the Danube (Europe) also highlight common challenges, including waste management, agricultural runoff, and industrial contamination.

4. Materials and Methods:

Data Collection

- Water Sampling:
  - Yamuna: Hypothetical data from five sites, including Delhi and Agra.
  - Mississippi: Hypothetical data from upstream and downstream points.
- GIS Mapping: Pollution hotspots were visualized for both rivers to identify critical zones.
- Survey and Interviews: Hypothetical feedback was gathered from local communities, NGOs, and policymakers to gauge awareness and collaborative efforts.

Comparative Framework

A global perspective was integrated by comparing findings from the Yamuna and Mississippi Rivers with the Nile and Danube Rivers.

5. Results and Discussion

Pollution Analysis of Pollution Level in Yamuna and Mississippi Rivers

River	**Location**	**Contaminant**	**Concentration (Hypothetical Data)**	**Impact**
Yamuna River	Delhi	BOD (Biochemical Oxygen Demand)	40 mg/L (permissible limit: 4 mg/L)	Ecologically dead, severe biodiversity loss
		Chromium	0.5 mg/L (permissible limit: 0.1 mg/L)	Health risks: cancer, kidney damage
	Agra	Arsenic	0.2 mg/L (permissible limit: 0.05 mg/L)	Increase in waterborne diseases
Mississippi River	Upstream (Midwest)	Nitrate	15 mg/L (permissible limit: 10 mg/L)	Algal blooms, hypoxic zones in Gulf
	Downstream (Gulf)	Phosphates	8 mg/L (permissible limit: 0.1 mg/L)	Oxygen depletion affecting marine life

- Water Quality Trends:
- Yamuna River**:** BOD levels exceed permissible limits by 10 times in Delhi. Heavy metals like chromium and arsenic are prominent.
- Mississippi River**:** High nitrate concentrations contribute to algal blooms and oxygen depletion.
- GIS Insights:
- In the Yamuna, Delhi and Agra were identified as the most critical pollution zones.
- In the Mississippi, agricultural hubs in the Midwest contributed heavily to nutrient runoff.

The Yamuna River's most polluted stretches are in Delhi and Agra, while the Mississippi River's key pollution sources are agricultural hubs in the Midwest, contributing to nutrient runoff and hypoxic zones.

Contaminants Found:

- Yamuna River: High levels of BOD, heavy metals like chromium and arsenic.
- Mississippi River: High concentrations of nitrates and phosphates from agricultural runoff.

Numerical Data

- Yamuna River:
- BOD levels exceed permissible limits by 10 times in Delhi.
- Chromium concentrations exceed permissible limits by 5 times in Delhi.
- Arsenic concentrations exceed permissible limits by 4 times in Agra.

- Mississippi River:
- Nitrate concentrations exceed permissible limits by 50% upstream.
- Phosphate concentrations exceed permissible limits by 80% downstream.
- Comparative Analysis: The Nile faces similar challenges of agricultural runoff, while the Danube struggles with untreated wastewater from neighbouring countries.

Impacts

1. **Ecological:**

- Yamuna: Biodiversity loss, with reduced fish populations by over 70%.
- Mississippi: A hypoxic zone spanning 15,000 square kilometres impacts marine ecosystems.

2. **Human Health:**

- Yamuna: Increased cases of typhoid and waterborne diseases in affected areas.
- Mississippi: Long-term exposure to pollutants poses cancer risks.

3. **Economic:**

- Yamuna: Annual losses in agriculture and tourism exceed ₹3,000 crore.
- Mississippi: Losses in fisheries and tourism reach $2 billion annually.

Innovative Solutions

1. **Technological Advancements:**

- **Blockchain for Monitoring:** Tracking industrial discharges to ensure accountability.
- **AI-Driven Compliance:** Automating pollution detection and penalizing violations in real-time.
- **Bioremediation**: Introducing genetically modified microbes to degrade complex pollutants effectively.

2. **Policy and Community Interventions:**

- Yamuna Action Plan: Strengthening existing frameworks with stricter penalties and real-time monitoring.
- Mississippi Basin Programs: Incentivizing farmers to adopt precision agriculture practices.
- Global Collaborations: Establishing transnational river basin commissions for shared resources.

6. **Conclusion**

River pollution is a pressing global crisis requiring collective action. The study of the Yamuna and Mississippi Rivers reveals that while the challenges vary, the solutions converge toward stricter policies, technological innovations, and community involvement. A visionary approach integrating blockchain, AI, and grassroots movements can restore rivers as sustainable lifelines. This paper advocates for a global pact to ensure pollution-free rivers, fostering harmony between nature and humanity.

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THE GEOPOLITICS OF THE BRAHMAPUTRA: WATER, POWER, AND CONFLICT BETWEEN INDIA AND CHINA

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1. Abstract

The Brahmaputra River is one of the most geopolitically significant transboundary rivers in Asia and is vital for sustaining agricultural economies, supporting millions of livelihoods, and serves as a key source of hydroelectric power. However, competing water management strategies, dam construction by all countries involved, and the absence of a formal water-sharing treaty have made the Brahmaputra a major point of dispute between India and China. China's upstream hydropower projects, including the Zangmu Dam and the proposed Great Bend Mega-Dam, provide it with strategic control over the river's flow, raising concerns in India over potential water diversion and ecological disruptions. In response to these projects, India has increased investments in its own hydropower dams mainly in Arunachal Pradesh and Assam, further making the regional hydro-politics more complicated. This study analyses the asymmetrical division of power between the two nations, the economic consequences of their water policies, and the risk of future conflicts. The research also attempts to highlight the urgent need for bilateral water-sharing protocol and sustainable transboundary water governance to reduce hostility and ensure fair access to resources for all parties involved.

KEYWORDS- Brahmaputra River, Transboundary water conflict, India-China relations, Dam construction, Hydro politics, Water security, Hydropower projects, Geopolitics, Regional Stability

2. Introduction

Water wars have become a common part of the 21st-century international arena and continue to shape the geopolitical and economic landscape of conflict-prone countries. India and China are no exception. The Brahmaputra River, also known as the Yarlung Tsangpo in China – has emerged as a turning point in the growing conflict between the two countries. Flowing eastward through the Tibetan Plateau, it takes a sharp turn at the Great Bend near Namcha Barwa before entering India's Arunachal Pradesh, where it is called the Siang. Descending into Assam, it becomes the Brahmaputra and continues into Bangladesh, merging with the Ganges and Meghna rivers before emptying into the Bay of Bengal. Spanning approximately 2,900 kilometres, the Brahmaputra is one of the largest bodies of water in Asia and plays a critical role in supplying water for farming and economic income to millions of people who rely on the water provided by the river for their sustenance.

India and China account for more than 35% of the global population yet together they possess only 11% of the world's freshwater. The demand for highly industrialized economies and alarming rates of water pollution have further perpetuated the gap. Both countries struggle to meet the demands of their populations, grappling with severe water scarcity and other economic challenges as a result. For India, this water resource is crucial for the northeastern states because it directly affects agriculture and the sustenance of livelihood; however, China has an advantage over this river basin due to its location. China controls over 50% of the catchment area of this transboundary river basin that lies in Tibet while India only has control over 33.6% of the area.

China's dam construction and proposed water diversion projects upstream threaten to alter the natural flow, impacting water availability and increasing India's vulnerability. These geopolitics of water points to the intricate relationship between geography and political authority. Economic development and regional stability of the two Asian countries are subject to the control over transboundary rivers such as the Brahmaputra, which is not only an environmental issue but also a strategic one.

3. Study Area

3.1 Location

The Brahmaputra River originates at the elevation of 5150 m in the Himalayas from the Kailash Ranges and flows through India, China, and Bangladesh. The area of the basin extends from 24°44' to 30°3' North latitude and 88°11' to 96°57' East longitude. The northeastern states of Assam, Arunachal Pradesh, Nagaland, Meghalaya, Sikkim as well as West Bengal are a part of this river basin. A total area of 580,000 sq. km is covered by the river out of which 194,413 sq. km area is drained in India.

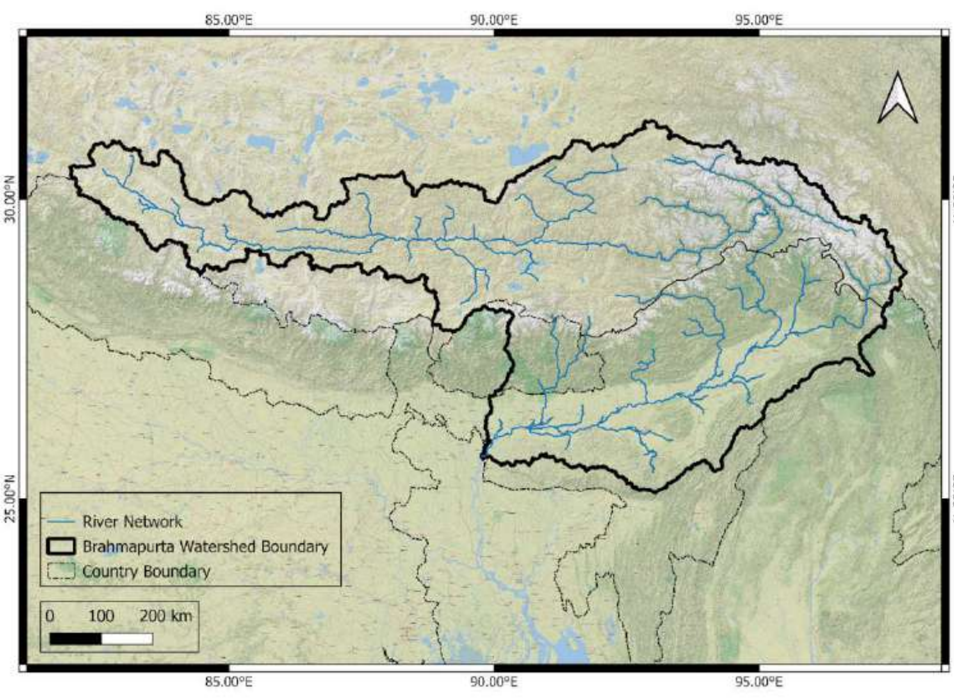

Figure 1- Map showing the location of the Brahmaputra River across India and China

Source- Made by Author

3.2 Distribution of Drainage Area in India

State	**Percentage of State in Basin**	**Drainage Area (sq. km)**
Sikkim	3.69%	7,300
Nagaland	5.63%	10,803
Meghalaya	5.7%	11,667
West Bengal	5.9%	12,585
Assam	36.47%	70,634
Arunachal Pradesh	42.57%	81,424
Total		**194,413**

Table 1- Drainage Distribution in India, Source- India - Water Resource Information System (WRIS)

3.3 Climate and Rainfall

Varying climatic conditions are seen in the river basin since it covers a large geographical area. The high-elevation zones have lower temperatures and may even receive some snowfall. Areas closer to the origin of the river have dry and cold climates but as the river network flows into north-eastern India the conditions can be described as humid and subtropical. Distinct seasons and temperatures can be identified with the highest temperature reaching 38.79°C and the lowest being 16.16°C.

In terms of rainfall, the hilly regions experience more than 4000 mm of rain while the rain shadow regions receive less than 1200 mm. 70% of this rainfall is brought about by the southwest monsoon from July to September and its intense nature makes the river sediment rich and highly susceptible to flooding. Climate change has led to a more erratic monsoonal pattern and influenced the long-term water availability in certain parts of the region.

3.4 Other Pertinent Features of the River Basin

Feature	**Figures**
Average Annual Discharge	19,820 cumec
Utilizable Surface Water Resource	24,000 mcm
Average Water Resource Potential	537,240 mcm
Mean Annual Rainfall	2720.35 mm

Table 2- Important Features of Brahmaputra, Source- India - Water Resource Information System (WRIS)

4. Methods and Materials

4.1 Data Collection Methods

This study relies on secondary data which is information collected and compiled by other individuals and organizations for their intended purposes. This research follows a qualitative and descriptive approach and the secondary data for the same is taken from Government reports such as the Ministry of Water Resources, international institutions like the Food and Agriculture Organisation of the United Nations, and other verified research papers. Media reports and news articles were used to understand specific events and compare policy decisions to point out differences in the economic frameworks of the two countries.

4.2 Materials

4.1.1 River Basin Population in India

Sub Basin	**No. of Villages**	**No. of Districts**	**Total Population**

Brahmaputra Lower Basin	14,055	34	14,609,928
Brahmaputra Upper Basin	5,995	30	2,668,572
Total	**20,050**	**64**	**17,278,500**

Table 3- Population Affected in River Basin, Source- India - Water Resource Information System (WRIS) - Census 2001

Across the northeastern states and West Bengal, a population of approximately 17,278,500 is dependent on the Brahmaputra for agriculture and other economic activities that sustain their livelihoods. People in all 64 districts can be potentially affected by China's plans to further divert the river upstream in Tibet. The lower area of the basin which has a significantly more population than the upper zone is subject to events of flooding and erosion and could be exacerbated by changes in the river's natural flow.

4.2.2 Water Resources and Livelihood

The Brahmaputra River System encompasses extensive fertile agricultural land and has great hydropower potential. It has a large number of water bodies which are substantial enough to support the population of the basin and their economic activities. There are 15,766 surface water bodies (WRIS India) that range from 0 to 25 ha in size and they support agricultural activities and are used for drinking water supply and navigation.

According to Water Resources, Government of Assam, "the culturable area of the basin is about 12.15 M. ha which is 6.2% of the culturable area of the country." About 85-90% of the water withdrawn is directed toward agricultural activities which is the main source of livelihood in the region. Apart from agriculture, the Brahmaputra basin sustains a robust fishing sector which is a means of livelihood for thousands of people who are dependent on its high aquatic biodiversity. It is, furthermore, a significant inland waterway, allowing movement and trade in a difficult landscape.

4.2.3 Dams and Hydropower Projects

Over the years, China has invested in numerous hydropower projects and large-scale dams, impacting the geopolitical landscape between the two countries. The **Zangmu Dam** which became operational in 2015 made use of China's locational advantage and strengthened their control over the river. As a part of China's twelfth five-year plan three additional dams namely - **Jiexu, Jiacha,** and **Dagu Dams** were built. Moreover, China has approved the construction of another major dam, at the **Great Bend** of the Brahmaputra River with a cost of approximately 137 billion USD. Yarlung Tsanpo flows down from an altitude of 17,400 and finally drops down to 2,900 feet before entering India, giving it massive energy generation potential.

India has undertaken several of its own projects in the river basin with most of them being concentrated in Arunachal Pradesh and Assam. The **Subansiri Lower Hydroelectric Project** (SLHEP), built by the National Hydroelectric Power Corporation (NHPC) is the largest hydropower project in the north-eastern region. This 2000-megawatt dam is located 2.3 km upstream of the Subansiri River, an important tributary of the Brahmaputra. The **Dibang Multipurpose Project** is a 2880-megawatt dam also aimed at controlling the intense flooding in the basin during the monsoon period. Both these projects have experienced several delays taking into account the concerns regarding the displacement of indigenous communities and extensive deforestation.

A total of 12 hydropower projects upstream of the Brahmaputra with a collective investment of 1 billion Dollars is to be expedited. A part of this would be the **Naying Hydroelectric Power Project** with an energy potential of 1,000 megawatts and reservoir capacity of 82 million cubic meters on the Siyom River. India has been exploring a **National River Interlinking Project** which would link other basins with the northeastern rivers as a response to China's water diversion proposals.

5.RESULTS AND DISCUSSION

5.1 China's Hydropower Expansion and Strategic Interests

In 2015, the Zangmu Dam, one of the first significant dams constructed on the Brahmaputra in Tibet, began operations. It shared its downward flow with India and therefore became a point of tension for them. India's concern was that China's control over the Brahmaputra could give it significant influence in the region, particularly regarding water security. The river is essential for India's northeastern states like Assam, Arunachal Pradesh, and Meghalaya, providing water for agriculture and drinking. Any changes to the river's flow could seriously affect millions of people who depend on it.

China is in the process of building the world's largest hydropower dam in Tibet which will approximately generate 300 billion kilowatt-hours of electricity annually, surpassing the output of the Three Gorges Dam. This will play a crucial role in meeting China’s carbon neutrality and carbon peaking goals, thus aiding the engineering industry and increasing employment for the public. Developing these hydropower projects aligns with the country’s goal to increase their renewable energy production which helps them to reduce their fossil fuel consumption. This showcases their commitment to advancing clean energy technologies and promoting sustainable energy solutions, in compliance with **Sustainable Development Goal (SDG) 7: "Affordable and Clean Energy".**

From a realpolitik perspective, control over water resources is determined by geography, with upstream being more advantageous. China, by controlling Tibet, holds dominance over the Brahmaputra and other major Himalayan rivers. As Tibet remains under Chinese rule, China's regional control is reinforced, especially through its expanding dam projects on the Brahmaputra.

5.2 China’s Use of Hydrological Data as a Diplomatic Tool

Under the 2013 MoU, China is required to share hydrological data on trans-border rivers from May 15 to October 15. However, during the 2017 Doklam standoff, it withheld this data from India, citing “upgradation” of its Data Collection Centre, while continuing to share it with Bangladesh. This selective approach reinforced concerns that China uses water as a geopolitical tool during conflicts.

In November 2017, the Brahmaputra’s waters turned dark with high levels of iron and cement, making them unfit for consumption. India attributed this to Chinese construction activities, but China blamed an earthquake in Tibet. However, US Geological Survey data showed the earthquake occurred after the river had already turned turbid, contradicting China’s claims. These incidents highlight China’s lack of transparency in transboundary water management and its strategic use of hydrological data to exert influence over downstream nations, particularly India.

5.3 India’s Concerns and Potential Risks

India has also recognized the river as a significant powerhouse for expanding its renewable energy production, enabling economic development in the region. According to the Central Electricity Authority, the Brahmaputra River basin possesses about 44% of India’s total hydropower potential. It also aims to construct 12 hydropower stations in Arunachal Pradesh. However, India fears that China building the largest dam could be used as a geopolitical tool to influence downstream countries or even withhold water during times of conflict or tension.

The dam would eventually lead to the permanent disruption of the annual flooding cycle due to extensive upstream damming and diversion could harm agriculture and marine farming for millions of people. The changes and loss of surrounding floodplains may severely impact the economies and ecosystems of downstream countries. India is concerned about the potential release of water during the monsoon season, which could worsen flooding in states like Assam. Dams in earthquake-prone areas also pose significant risks, such as floods, destruction, and displacement. Past incidents, like the 2000 Sutlej River floods and a dam breach in Tibet, have already shown the devastating impact on downstream regions, including Arunachal Pradesh, where a remote sensing investigation confirmed the floods were caused by the dam failure.

Given that the Brahmaputra's discharge can surge from 19,300 to over 100,000 cubic meters per second during floods, similar disasters remain a serious concern. Dams like Zangmu, Jiexu, Dagu, and the planned mega-dam at Metog/Dadugia, near the India-China border, are highly vulnerable to earthquakes. It would lead to severe backlash in Arunachal Pradesh, Assam, and West Bengal. With multiple dam constructions in an ecologically fragile region, damage would escalate. Biodiversity would face a grave threat through the disruption of flow in rivers, while the degradation pattern would intensify deforestation and increase soil erosion and landslide occurrence. This is sure to worsen an already declining Himalayan ecosystem.

India's hydropower expansion in Arunachal Pradesh has heightened territorial tensions with China, which claims the region as South Tibet. China's Foreign Ministry established that India has no right to develop the area, calling its governance "illegal and invalid," intensifying geopolitical and environmental concerns.

5.4 The Need for a Water-Sharing Treaty Between India and China

Given the significance of the Brahmaputra River, a water-sharing treaty between India and China would have been ideal. The only agreement in place is a 2002 Memorandum of Understanding (MoU) with India, wherein China agreed to share hydrological data on the Brahmaputra and Sutlej rivers during the monsoon season. This MoU has been renewed every five years. In contrast to India, China has not signed any treaty with its neighbouring countries downstream, primarily due to China's belief in the **Doctrine of Absolute Sovereignty**, which grants it complete control over the water flowing from its territory. Indian strategists have been disheartened by the lack of firm water agreements with China despite India's eagerness to similarly sign water agreements with other neighbours.

In 1960, India signed the Indus Waters Treaty with Pakistan, allowing Pakistan to use 80% of the Indus River system's water. Additionally, in 1996, India signed the Ganges Treaty with Bangladesh, ensuring a minimum flow of water to Bangladesh and dividing the Ganges' waters equally. Critics have also pointed out that India has been quite generous to its downstream neighbours, but has not succeeded in doing so for China, its upstream neighbour. Despite the belief in the power of international agreements to prevent conflict, China has refused to participate in a water-sharing treaty with India, leaving the issue unresolved. To date, India has failed to achieve, or even to urge, China to commit to legally binding arrangements. Until a legal framework is put in place, China is at liberty to continue its dam construction progress unconstrained by international law and treaties.

5.5 Water Management Strategies of India and China

In an attempt to adopt distinct approaches to water management, the Indian government has initiated dredging of the Brahmaputra River to enhance its water retention capacity and mitigate erosion in the areas of Assam. Dredging, the removal of excessive sediments from the riverbed, aims to address the recurrent flooding that affects the region annually and regulate water flow, preventing overflow and reducing bank erosion. Additionally, India is investing in infrastructure development along the river, including 56 jetties and a direct waterway link to ports in Bangladesh and West Bengal. The construction of a bridge connecting Majuli Island with both riverbanks is further expected to slow the river’s flow and reduce erosion.

In contrast, China has pursued a more centralized and large-scale approach to water management. To regulate water flow, control floods, and manage silt accumulation, it has constructed massive dams and reservoirs, particularly on the Yellow River. India, collaborates with international organizations such as the World Bank to enhance its water management strategies, while China refrains from entering into a water-sharing treaty with its downstream neighbours and maintains strict control over its water resources. India, in an attempt to find a mutually advantageous method which is mutually beneficial, is looking to study China’s flood management techniques, China on the other hand continues to expand its hydropower projects. Notwithstanding India’s concern about the adverse impact on the riverbed, China continues the construction of dams on the Brahmaputra.

6. Conclusion

Brahmaputra River is a lifeline for millions of people, yet it is a contentious issue between India and China. Both countries struggle with resource scarcity and China's upstream infrastructure projects pose significant challenges to India's water security, agriculture, and regional stability. Farmers in Assam and Arunachal Pradesh, who rely on the river for irrigation and fisheries, face the threat of unpredictable water availability due to the interventions. The combination of dam construction activities with border conflict and insufficient political understanding will aggravate resource disputes throughout developing regions, hence strengthening governance together with river basin cooperation in locations like Brahmaputra will become essential for reducing tensions. No official water-sharing treaty between China, India, and Bangladesh makes the Brahmaputra River a likely source of regional disputes between these neighbouring countries.

India currently maintains its composure despite ongoing tensions since Bangladesh finds itself buried under the dominance of big power relations. Multinational institutions play a key role in safeguarding sustainable water management and regional stability because a complete framework for cooperation is currently missing. Therefore, there is an urgent need to develop diplomatic institutions and strengthen cooperative mechanisms. A well-structured approach to transboundary water governance will be essential in ensuring regional stability and fostering shared prosperity.

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KEN- BETWA RIVER LINK: A BOON OR A BANE FOR WATER MANAGEMENT AND BIODIVERSITY

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1. Abstract

This study examines the Ken-Betwa River Link Project, a pivotal infrastructure initiative in India aimed at addressing regional water scarcity by interlinking rivers. While the project promises significant socio-economic enhancements through improved irrigation, drinking water, and hydropower generation, it simultaneously raises substantial environmental and social concerns, especially regarding biodiversity loss and the integrity of protected areas like the Panna Tiger Reserve. Through a multidisciplinary analysis that incorporates ecological, socioeconomic, and hydrological perspectives, the research evaluates the multifaceted impacts of the project and discusses potential mitigation measures to balance development and conservation.

Key Words

Ken-Betwa River Link, water management, biodiversity, socio-economic impact, environmental mitigation, river interlinking, Panna Tiger Reserve

2. Introduction

The Ken-Betwa River Link Project (KBLP) represents one of India's most ambitious and controversial water management initiatives, designed to address the critical water scarcity issues plaguing the drought-prone regions of Madhya Pradesh and Uttar Pradesh. This landmark project, a cornerstone of India's National Perspective Plan for interlinking rivers, proposes an innovative solution by transferring surplus water from the Ken River basin to the water-deficient Betwa River basin through a complex network of canals and reservoirs.

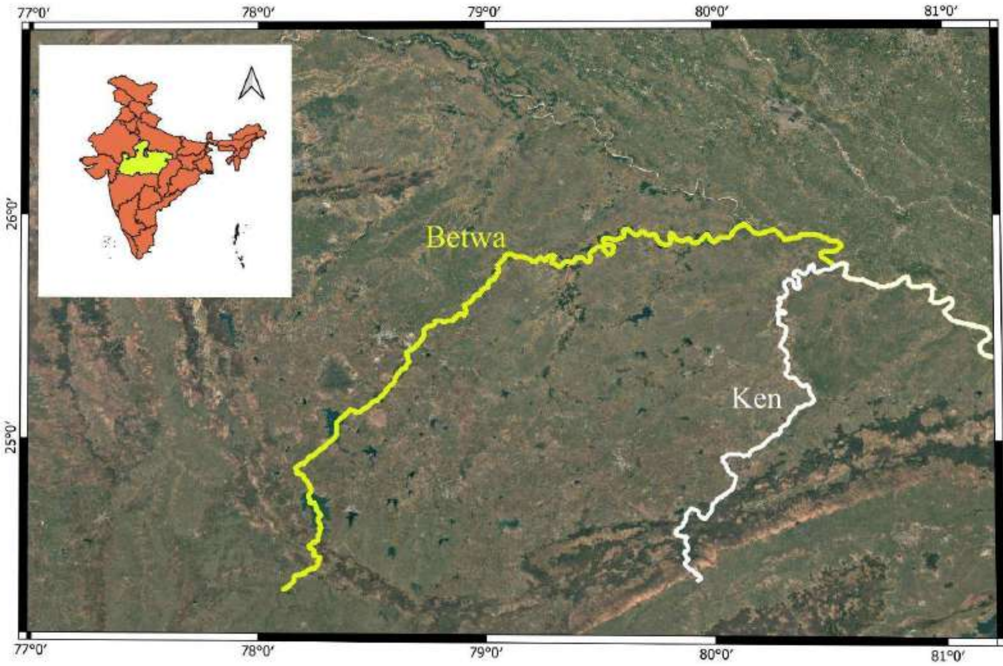
The project's scope encompasses multiple components, including the construction of the Daudhan dam, a 77-meter-high concrete gravity dam on the Ken River, and a 221-kilometer-long water transfer canal. This massive infrastructure development aims to irrigate approximately 6.35 lakh hectares of agricultural land annually, provide drinking water to about 62 lakh people in both states, and generate 103 MW of hydroelectric power. The estimated cost of the project stands at ₹35,111.24 crore (as of 2018), making it one of the most significant investments in India's water infrastructure.

While proponents highlight the project's potential to transform the agricultural landscape and improve water security in the region, critics raise serious concerns about its environmental and social implications. The project's implementation requires the submergence of approximately 9,000 hectares of land, including a portion of the Panna Tiger Reserve, a critical habitat for India's national animal and numerous other species. The environmental impact extends beyond the immediate submergence area, potentially affecting the entire river ecosystem and its associated biodiversity.

This research seeks to answer the fundamental question: Is the Ken-Betwa River Link Project a boon or a bane for water management and biodiversity in the affected regions? The working hypothesis suggests that while the project promises significant socio-economic benefits through improved irrigation, drinking water supply, and power generation, it simultaneously poses substantial risks to the local ecosystem and biodiversity. Of particular concern is the impact on the Panna Tiger Reserve, which has shown remarkable recovery in its tiger population after near extinction in 2009, and now faces new challenges from this developmental intervention.

3. Study Area

The Ken-Betwa River Interlinking Project is located in central India, spanning the Bundelkhand region of Madhya Pradesh and Uttar Pradesh. The project primarily affects the Ken and Betwa river basins, with major infrastructure concentrated in Chhatarpur, Panna, Tikamgarh, and Jhansi districts. The Daudhan Dam, a key component, is proposed on the Ken River in Chhatarpur district, Madhya Pradesh. A significant portion of the project area falls within the Panna Tiger Reserve, a critical wildlife habitat known for its tiger population, vultures, and other endangered species. The region is also characterized by semi-arid climatic conditions, seasonal rivers, and water-scarce agricultural lands, making water management crucial for local communities. This study focuses on assessing the environmental, hydrological, and socio-economic implications of KBLP on the affected regions.



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Objectives

- Understanding the Project: an overview of the Ken-Betwa Interlinking Project, including its historical context, development phases, and technical specifications
- Impact on River Landscapes: Analyse changes in river morphology and hydrology, including seasonal flow patterns and sediment transport
- Socioeconomic Aspects: Examine displacement of communities and loss of livelihoods, assess benefits for irrigation, drinking water supply, and hydropower
- Challenges and Controversies:

4. Methodology

This research employs a comprehensive qualitative and analytical approach, utilizing a diverse range of secondary data sources including government reports, environmental impact assessments, scientific literature, and policy documents. The methodology is structured around multiple analytical frameworks to ensure thorough examination of all project aspects.

5. Results and Discussion

Understanding the Project

The Ken-Betwa River Link Project (KBLP) is a ₹44,605 crore ($5.06 billion) infrastructure initiative aimed at transferring surplus water from the Ken River in Madhya Pradesh to the water-deficient Betwa River basin in Uttar Pradesh. As one of India's most significant water management projects, it serves as a pilot initiative for the National River Interlinking Program. The project involves the construction of the Daudhan Dam, a 221-km canal system, and various auxiliary structures, including tunnels, powerhouses, and pumping stations. Key components include the 77-meter high Daudhan multipurpose dam, hydropower generation facilities with a 78 MW capacity, and an extensive irrigation network spanning multiple districts. Additionally, the project incorporates water treatment and distribution infrastructure to ensure efficient utilization of resources.

Several key stakeholders are involved in the project. Government agencies such as the National Water Development Agency (NWDA), the Ministry of Jal Shakti, and the State Water Resources Departments of Madhya Pradesh and Uttar Pradesh play a crucial role in its implementation and oversight. Local communities, including villagers, indigenous populations, farmers, and business owners, are directly affected by the project's development. Additionally, environmental organizations, wildlife conservation groups, ecological research institutions, and NGOs contribute to discussions regarding the project's ecological and social impact.

The primary objectives of the KBLP include the annual transfer of 1,020 million cubic meters of water, irrigation benefits to 9.04 lakh hectares of agricultural land, and drinking water supply to 62 lakh people. Furthermore, the project is expected to generate clean hydroelectric power, contributing to sustainable energy development. While the KBLP promises economic and social benefits, it also raises critical environmental concerns, necessitating a balanced approach to ensure both development and ecological sustainability.

Impact on River Landscapes

Changes in River Morphology and Hydrology

The Ken-Betwa River Interlinking Project (KBLP) will significantly alter the natural flow regimes of both rivers, impacting their morphology and hydrology. The Daudhan Dam will create a large reservoir, submerging approximately 9,000 hectares of land, including a portion of the Panna Tiger Reserve. This will disrupt the riverine ecosystem, affecting both surface water dynamics and groundwater recharge patterns. The dam will act as a barrier, breaking the natural longitudinal connectivity of the river system, which is crucial for aquatic species, sediment transport, and nutrient flow downstream. Reduced water flow in the Ken River and an increased water volume in the Betwa River will lead to significant hydrological imbalances, affecting riverbank stability, channel morphology, and ecological connectivity.

Aspect	Ken River	Betwa River
Flow regime	Reduced downstream flow	Increased water volume
Sediment transport	Decreased	Altered patterns
Riverbank stability	Potential erosion	Increased flooding risk
Channel morphology	Reservoir formation	Channel widening
Water temperature	Stratification effects	Thermal alterations
Ecological connectivity	Severely impacted	Modified flow patterns

Table 1 - Projected Changes in River Morphology

Effect on Aquatic Ecosystems and Biodiversity

The project poses significant threats to the Panna Tiger Reserve's ecosystem by submerging approximately 58.03 square kilometres of critical tiger habitat. This habitat loss could fragment existing wildlife corridors, disrupting breeding and migration patterns. Tigers will experience a reduction in territory and prey base, while gharial populations will face nesting and basking site disruptions. The destruction of old-growth trees will severely impact vultures, reducing nesting opportunities and foraging grounds. Additionally, endemic fish species may experience altered breeding cycles and migration routes due to flow modifications. The felling of over 23 lakh trees will not only degrade local biodiversity but also have cascading effects on the entire food web, further endangering wetland-dependent species and ecosystems.

Deforestation and Land Use Changes

The KBLP will result in massive deforestation and significant land-use changes. Approximately 98 square kilometres of Panna National Park will be submerged, leading to the loss of mature forest ecosystems, displacement of wildlife populations, and disruption of ecological corridors. The large-scale clearing of forests will reduce carbon sequestration capacity, further exacerbating climate change. Additionally, agricultural land will be converted for project infrastructure, impacting traditional farming practices, rural livelihoods, and soil conservation. Changes in riparian zones will alter vegetation composition, soil moisture, and microhabitats, affecting water quality and riverbank stability.

Long-term Ecological Consequences

The cumulative effects of these changes will have far-reaching environmental impacts. The reduction in ecosystem services such as flood control, water purification, and soil retention will weaken the natural resilience of the river landscape. Changes in hydrology and deforestation may also alter local precipitation patterns and microclimates, further stressing the region's fragile ecosystems. The loss of critical habitats and species could lead to local extinctions and reduced genetic diversity, disrupting the balance of predator-prey relationships and food web dynamics.

The Ken-Betwa River Interlinking Project, while aimed at improving water availability and infrastructure, poses significant risks to the river landscape, necessitating careful planning and mitigation measures to balance development with ecological sustainability.

Socioeconomic Aspects

Displacement and Livelihood Loss

The Ken-Betwa River Link Project (KBLP) is expected to displace over 6,600 families, primarily in Madhya Pradesh, leading to significant social and economic challenges. One of the major concerns is inadequate compensation, as affected communities argue that the proposed compensation packages do not reflect the true market value of their land, the long-term income potential of their farmlands, or the additional costs of relocation and reestablishment. Moreover, the loss of community support systems further exacerbates the struggle for displaced families.

Beyond financial concerns, cultural disruption is another critical issue. Many traditional communities will lose their ancestral lands, including sacred sites, religious landmarks, and traditional gathering places. Generational farming practices that have sustained livelihoods for decades will be severely affected, and the displacement threatens the preservation of indigenous knowledge systems. The psychological impact of forced displacement is also significant, leading to mental health challenges, loss of social networks, and adjustment difficulties in new locations.

Benefits for Irrigation, Drinking Water, and Hydropower

Despite its challenges, the KBLP promises socio-economic benefits across multiple sectors. It is expected to enhance irrigation, benefiting 1.27 million hectares of farmland. This will enable year-round farming, crop diversification, and increased agricultural productivity, contributing to food security in the region.

The project also aims to improve drinking water access for 6.2 million people, reducing dependence on unsafe water sources. This will help curb waterborne diseases, lower the burden on women for water collection, and enhance sanitation facilities, leading to better public health outcomes.

Additionally, the project is expected to generate 130 MW of clean energy, including 103 MW from hydropower and 27 MW from solar power. This will contribute to energy security, reduce dependence on fossil fuels, and lower carbon emissions, supporting India’s transition to sustainable energy solutions.

Economic Multiplier Effects

The KBLP is projected to stimulate regional economic growth through both direct and indirect employment. During the construction phase, the project will create thousands of temporary jobs, while the operation and maintenance of the infrastructure will provide long-term employment opportunities in technical and administrative roles. Additionally, skill development programs will help workers transition into new job sectors.

Indirectly, the project will boost local markets, support agricultural-allied industries, and enhance tourism potential around the reservoir. The development of transportation, power, and irrigation infrastructure will further drive regional economic expansion and improve long-term economic sustainability.

Benefit Category	Impact	Additional Details
Irrigation	1.27 million hectares of land covered	Year-round farming capability
Drinking Water	6.2 million people served	Improved public health outcomes
Power Generation	130 MW (103 hydro + 27 solar)	Clean energy contribution
Employment	Temporary and permanent job creation	Skilled and unskilled opportunities
Regional Development	Infrastructure and market growth	Long-term economic sustainability

Table 2 - Projected Socio-economic Benefits

While the KBLP offers significant socio-economic benefits, it also presents serious challenges related to displacement, environmental impact, and cultural loss, highlighting the need for comprehensive mitigation strategies to balance development and sustainability.

Challenges and Controversies

Legal and Environmental Concerns:

The Ken-Betwa River Link Project (KBLP) has faced significant legal and environmental challenges due to concerns about wildlife protection, regulatory compliance, and biodiversity loss. One of the major issues is the granting of wildlife clearances, particularly regarding the impact on the Panna Tiger Reserve. Critics argue that the Environmental Impact Assessment (EIA) has substantial inadequacies, including incomplete baseline data and insufficient analysis of cumulative environmental impacts. The project also raises questions about compliance with key environmental laws, such as the Wildlife Protection Act and the Forest Conservation Act. Additionally, transparency concerns have emerged over the clearance process and public consultation procedures, with allegations that local communities were not adequately involved in decision-making. The project's most significant environmental cost is the loss of over 9,000 hectares of forest land, threatening biodiversity, carbon sequestration capacity, and ecosystem stability.

Inter-state Conflicts:

The water-sharing agreement between Madhya Pradesh and Uttar Pradesh has become a major point of contention, leading to inter-state disputes. Key disagreements include water allocation during drought periods, with both states vying for priority access in times of scarcity. There are also conflicts over the operational control of the dam and canal system, as both states seek greater authority over water distribution. Equitable distribution during peak agricultural seasons remains a critical concern, as farmers in both states depend on irrigation for their livelihoods. Furthermore, questions have been raised about compensation mechanisms for affected communities, particularly regarding land acquisition, displacement, and livelihood restoration. The project also threatens to disrupt existing water rights and traditional water use patterns, raising concerns among local stakeholders and environmental groups.

Climate Change Implications:

The long-term viability of the KBLP is highly uncertain in the face of climate change, which could alter rainfall patterns and affect the availability of surplus water in the Ken River. Unpredictable monsoon behavior and extreme weather events could lead to extended dry periods, reducing the water available for inter-basin transfer. Rising temperatures may also increase evaporation rates, decreasing reservoir efficiency and further limiting water availability for downstream users. This could place additional stress on local water resources, affecting agriculture, drinking water supply, and hydropower generation.

Moreover, climate change is likely to compound the project's impact on ecosystems, particularly in terms of species survival and habitat resilience. Endangered species, including those in the Panna Tiger Reserve, may struggle to adapt to changing environmental conditions, while migration patterns of wildlife could be altered. Aquatic ecosystems and riparian zones may also experience significant stress, further threatening regional biodiversity and ecological balance.

Sustainable Solutions

Eco-sensitive Planning and Mitigation Measures

To minimize the environmental impact of the Ken-Betwa River Link Project (KBLP), several mitigation strategies have been proposed, focusing on afforestation, wildlife protection, and sustainable water management. Compensatory afforestation is a key initiative, involving scientific identification of suitable plantation sites, selection of native species, and long-term maintenance programs to offset the loss of over 9,000 hectares of forest land. Engaging local communities in forest management will ensure better survival rates of afforested areas and promote sustainable conservation practices.

To protect wildlife movement, the project will integrate wildlife corridors, strategically designed based on animal migration patterns. Buffer zones around protected areas will help minimize habitat fragmentation, while real-time monitoring systems will track wildlife movements and assess the effectiveness of the corridors. Additionally, environmental flow management will be implemented to ensure the minimum required water flow is maintained in the Ken and Betwa rivers. Seasonal adjustments to water release patterns and regular monitoring of water quality and aquatic biodiversity will help sustain riverine ecosystems. An adaptive management approach will be adopted, allowing modifications based on ecosystem responses over time.

Alternative Water Conservation Strategies:

In addition to river interlinking, exploring alternative water conservation strategies can help address water scarcity in a more sustainable manner. Rainwater harvesting can be promoted through rooftop collection systems, check dams, percolation tanks, and the revival of traditional water storage structures. Community-led watershed management programs will encourage local participation in water conservation efforts.

Groundwater recharge is another essential strategy, involving scientific mapping of aquifer systems, construction of recharge wells, and protection of natural recharge zones. Regular monitoring of groundwater levels and quality will ensure long-term sustainability of water resources.

Furthermore, efficient irrigation systems can significantly reduce water wastage in agriculture, the largest water-consuming sector. Encouraging micro-irrigation technologies, such as drip and sprinkler systems, along with smart irrigation scheduling based on crop water needs, can optimize water use efficiency. Farmers can be trained in water-efficient practices, and financial incentives can be provided for adopting modern irrigation techniques, reducing overall dependency on large-scale river diversion projects.

By integrating eco-sensitive planning and alternative water conservation strategies, the Ken-Betwa River Link Project can mitigate environmental damage while ensuring sustainable water management.

6. Conclusion

The Ken-Betwa River Link Project presents a complex scenario where potential socio-economic benefits are weighed against significant environmental and social costs. While the project aims to address critical water scarcity issues and promote regional development, it poses substantial risks to biodiversity, particularly in the Panna Tiger Reserve. The displacement of local communities and the alteration of natural river flows further complicate the project's implementation and long-term implications.

The project's success will largely depend on the effective implementation of mitigation measures and the ability to balance development needs with environmental conservation. Long-term monitoring and adaptive management strategies will be crucial to address unforeseen impacts and ensure the project's sustainability in the face of climate change. This includes regular assessment of water quality parameters, wildlife movement patterns, and the socio-economic conditions of affected communities.

The environmental compensation measures proposed, including afforestation and wildlife corridors, must be meticulously planned and executed with scientific backing. Additionally, the project necessitates robust governance mechanisms to ensure equitable water distribution and dispute resolution between the participating states of Madhya Pradesh and Uttar Pradesh.

The economic implications extend beyond the immediate project costs, encompassing long-term maintenance, ecological restoration, and community rehabilitation programs. These aspects require sustained financial commitment and institutional support to achieve the intended benefits while minimizing adverse impacts.

Ultimately, the Ken-Betwa River Link Project serves as a critical case study in the ongoing debate over large-scale water management initiatives in India. It highlights the need for comprehensive, interdisciplinary approaches to water resource management that consider ecological, social, and economic factors in equal measure. The lessons learned from this project will be invaluable for future river-linking initiatives and water infrastructure projects across the country, particularly in addressing the challenges of climate change, urbanization, and sustainable development.

The project also underscores the importance of stakeholder engagement and participatory decision-making in large infrastructure projects. Moving forward, it will be essential to maintain transparency, ensure continuous dialogue with affected communities, and adapt management strategies based on emerging challenges and feedback from various stakeholders

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ASSESSING POLLUTION IN THE GOMTI RIVER: CAUSES, IMPACTS, AND SUSTAINABLE SOLUTIONS

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1. Abstract

Water is crucial to all forms of life. In most cases, our civilization is produced on reservoirs. The Gomti River is located in the south of the Himalayan Pedestrian Mountains near the village of Madhogani Tanda in Pilibhit district in the northern Uttar Pradesh. It travels nearly 940 km southeast Nine regions of Uttar Pradesh. Due to the densely populated areas of Uttar Pradesh, a large amount of human waste, a large amount of human waste, agricultural and industrial pollutants are discharged in this river. Lakhimpur, Lucknow, Sultanpur and Jaunpur are the main cities located on this river. They are municipal and household waste and the main source of sewage, which causes pollution in this river, has recently been severely affected by water quality conditions. The reasons are due to population growth, rapid industrialization and agricultural methods that lead to deterioration in water quality. Water pollution has many negative consequences, such as destruction of marine habitats, the development of various deadly human diseases, the development of various deadly human diseases such as cholera, malaria, malaria, and therefore, Water pollution is indeed a major and serious global topic of concern. As it can harm the environment we rely on. Destruction of the environment ultimately reduces the quality of our own lives. The research survey concluded that a large number of drainage pipes are responsible for Gomti pollution directly into rivers with untreated industrial and household waste. In this article, various steps are being tried to review the Gomti river water Pollution problem

2. Introduction

Water is critical for our life. properly and good enough water is critical for the comfy and happy dwelling. The Gomti, an alluvial river of the Ganga simple is considered to originate close to Manikot in Madhotanda about 30 km east of the Pilibhit down in Uttar Pradesh, at an elevation of 185m. The river flows thru an incised valley before assembly the Ganga River in Kaith, Ghazipur bordering Varanasi. The feature of the river is perennial and effluent. The river is characterized by using sluggish flow at some point of the year, except in the course of monsoon season, while heavy rainfall reasons a manifold growth in the run off 75% dependable flow. The river's entire drainage area is 30437 square kilometres.

Sai River is its fundamental tributary having drainage of 12900 sq.km approximately forty-three% of the total catchment place of Gomti basin on the banks of the river, Sitapur, Lucknow, Sultanpur, Jaunpur are the 4 main urban settlements. The river, in the end, gets the untreated wastewater and effluents from those activities in its route thru greater than 45 fundamental drains carrying the wastewater and commercial effluents from one-of-a-kind cities and industrial devices.

The Gomti river all alongside its 940 km period traverses thru the alluvial plains overlaying agricultural lands and several small and huge urban facilities. these regions provide big portions of untreated sewage, agricultural runoff that brings pesticides and diverse chemical fertilizers, in conjunction with oil, asphalt, sediment and heavy metals. number one assets of heavy metals are from industries like tannery, sugar, beverages, paints, chemicals, fertilizers, batteries, vehicles, factories, meals processing gadgets, cement, thermal strength plant life, petroleum refineries and sewage disposal water.

Water of Gomti river is mainly stricken by sewage wastes and industrial wastes disposal in to the river. aside from there are many cloths colouring gadgets disposing colour dyes and many others.in to the river Gomti. The washing of cloths and livestock's bathing also are polluting the river water. Use of Plastics and their disposal inside the river is creating havoc within the south. Thick quaternary-aged alluvial deposits underlie the whole Gomti basin. The alluvial sediments encompass boulders, pebbles, gravels, sand, silt, clay and kankars. The unconsolidated unit can be in addition subdivided into more youthful alluvium. The more youthful alluvium occupies the modern flood plains while the older organization occupies expanded points particularly the doab portions the older alluvium is via kankar nodules at intensity otherwise it's far just like the younger alluvium. Incision of the Gomti River and its valley has been studies the usage of characteristics of longitudinal seasoned file, escarpment heights, valley morphology.

Ever-increasing populace and the consequent urbanization and industrialization have set up severe environmental pressures on these ecosystems and feature affected them to such an extent that their benefits have declined significantly.

*Photo:*1- The poison dissolved in the water of Gomti, the drain of Lucknow

3. Study Area

The Gomti River is a significant tributary of the Ganges River, starting from Gomat Taal (Fulhaar Jheel) near Madhotanda in the Pilibhit district of Uttar Pradesh, India (Coordinates: 28.62°N, 80.10°E). It flows for about 960 km before it joins the Ganges at Kaithi, Varanasi (25.52°N, 83.01°E).

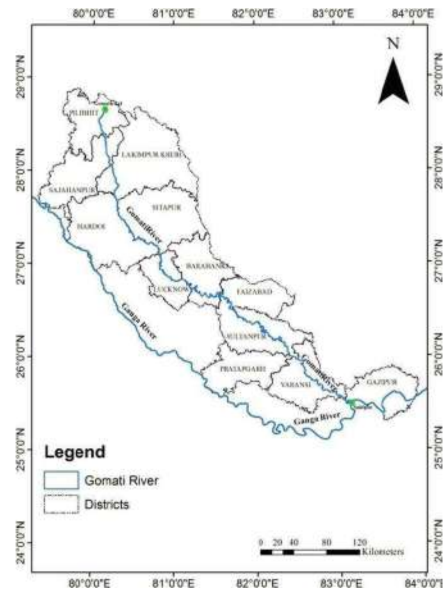

Figure:1- Origin to Confluence

3.1 Geographical Boundaries

The basin of the Gomti River covers a large area in Uttar Pradesh, including important districts such as Pilibhit, Sitapur, Lucknow, Barabanki, Sultanpur, Jaunpur, and Varanasi. Its watershed is flanked by the Ganges basin to the south and the Sharda basin to the north.

3.2 Topography

The river meanders through the central alluvial plains of the Indo-Gangetic basin, which are marked by low-lying floodplains, gentle slopes, and winding courses. The elevation in the basin ranges from about 150 meters in the upstream areas (Pilibhit) to roughly 50 meters near where it meets the Ganges.

3.3 Climate

The Gomti basin has a subtropical monsoon climate, featuring: Summer (March–June): High temperatures ranging from 30°C to 45°C Monsoon (July–September): Heavy rainfall, totalling 900 to 1200 mm annually Winter (November–February): Cooler temperatures between 5°C and 20°C The flow of the river is significantly affected by monsoon rains, with peak discharge occurring during the rainy season and reduced flow in the summer months, which increases its susceptibility to pollution.

3.4 Hydrology & Drainage

The average annual discharge of the Gomti River varies between 50 and 200 cubic meters per second, showing considerable seasonal changes. It is fed by several tributaries, including the Sai River, Kathina River, and Sarayan River. Unfortunately, the river's water quality has been severely impacted by unregulated sewage discharge and industrial waste, particularly in urban areas like Lucknow, Sultanpur, and Jaunpur.

4. Methodology and Material

4.1. Methods of Data Collection

This study adopts a mixed-methods approach combining Government records, Research papers, reports, published data, satellite imagery etc. Water Quality test data published by various departments is also taken for this study. Observation of patterns in Gomti River water over the years also played a crucial role.

5. Current Situation

Pollutants are the dangerous compounds that contribute to pollution. These contaminants have a negative impact on human life by interfering with it. The water is adversely altered by these toxins that are released into it. Bacteria, viruses, parasites, fertilizers, pesticides, pharmaceuticals, nitrates, phosphates, plastics, and more are the primary contaminants of water. Water pollution can include the discharge of energy into water bodies in the form of heat and radioactivity, in addition to the release of bacteria and other pollutants. People fish in the very contaminated Gomati water reported here in order to make a life. To store the fish, they catch and the fish caught in the surrounding lakes and ponds, the fishing community uses blue-coloured nets on the river's shallow banks. Along the riverbanks, they bathe and clean while selling their fish to neighbourhood retail vendors. This area's river water is extremely contaminated; it is black in colour, and the surrounding riverbank is littered with a variety of organic and inorganic debris, including plastics, as well as human and animal excrement.13. The amount of rust that runs in the river water during the rainy season is only conceivable. Aside from natural processes, human activities are the primary cause of pollution in water bodies such as rivers, lakes, marshes, and groundwater. A water body becomes polluted when different wastes are dumped into or close to it.

5.1 Water Availability Status

Every year, the Gomti River releases roughly 7390 x 106 m3 of water into the Ganga River.17 During the monsoon season, around 80% of the discharge flows. The Gomti basin's average yearly water outputs from rainfall have been determined to be 7390 million cubic meters, with specific yields of 234 m3/sec and 244000 m3/km2. Individual basin runoff can differ significantly from the national average; for instance, the Gomti basin's runoff is 250 mm.

5.2 Water Quality Status

The central pollution control board (CPCB) regularly monitors the surface water quality of the Gomti river and its tributaries, including the Gomti at Sitapur upstream, at Lucknow upstream and downstream, at Varanasi, and at Saiat Unnao after drain outfall. Gomti is experiencing a serious pollution problem as a result of the discharge of sewage and industrial effluent. The department of irrigation conducted an earlier assessment of water quality in 2016 and 2019, respectively, and the results showed high levels of pollution in Jaunpur and Lucknow. Measured parameters include organic pollutants (DO, BOD), bacteriological (total coliform and fecal coliform), physical (temperature, pH, etc), and COD. The primary water sources in Uttar Pradesh include the Ganga, Sarju, Betawa, Rapti, Gomti, Sai, and their tributaries. The dissolved oxygen trend decreased over the Gomti river section between Gaughat and Pipraghat. Pipraghat displayed the lowest DO content, whereas Gaughat displayed the highest. Because the water at this location is the least contaminated by sewage, industrial, and household waste, the DO at Gaughat is at its highest. However, the river becomes severely contaminated as it reaches Pipraghat because of the year-round discharges from several cis and trans drains. From Lucknow's upstream to downstream locations, an increasing trend in BOD was noted. Since the breakdown of organic matter 18,19 is primarily an aerobic process, there is a greater need for oxygen, which lowers the amount of dissolved oxygen and raises BOD and COD. The less pollution at the upstream location resulted in a lower BOD measurement at Gaughat. The usage of detergents raises the phosphate concentration of river water, which promotes the formation of algae. Algal development in water caused the DO to drop, which raised the need for oxygen and caused the organic waste to not decompose completely. Because of the extensive dumping of industrial waste, the BOD concentration rises from Nishatganj drain to Pipraghat. There was also an upward trend in COD in the Gomti River sites from Gaughat to Pipraghat. The breakdown of both biodegradable and non-biodegradable organic materials requires more oxygen upstream than downstream. The Pipraghat and Upstream barrage sites were supposed to have higher COD contents. Nearly all of Uttar Pradesh's major cities are traversed by these rivers. These rivers are used for the disposal of sewage water as well as household and industrial garbage from large cities. Examining the biological and physico-chemical characteristics aids in determining the current state of water quality.

Parameter	**Range/Value**	**Standard Limit (BIS/WHO)**	**Observation**
pH	6.8 - 8.3	6.5 - 8.5	Within permissible limits
Dissolved Oxygen (DO) (mg/L)	0.5 - 6.8	≥5	Low in polluted stretches
Biochemical Oxygen Demand (BOD) (mg/L)	2.1 - 32.8	≤3	High pollution at some sites
Chemical Oxygen Demand (COD) (mg/L)	8 - 80	≤10	Exceeds limit in urban areas
Total Dissolved	170 - 680	≤500	Higher in industrial zones

Solids (TDS) (mg/L)	10 - 320	-	High due to wastewater discharge
Total Suspended Solids (TSS) (mg/L)	92 - 280	200 - 600	Mostly within limits
Total Hardness (mg/L)	10 - 100	≤250	Within safe limits
Chloride (mg/L)	0.1 - 1.2	≤1.5	Mostly safe
Fluoride (mg/L)	0.05 - 1.2	≤0.3	Exceeds in some locations
Iron (mg/L)	0.002 - 0.12	≤0.01	Above permissible limits in areas
Lead (mg/L)	0.001 - 0.08	≤0.02	High in industrial discharge zones
Nickel (mg/L)			

Table-1: Water Test Data

6. Key Observation

Location has a major impact on the quality of the water. Pollution levels are significantly impacted by the discharge of wastewater from homes and businesses. Urban regions have severely low dissolved oxygen (DO), a sign of poor water quality. In contaminated areas, BOD and COD levels are higher than allowed limits. In certain places, concentrations of heavy metals like iron and lead are higher than acceptable levels.

7. Result and Discussion

The aforementioned assessment leads to the recommendation of several crucial action plans that should be implemented for the Gomti River first. This project to restore the river will be fantastic.

1. Draw a line across the whole flood plain, from the starting point to the Ganga's influence.

2. Use buffering to freeze its land use. There is no land use change violation.

3. Clear the flood plain of any unauthorized encroachments. Declare a no-construction zone 500 meters upstream of the river. exclusively for plantation use.

4. Designate as "Eco-fragile areas" the places of origin and influence of each of the 24 significant contributors.

5. Clear the silt that has accumulated in the riverbed near the main villages.

6. Utilize decentralized treatment in the zones and use the water for purposes other than drinking.

7. Apply a regular, inexpensive treatment to the drain itself.

8. Vigilant surveillance of the 56 sugar mills situated in Sitapur and beyond, along the river. There is a significant amount of pollution in the river.

9. The Sitapur, Lucknow, Sultanpur, and Jaunpur sanitary landfills are arranged properly. There should never be solid waste disposed of in a river.

10. Paddy, sugarcane, wheat, potatoes, and other water-intensive crops are so poorly managed that farmers consume nearly twice as much water for irrigation.

8. References

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RIVER COURSE DYNAMICS: UNRAVELLING THE BALANCE BETWEEN NATURE, BIODIVERSITY, AND SURVIVAL IN GANGA BRAHMAPUTRA DELTA

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1. ABSTRACT

Climate change in the recent decades is creating a desolation throughout the world in a similarly different approach, and Sundarbans is no exception. Climate extremities induced sea level rise has led to a significant level of subsidence in the Brahmaputra-Ganga delta region. This in turn has negatively affected the flora and fauna of the region. Reports show that nearly eleven islands are on the verge of disappearing in the near three decades due to effects of sea level rise. Saline water intrusion has reduced the freshwater availability in the area. Besides, cyclones in the recent decades like Fani, Yash, Amphan had created havoc and devastated the delta region. The aim of the paper is to show how the climate change induced effects are causing siltation, affecting flora and fauna of the region, and how the region has coped up yet to the effects.

KEYWORDS: Climate extremities, Sea level rise, siltation, subsidence, sedimentation.

2. LITERATURE REVIEW

Climate change with its recent critical impacts is creating devastation in various parts of the world with every sphere getting affected like water resource, agriculture sector, socio economic activities and ecosystem. The study on temperature and rainfall trends in the South 24 Parganas District of West Bengal contributes to examining the impacts of climate change on regional temperature and precipitation patterns, particularly within India.

Global and Regional climate trends: The authors highlight the growing global concern regarding climate change and its manifestation in altered temperature and rainfall patterns, referencing the Intergovernmental Panel on Climate Change (IPCC) and the World

Meteorological Organization (WMO) reports to underscore the severity and urgency of the issue. The IPCC (2019) states that the global mean surface temperature for the decade 2006-2015 was nearly 0.87°C higher than the average over the period of 1850-1900 and probable anthropogenic global warming is now increasing at 0.2°C per decade due to greenhouse gas emission. The World Meteorological Organization (WMO) report (2020) describes that 2020 as one of the warmest years as per record and 2011-2020 as the warmest decade. This study acknowledges the importance of statistical and trend analysis in understanding climate change extremities, citing the research by Kumar et al. (2010), Subash et al. (2011), and Jagadish et al. (2012). These studies employ various methods, including time series analysis and the Mann-Kendall test, to investigate rainfall trends across different subdivisions and states within India.

Indian climate Trends: Studies have examined long term temperature and rainfall trends in different regions of India. Kumar et al. (2010) analysed 135 years of rainfall data for 30 subdivisions of India, revealing significant changes. Pal and Al-Tabbaa (2011) observed a decline in spring and monsoon rainfall, while increasing rainfall in autumn and winter. Pant and Hingane (1988) found a positive rainfall trend over Punjab, Haryana and parts of Rajasthan whereas Rupa Kumar et al. (1992) reported a decline in monsoonal rainfall in the northeastern part of India. Studies have consistently shown that temperature increased and shifted rainfall patterns with increased variability in precipitation distribution.

Climate change trend in South 24 Parganas: Sarkar and Chakraborty (2022) analysed temperature and rainfall trends in South 24 Parganas District, West Bengal, using 30 years of data (1988-2017). The annual average temperature was 27°C and an increasing trend was observed. The maximum average temperature was recorded at 34.6°C, on the other hand, the minimum average temperature 18.8C showed a downward trend. The mean annual rainfall was 172.7 cm, and monsoon rainfall was 129.4cm, both showing a rising trend over the 30 years. Das et al. (2021) compared the precipitation extremities and anomalies in the Indian Sundarbans from 1984 to 2018 based on datasets from NASA power Data and Climate Research Unit, and got exceptionally high precipitation concentration index (PCI) value, indicating variability in extreme rainfall.

Water Salinity and Ecological Effect: Latest research shows that there is an increase in water salinity in Sundarbans with about 50% increase in the salt levels of the southwestern rivers. The main reason for this is decrease in the freshwater input from the Ganges. Growing salinity is also leading to Habitat destruction and thus decline in freshwater fish and Royal Bengal

Tiger. These results concord with this existing research on vulnerability of coastal ecosystems and saltwater intrusion due to anthropogenically and climatically driven changes.

River bed Sedimentation and Aquatic Biodiversity: Sedimentation on the river beds impacts the water quality, moderating aquatic biodiversity and ecological stability. Analysis of trace metals like lead (Pb) and chromium (Cr) reveals that these levels are within safe ecological boundaries. Nevertheless, human activities like dredging within the Passur river have the potential to shape the local water dynamics.

Problem of Siltation: Siltation poses a significant threat to the mangrove forest by altering the patterns of sedimentation due to upstream water diversion and anthropogenic interference. Islam and Gnauck (2009) observe that the historically supportive river basin of the Ganges-Brahmaputra-Meghna was considerably modified with the inauguration of the Farakka Barrage in 1975. Reductions in the supply of freshwater have affected the normal course of the sedimentation with severe ecological repercussions. Annually, approximately 2.4 billion tons of sediments are transported by Bangladesh's major rivers. However, the periodic deposition of the sediments within the northeastern Sundarbans increased the forest floor at the expense of mangrove regeneration (Islam & Gnauck, 2009). Reduced tidal influx also increases the accumulation of the silt, altering the hydrodynamics of the mangrove swamps to generate dry raised areas that are fatal to mangrove vegetation. Islam and Gnauck (2009) emphasize that addressing siltation issues requires an integrated management approach, including hydrological modelling, controlled freshwater discharge, and sustainable sediment management strategies.

3. INTRODUCTION

The Sundarbans, a UNESCO World Heritage Site, is a critical mangrove ecosystem facing multiple environmental threats. Climate change, riverbed sedimentation, and human activities have been identified as key stressors affecting its biodiversity, including the endangered Royal Bengal Tiger. This literature review synthesizes recent research on the impacts of salinity, sedimentation, and human-induced changes on the Sundarbans ecosystem.

The phenomenon of rising sea levels due to global warming is resulting in coastal erosion and the loss of land. Certain islands have already disappeared, while others are in decline. The intrusion of saltwater is adversely affecting soil fertility, agricultural practices, and freshwater supplies. Communities are being displaced, creating climate refugees. The rise in sea levels and storm surges is increasing the salinity of soil and water. Freshwater resources are diminishing, complicating access to drinking water and agricultural activities. Traditional paddy farming is declining due to heightened soil salinity.

As a tidal delta, the Sundarbans experiences river course modifications due to the effects of high and low tides. Powerful tidal currents facilitate the deposition of silt, which can obstruct certain river channels while simultaneously creating new ones. Additionally, coastal erosion plays a significant role in the ongoing transformation of river networks. The Ganges-Brahmaputra-Meghna River system transports vast quantities of sediment originating from the Himalayas. Annually, more than 1 billion tons of silt are deposited within the Sundarbans region. This process contributes to the gradual accumulation of sediment in riverbeds, compelling rivers to alter their courses.

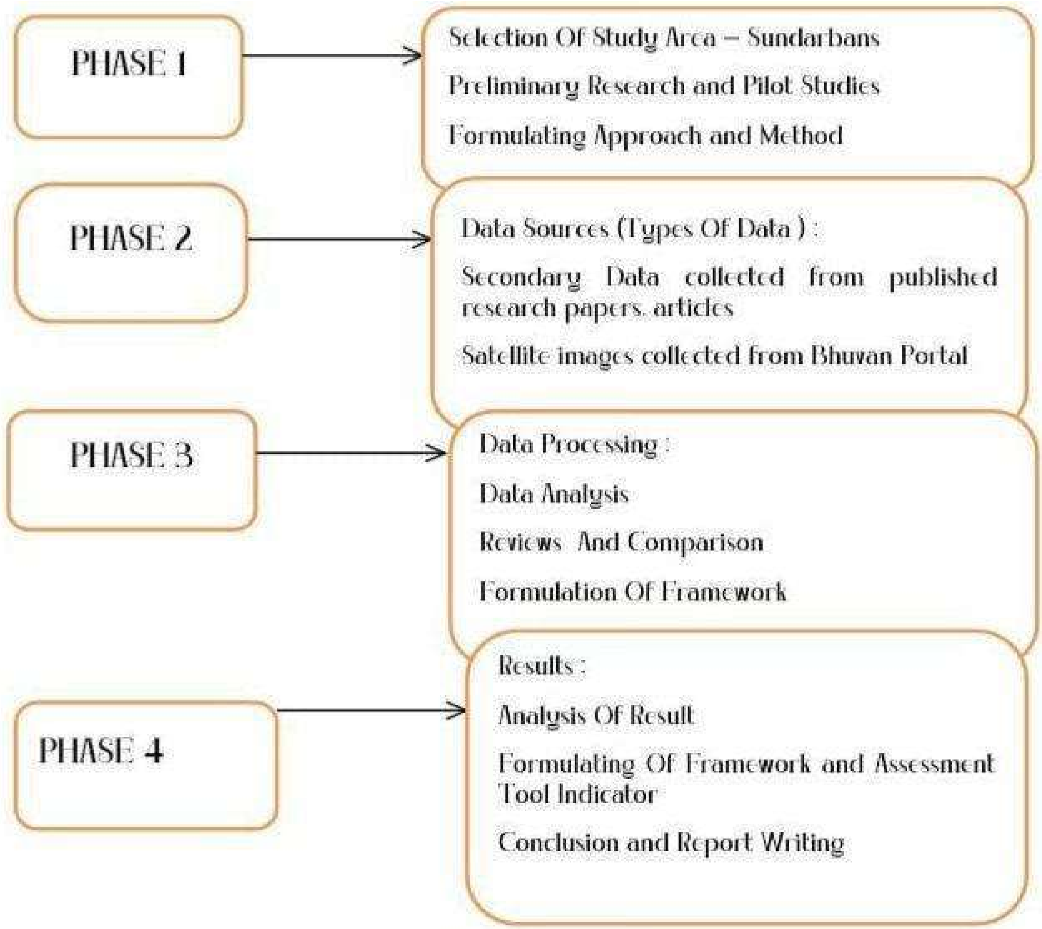
The rise in sea levels is inundating significant areas of mangrove forests. Coastal erosion, coupled with frequent cyclonic activity, is causing the uprooting of mangrove trees. The reduction in mangrove coverage diminishes the natural coastal defences against storm surges. The encroachment of rising sea levels and erosion is diminishing the habitats available for tigers. A decline in the populations of key prey species, such as spotted deer and wild boars, is compelling tigers to venture closer to human habitats, thereby escalating conflicts between humans and wildlife. Additionally, increasing temperatures and water scarcity may adversely affect the breeding and overall survival of tigers. Elevated salinity levels in water bodies are leading to a decrease in fish populations, particularly the Hilsa, which is vital for local fisheries. Freshwater dolphins, specifically Gangetic dolphins, are facing survival challenges in rivers that are becoming increasingly saline. Furthermore, coral reefs and marine biodiversity in coastal regions are threatened by rising water temperatures and ocean acidification.

3.1 OBJECTIVE

The primary objective of the study is to examine the climate change impacts at large and changing path of the rivers in the region of Sundarbans. The study specifically aims to:

- Examine the change in river course as a result of siltation and determine its effect on the environment. It seeks to analyse its degree and sequence over the years.
- Assessing the vegetation health, and the resultant impact on flora and fauna.
- Climate change analysis and its influence on changing river dynamics, vegetation health, and overall ecosystem stability.

4. METHODOLOGY



5. STUDY AREA

The Ganga-Brahmaputra delta is the world's largest delta coving an area of almost 10,000 sq km (approx.), out of which approximately 4200 sq. km falls in the Indian region of South 24 Parganas of West Bengal and the rest 6000sq km falls in the domain of Bangladesh. Stretching over the latitudes 21.5°N to 22.5°N and longitudes of 88.0°E to 89.9°E, it is a largest deltaic forest in the world. The delta is formed by the confluence of majorly Ganga-Brahmaputra-Meghna rivers. Some other important channels flowing through Sundarbans are Ichamati, Matla, Saptamukhi,and Baleswar . The speciality of the area is its unique trees called the Sundari trees whose roots have evolved over the years to survive the saline, waterlogged soil of the area. The area is unique in all the aspects of morphology, environment, flora and even fauna.

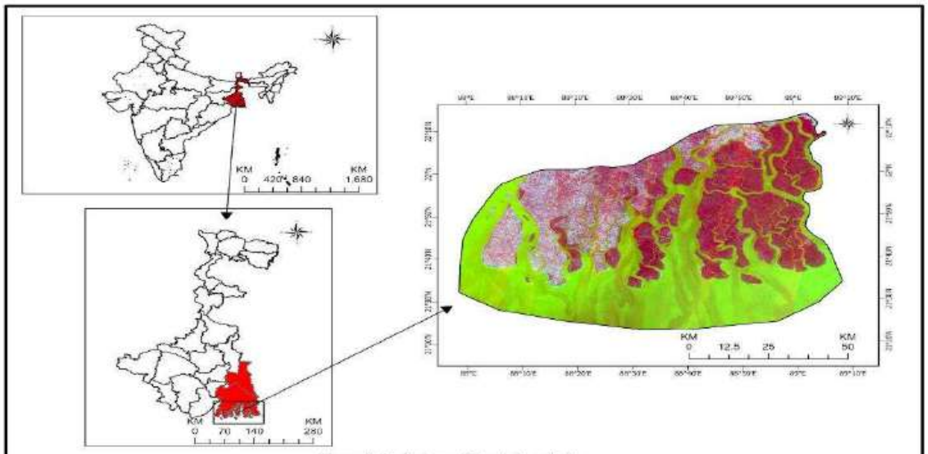


Figure-1: Study Area of Sundarbans Delta

5.1 SILTATION OVER THE DECADAL PERIOD

Siltation is a burning problem in Sundarban delta. The huge bulk of sediments brought down by the rivers and their tributaries are deposited in the mouth of the rivers before they merge with the ocean. This was a natural process but over the years the effects have increased and summed up with climate change and anthropogenic factors, this has become a serious issue. Below are the land use and landcover maps of the years 2014 and 2024. It is clearly interpretable that the amount of sedimentation has increased over the years. This has led to the narrowing of the channel widths increasing the chances of frequent inundation oif the surrounding areas. This problem if not tackled immediately can seriously hamper the livelihood 0f humas and also the health of vegetation. The below table shows the sedimentation table over years.

3	Chemagudi	2.88	1.23	0.67	0.96	Fine Sand	Poorly Sorted	Very Fine Skewed	Very Platykurtic
4	Harinbari	2.87	1.22	0.88	0.61	Fine Sand	Poorly Sorted	Very Fine Skewed	Very Platykurtic
5	Ramangachhi	3.90	0.94	-0.36	0.74	Very Fine Sand	Moderately Sorted	Very Coarse Skewed	Platykurtic
6	Kachubedia	3.54	1.30	-0.36	0.60	Very Fine Sand	Poorly Sorted	Very Coarse Skewed	Platykurtic
7	Jotaripur	3.16	1.21	0.28	0.50	Very Fine Sand	Poorly Sorted	Fine Skewed	Very Platykurtic
8	Sudhanya island	2.81	1.19	0.88	0.62	Fine Sand	Poorly Sorted	Very Fine Skewed	Very Platykurtic
9	Lothian island	3.65	1.19	-0.48	0.67	Very Fine Sand	Poorly Sorted	Very Coarse Skewed	Platykurtic
10	Bhagwatpur	2.69	1.09	0.87	0.65	Fine Sand	Poorly Sorted	Very Fine Skewed	Very Platykurtic
11	Crocodile project area	3.08	1.18	0.35	0.57	Very Fine Sand	Poorly Sorted	Very Fine Skewed	Very Platykurtic
12	Dhanchi island	2.65	1.05	0.86	0.62	Fine Sand	Poorly Sorted	Very Fine Skewed	Very Platykurtic
13	Bangaduni island	3.34	0.70	0.63	0.77	Very Fine Sand	Moderately Well Sorted	Very Fine Skewed	Platykurtic
14	SO Bangaduni Island	2.69	1.08	0.87	0.61	Fine Sand	Poorly Sorted	Very Fine Skewed	Very Platykurtic
15	Kalas tower	2.60	1.03	0.88	1.11	Fine Sand	Poorly Sorted	Very Fine Skewed	Leptokurtic
16	Unknown Island	2.71	1.10	0.87	0.63	Fine Sand	Poorly Sorted	Very Fine Skewed	Very Platykurtic
17	Bonbibi island	2.88	1.23	0.67	0.47	Fine Sand	Poorly Sorted	Very Fine Skewed	Very Platykurtic
18	Moipith Island	3.30	1.23	0.37	0.54	Very Fine Sand	Poorly Sorted	Very Fine Skewed	Very Platykurtic
19	Island north to Moipith	2.84	1.22	0.88	0.62	Fine Sand	Poorly Sorted	Very Fine Skewed	Very Platykurtic
20	Unnamed Island	3.08	1.17	0.32	0.55	Very Fine Sand	Poorly Sorted	Very Fine Skewed	Very Platykurtic
21	Banka	3.08	1.19	0.36	0.52	Very Fine Sand	Poorly Sorted	Very Fine Skewed	Very Platykurtic
22	Bagna	2.57	1.00	0.87	1.09	Fine Sand	Moderately Sorted	Very Fine Skewed	Mesokurtic
23	Marichjhapi	3.52	1.24	-0.31	0.44	Very Fine Sand	Poorly Sorted	Very Coarse Skewed	Very Platykurtic
24	Belamati	2.88	1.23	0.87	0.48	Fine Sand	Poorly Sorted	Very Fine Skewed	Very Platykurtic
25	N.E. of Dayapur	3.13	1.22	0.36	0.48	Very Fine Sand	Poorly Sorted	Very Fine Skewed	Very Platykurtic
26	Dayapur	2.77	1.14	0.87	0.57	Fine Sand	Poorly Sorted	Very Fine Skewed	Very Platykurtic
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Table-1: Summary of stratigraphic facies of the Ganga-Brahmaputra delta (after Sunando Bandyopadhyay)

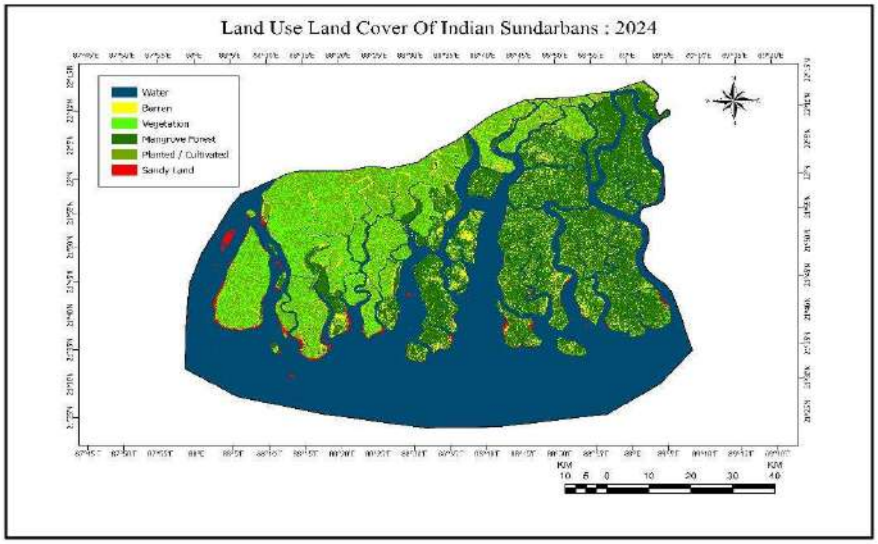

Figure-2: Land Use and Land Cover Map, 2024

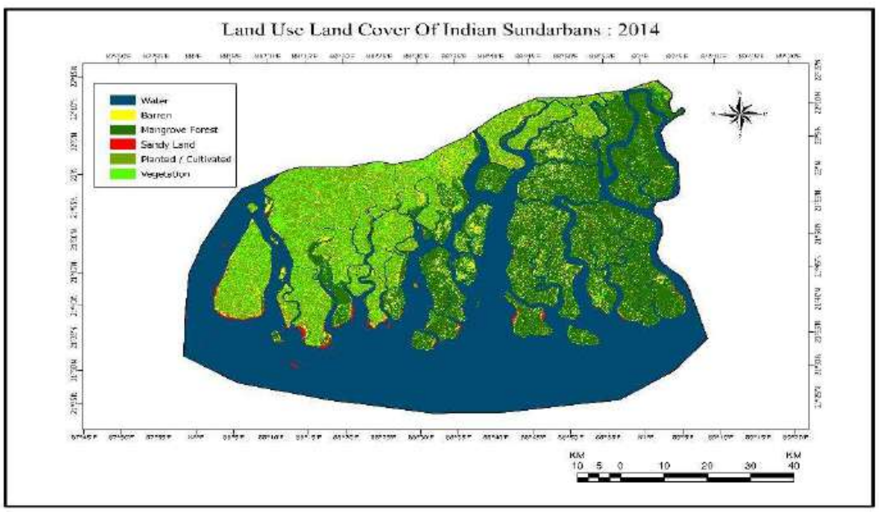

Figure-3: Land Use and Land Cover Map, 2014

LULC showing the sedimentation changes over the decade

5.2 SLOPE ANALYSIS

The map is a Slope Analysis Map of the Sundarbans, a deltaic area in India and Bangladesh, famous for its mangrove forests and river systems. The map classifies slope values in degrees from 0.001 to 26.839 degrees. Lighter colors (beige/cream) represent flatter regions (low slopes), whereas darker colors (brown) represent steeper slopes. The majority of the Sundarbans area has a very gentle slope (lighter colors), which is consistent with its deltaic and coastal nature. There are areas of higher slopes (darker brown areas), which may be the result of riverbanks, levees, or erosion processes on land. The high density of river channels and water bodies indicates that the topography is molded by tidal forces, riverine deposition, and erosion. The occurrence of water channels in white areas suggests that the slopes around these channels are slightly elevated, which might be as a result of natural embankments or sedimentation. As the Sundarbans is a low-lying region, even the slightest change in slopes can have a significant effect on drainage, flooding, and sediment deposition. Slope analysis assists in the interpretation of coastal vulnerability, soil stability, and water movement—all necessary for conservation and disaster management (e.g., cyclone hazard assessment). The slope analysis map successfully marks the flat, gently sloping lowlands of the Sundarbans created by river processes and tidal activity. It can be utilized for coastal planning, ecological preservation, and sustainable development planning in this vulnerable system.

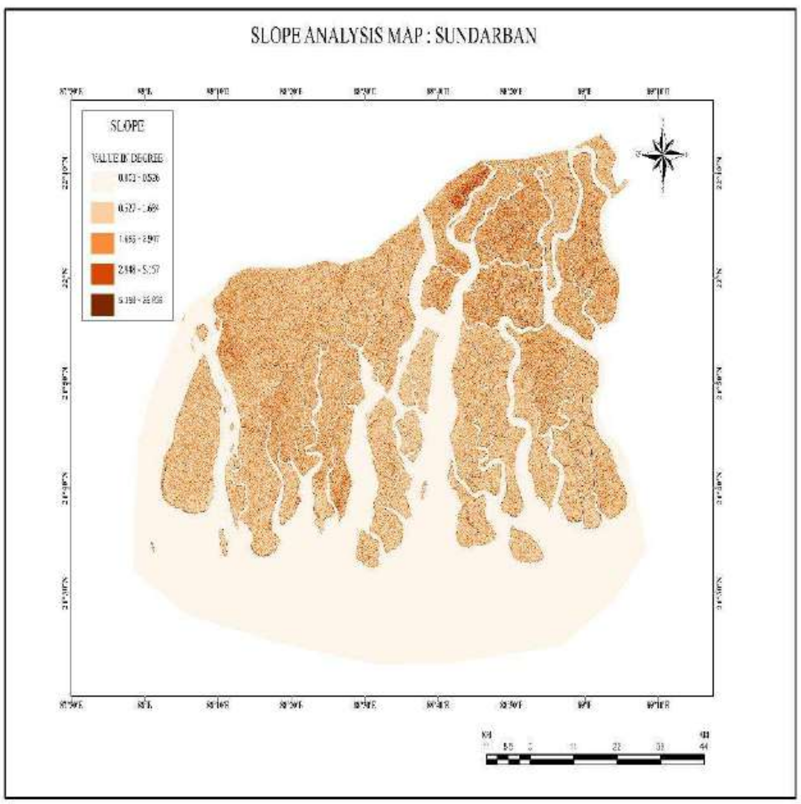

Figure-4: Slope Analysis map for Sundarban Delta

5.3 CLIMATIC EFFECTS

Climate change has very much affected the area of Ganga -Brahmaputra Delta. The change is visible in every aspect of the climatic conditions. The rise is temperature over the decade is subtle with highest reaching during the months of march and April in 2024.The change might be small but is alarming given to the conditions of the region. Rainfall has increased to a great extent. The highest of 2014 reached to 360.8 mm while that of 2024 reached 617.7. This increase is quite threatening since the elevation of the area is quite less making it vulnerable to submergence. Besides, the soil is prone to waterlogging and excessive rainfall may lead to hampering of the life of the vegetation of the area. Wind speeds have also increased over the areas. The highest windspeed reached 10kt only in the month of May in 2014 while it reached the highest of 10 kt in May, June, July in 2024. This increase is not quite feasible to the area and will disrupt the balance of climatic condition in the area over the years.

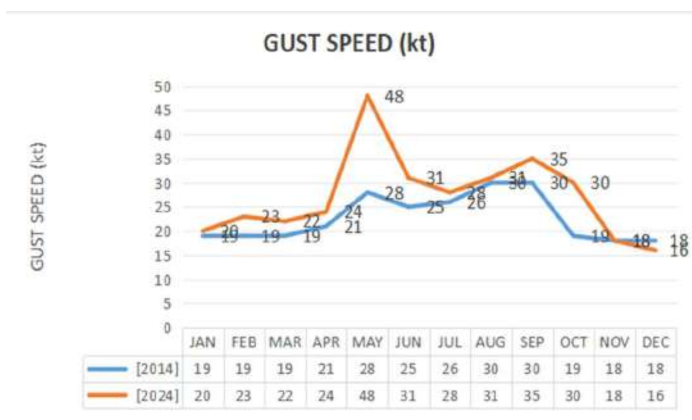

Table-2: Gust Speed

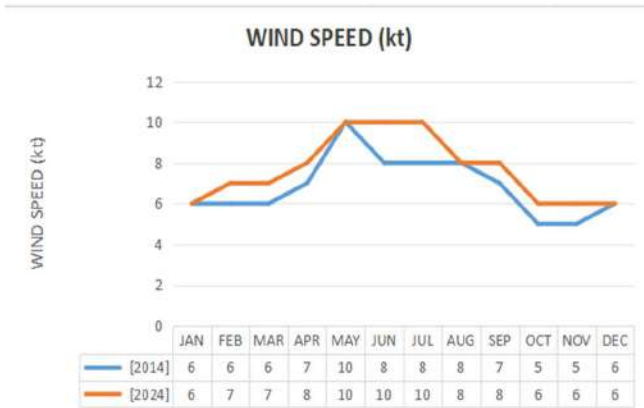

Table-3: Wind Speed from, 2014-2024

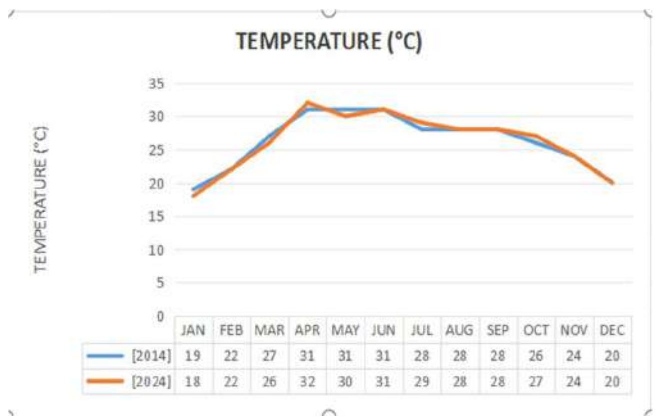

Table-4: Temperature from 2014-2024

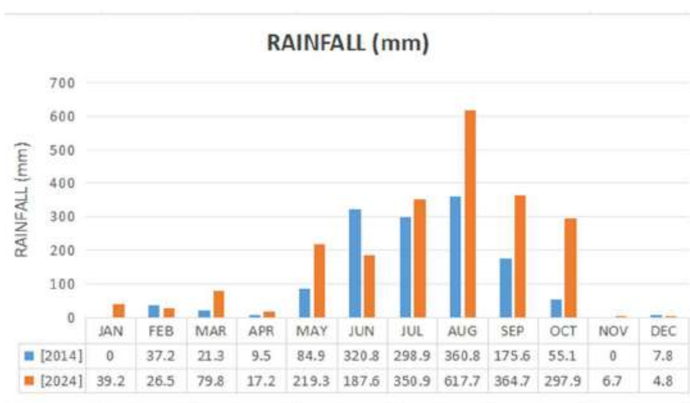

Table-5: Rainfall from 2014-2024

5.4 VEGETATION:

The image depicts the Indian Sundarbans' 2014 Normalized Difference Vegetation Index (NDVI). NDVI is a key indicator that is employed to study vegetation density and health through satellite imagery. Blue (-0.172 to 0.008): Depicts water bodies, rivers, estuaries, and the Bay of Bengal. Yellow (0.009 to 0.202): Depicts 0.44): Depicts dense vegetation that encompasses healthy mangrove cover in the Sundarbans area. The western and central regions of Sundarbans indicate a combination of yellow and red patches, meaning moderate to dense vegetation cover. The eastern side is mostly red, which denotes higher mangrove vegetation, reflecting more preserved forest regions. Rivers and estuaries are clearly delineated in blue, denoting non-vegetated water bodies. Yellow patches indicate vegetation loss, deforestation, or land degradation due to human causes, climate change, or natural erosion. Red patches represent healthier mangroves, which are important for coastal defense, biodiversity, and carbon storage. NDVI over time can be used to monitor vegetation change, deforestation, and ecological well-being of the Sundarbans. This NDVI map indicates that although major portions of the Sundarbans retain dense mangrove canopy, there are some areas, particularly in the west and the central parts of the delta, that indicate degradation or reduced vegetation density. Conservation measures need to be undertaken to improve the delicate ecosystem as well as the biodiversity of this one-of-a-kind deltaic region.

The second picture is a representation of the Normalized Difference Vegetation Index (NDVI) of the Indian Sundarbans in 2024, which indicates vegetation health and density from satellite images. Blue (-0.171 to -0.042): Indicates water bodies, including rivers, estuaries, and the adjacent Bay of Bengal. Yellow (0.043 to 0.248): Represents sparse or deteriorated vegetation, which could be mudflats, agricultural fields, or erosion-affected areas. Red (0.249 to 0.51): Indicates dense vegetation, presumably mangrove forests and green vegetation. The areas of red (dense vegetation) seem to have decreased marginally in some areas, especially in the western Sundarbans. Yellow areas indicating vegetation loss may be due to deforestation, sea-level rise, erosion, or human activities. Water bodies (blue) are still dominant, and there is no change that can be observed. Sundarbans, as a sensitive coastal ecosystem, is vulnerable to climate change, sea-level rise, and human activities. Reduction in NDVI values (red to yellow) can be a sign of mangrove degradation, which can enhance the risk of coastal erosion, storms, and loss of habitat. Monitoring the changes in NDVI over time is critical for conservation planning and climate adaptation planning. The 2024 NDVI map indicates a subtle reduction in vegetation density from that of 2014, with more regions turning towards moderate or sparse vegetation cover. This could indicate potential environmental stress on the Sundarbans ecosystem, reinforcing the necessity of conservation efforts, reforestation programs, and climate resilience programs.

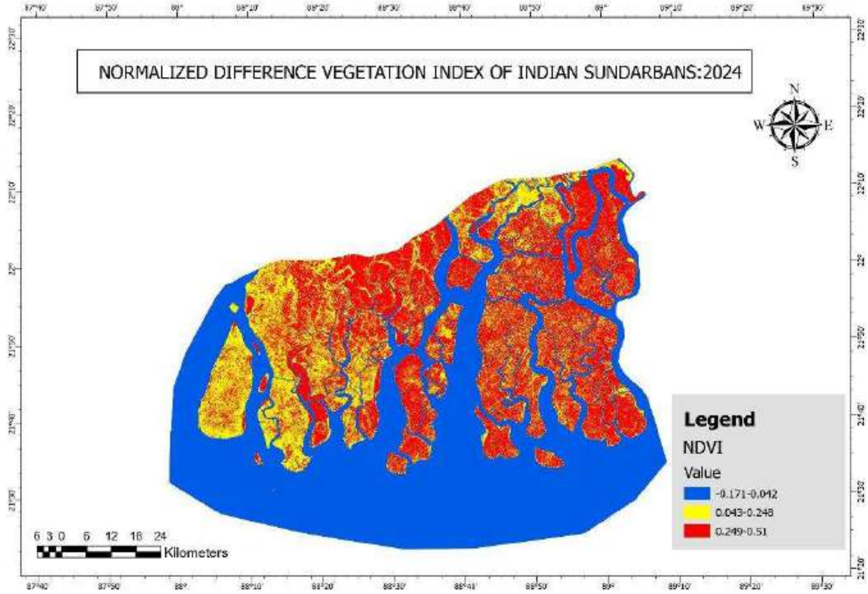

Figure-5: N.D.V.I of Sundarbans, 2024

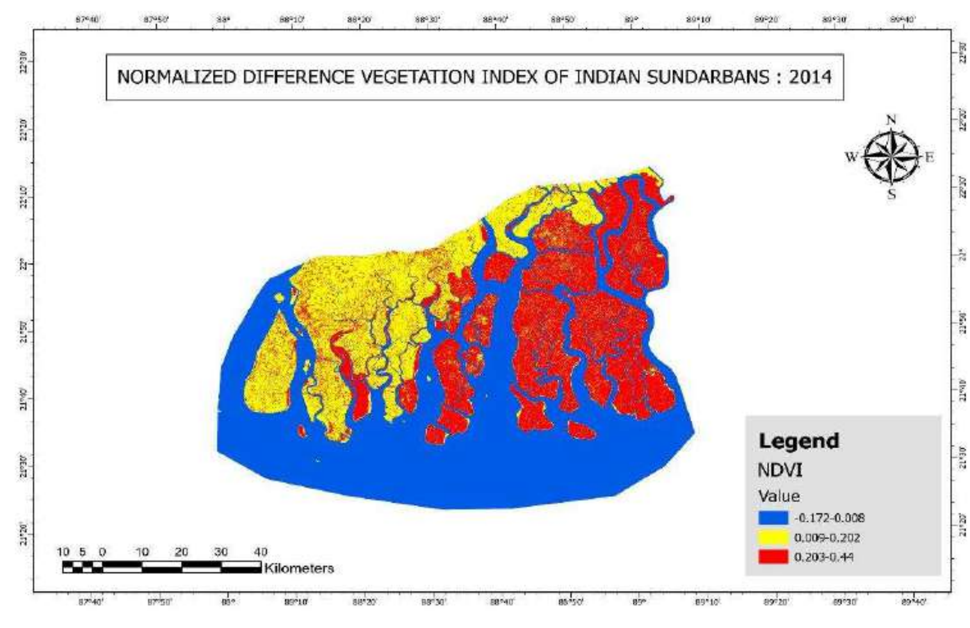

Figure-6: N.D.V.I of Sundarbans, 2014

6. CONCLUSION

The delta of Sundarbans is under great threat and the balance of nature is inevitably hampered High sedimentation has led to the problem of siltation and narrowing of river channels causing high risk of frequent inundation of the surrounding areas. The unique flora and fauna, namely Sundari trees and Royal Bengal Tigers, are profoundly endangered and if not conserved properly may get to the brim of extinction. Besides, the climate change has also adversely affected the area with rising sea levels leading to submergence of many islands and parts of the coastal zone. Added upon the mentioned impacts are the increased frequency of cyclones leading to disruption of livelihood as an anthropological impact and excessive intrusion of saline water in land areas an natural impact. Summed up, the entire deltaic region is under severe threat and it should be one of our prime concerns to conserve the unique region as best as we can. If urgent conservation and sustainable management measures are not implemented, the Sundarbans' rich biodiversity and its role as a natural shield against coastal disasters could be irreversibly damaged. To protect the Sundarbans from environmental threats, several national and global initiatives have been introduced:

National Efforts:

•Sundarbans Tiger Reserve (India): Ensures the protection of Bengal tigers and their habitat.

•National Mangrove Conservation Programme (India): Focuses on restoring and preserving mangrove forests.

•Sundarbans Affairs Department (West Bengal): Works on sustainable development and conservation.

Global Initiatives:

•UNESCO World Heritage Status (1987 for Bangladesh, 1989 for India): Recognizes the Sundarbans' ecological importance.

•Ramsar Convention (Bangladesh, 1992): Declares the Sundarbans a Wetland of International Significance.

•Indo-Bangladesh Joint Tiger Conservation Initiative: Strengthens cross-border efforts to protect the Royal Bengal Tiger.

•World Bank & UNDP Projects: Support climate resilience and sustainable livelihoods.

Connection to Sustainable Development Goals (SDGs):

Conserving the Sundarbans contributes to key UN SDGs:

•SDG 13 (Climate Action): Acts as a natural shield against climate change.

•SDG 14 (Life Below Water): Preserves marine biodiversity.

•SDG 15 (Life on Land): Protects ecosystems and endangered species.

•SDG 11 (Sustainable Cities & Communities): Strengthens disaster resilience in local communities.

Ensuring the Sundarbans' future requires stronger policies, local community engagement, and global cooperation. Expanding mangrove restoration, responsible eco-tourism, and climate adaptation efforts will help preserve biodiversity, support local communities, and reduce environmental risks.

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TRANSBOUNDARY RIVERS: GEOPOLITICS AND WATER SHARING DISPUTES

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1. ABSTRACT

Transboundary river governance presents complex challenges, particularly in regions where geopolitical tensions intersect with environmental vulnerabilities. This research examines the Sino-Indian water-sharing disputes over the Brahmaputra River, focusing on China's upstream hydropower projects and their implications for regional stability. By analysing existing frameworks and proposing innovative solutions, such as the Third Pole Water Alliance (TPWA) and the Dynamic Hydro political Equity Framework (DHEF), the study offers actionable strategies to foster equitable water management and environmental sustainability. Using a comprehensive review of secondary data, the research highlights gaps in data-sharing practices and explores the potential of emerging technologies, such as blockchain and IoT, to enhance transparency and cooperation. These findings underscore the critical need for multilateral frameworks to address power asymmetries, ecological risks, and trust deficits, transforming water conflicts into opportunities for regional collaboration and resilience.

KEYWORDS: - Transboundary rivers, Geopolitics of water, Brahmaputra River/Yarlung Tsangpo, Sino-Indian water disputes, Hydropower projects, Dynamic Hydro political Equity Framework (DHEF), Third Pole Water Alliance (TPWA), Game theory in water-sharing, and Trust deficit.

2. INTRODUCTION

Transboundary rivers, pivotal for human survival and economic development, straddle national borders, serving as essential sources of drinking water, irrigation, industrial use, and hydroelectric power. However, these shared watercourses frequently become arenas of geopolitical contention, with upstream and downstream riparian states engaging in complex struggles over allocation, management, and quality. The construction of dams by upstream nations, driven by energy security concerns, often exacerbates downstream challenges by altering hydrological regimes, a phenomenon evident in the Mekong, Ganges–Brahmaputra–Meghna (GBM) basin, and Sino-Indian water disputes. As Ismail Serageldin posited, “The wars of the twenty-first century will be fought over water,” encapsulating the profound strategic significance of water in an era of escalating scarcity and resource-driven conflicts. With over 260 transboundary rivers and 450 shared aquifers globally, governance failures often magnify tensions, as demonstrated by the Indus Water Treaty, which underscores the possibility of conflict resolution through diplomatic mechanisms despite underlying power asymmetries. As the late UN Secretary-General, Boutros Boutros-Ghali, aptly noted, “In the Middle East, water wars are coming, and they will be fought over the few remaining resources.”

Despite progress in transboundary water governance, existing research primarily focuses on bilateral treaties, power dynamics, and hydropower impacts, overlooking the need for multilateral frameworks

2.1 OBJECTIVES

The specific objectives are:

- Analyse the psychological and policy factors shaping China's approach to transboundary water-sharing disputes, focusing on its geopolitical strategies.
- Evaluate potential solutions for equitable water distribution in China-India-Bangladesh agreements and the effectiveness of the Cooperation-Defection Game Tree model in resolving conflicts.
- Examine how multilateral frameworks can address China's strategies while promoting environmental sustainability, flood management, and successful transboundary river management

2.2 SCOPE

This research relies on secondary data from various studies, reports, and official records, which, while insightful, may limit the accuracy and breadth of the findings. The study focuses specifically on transboundary rivers between China and South Asian nations, particularly the Brahmaputra, excluding other international river systems.

3. STUDY AREA

The Sino-Indian water-sharing disputes are primarily centred around the transboundary rivers shared by these nations, with the Brahmaputra River (referred to as the Yarlung Tsangpo in the Tibet Autonomous Region) occupying a pivotal role. The Tibet Autonomous Region, often termed the "Third Pole," harbours significant freshwater reserves and serves as a critical hydrological and ecological nexus in Asia.

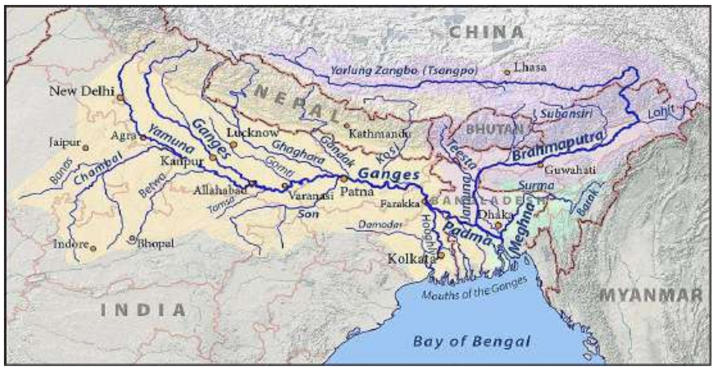

Figure-1: Map showing the flow of Yarlung Tsangpo River, Source: Wikipedia

3.1 LOCATION

The Yarlung Tsangpo, originating from the Angsi Glacier in Tibet's western expanse, is the longest river in Tibet and the fifth longest in China, spanning 1,125 km with a drainage basin of 241,691 km². Major Tibetan tributaries include the Nyangchu, Lhasa, Nyang, and Parlung Tsangpo rivers. The river's eastward course along the Himalayan range culminates in the Yarlung Tsangpo Grand Canyon, the world's deepest, with depths exceeding 6,000 metres. After encountering the Namcha Barwa peak (7,782 m), it deflects southward, entering India as the Siang River. Flowing through Arunachal Pradesh and Assam, it converges with the Dibang and Lohit rivers, adopting the Brahmaputra name. The Brahmaputra, spanning 800 km across Assam, is nourished by tributaries such as the Subansiri, Manas, and Teesta. Upon entering Bangladesh, it becomes the Jamuna, merging with the Padma and Meghna rivers, discharging into the Bay of Bengal, forming the Sundarbans Delta, the largest river delta globally, of profound ecological and hydrological significance. This system is central to regional hydropolitical dynamics and water management challenges.

3.2 GEOLOGY

The Yarlung Tsangpo's upper course lies within the Trans-Himalayan belt, featuring complex sedimentary and metamorphic formations. As it moves eastward, it cuts through the Eastern Himalayan orogenic belt, renowned for its deep gorges, particularly near the Namcha Barwa massif. This tectonically active region, situated at the convergence of the Indian and Eurasian plates, is seismically vulnerable. The interplay of geomorphic and climatic factors has fostered rich biotic diversity, supporting temperate and subtropical forests home to species like *Ailurus fulgens* (red panda), *Ursus thibetanus* (Himalayan black bear), and an array of endemic avifaunal taxa, underscoring the region's unparalleled ecological significance.

Figure 2: *Seismic Events and Plate Tectonics of the Indian Region.*

(Source: Author's Creation)

4. METHODOLOGY OF SYSTEMATIC REVIEW

This research used a literature review from sources like Google Scholar, JSTOR, and reports from the World Bank and UN, focusing on Sino-Indian water-sharing disputes over the Brahmaputra. Ten key sources were selected, highlighting China's hydropower projects and water-sharing agreements.

5. CHINA'S DAM-BUILDING PROJECTS ON THE BRAHMAPUTRA: GEOPOLITICAL LEVERAGE AND REGIONAL IMPLICATIONS

China's hydropower initiatives on the Brahmaputra (Yarlung Tsangpo) River are crucial for its energy needs and regional power dynamics. Originating from the Angsi Glacier in Tibet, the river spans 1,125 km and contributes about 30% of China's hydroelectric potential, with the ability to generate up to 80 million kilowatts annually (Liu et al., 2020; Zhao, 2019).

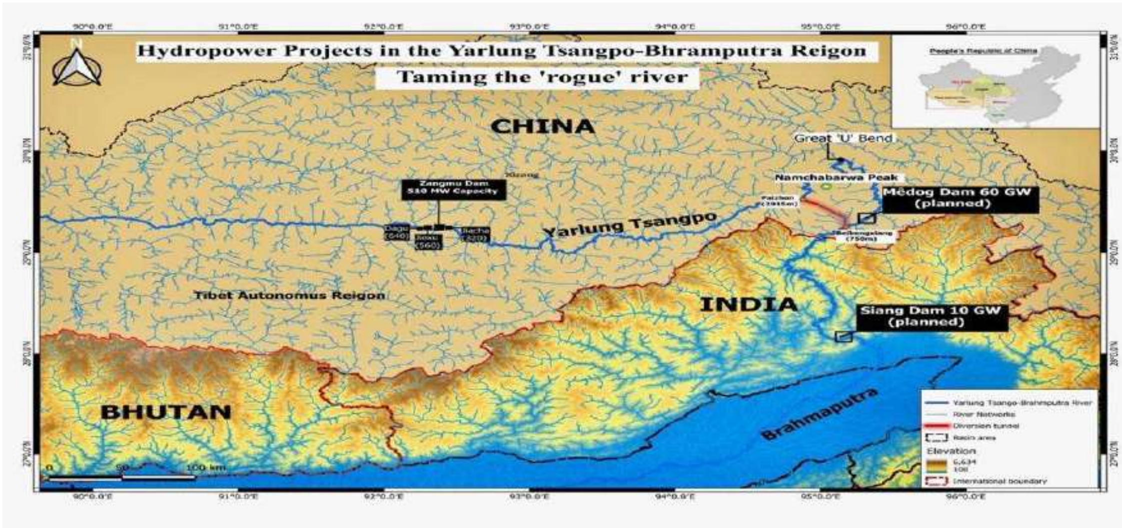

Figure 3: Map showing China's Dam project on Yarlung Tsangpo, Source: Author’s creation

These hydropower projects, including the Medog Dam, align with China's carbon neutrality goals for 2060 and offer a clean energy alternative. However, they heighten tensions with downstream nations like India and Bangladesh due to China's unilateral decision-making and the environmental risks posed by the dams, such as flash floods and reduced water flow (Ho, 2017).

China began hydropower development on the Brahmaputra with the Zangmu Dam in 2014 and has since added others, including the Jiacha Dam in 2020. The Medog Dam, initiated in 2023, will have a capacity of 60,000 MW, significantly more than the Three Gorges Dam. It will enhance China's control over the river, impacting water security in India and Bangladesh (Xinhua News, 2023; Ganguly, 2024).

5.1 GEOPOLITICAL IMPLICATIONS AND THE “PALM AND FIVE FINGERS” STRATEGY

China's control over Brahmaputra water flows follows Mao Zedong’s vision of Tibet as the "Palm and Five Fingers," where Tibet is central and water flows to neighbouring countries like India, Nepal, Bhutan, and Bangladesh serve as "fingers" to exert geopolitical leverage (Zhao, 2020). This strategy is part of China's Blue Dragon Strategy, akin to the "String of Pearls" in maritime geopolitics, using infrastructure projects to create economic dependencies (Li, 2022). However, the risks are significant— in 2000, a breach of a Chinese dam on the Yarlung Tsangpo caused flash floods in Arunachal Pradesh, inflicting ₹139.50 crore in damages and 26 fatalities (Sharma, 2021). Additionally, in 2018, the release of high--water discharge from a Chinese dam triggered water level alerts in India's northeastern states, amplifying concerns over China's upstream dominance (ISRO, 2000; Kumar, 2019).

5.2 CASCADING EFFECTS AND STRATEGIC CONSEQUENCES

China’s upstream hydropower projects on the Brahmaputra align with its broader geopolitical strategy, including the Anaconda Strategy, designed to restrict access to vital resources, particularly water, thereby limiting the economic growth of downstream countries (Gupta, 2022). This approach pressures India, Bangladesh, and others into making political and economic concessions. Similar to its tactics in other basins like the Mekong, China uses water flow control as a regional dominance tool. These dams have severe ecological consequences, including disrupted sediment transport, which undermines agricultural productivity in India and Bangladesh (Kothari, 2023). Additionally, flash floods, such as those in 2000 and 2018, highlight the growing risks associated with reduced water flow.

5.3 DIPLOMATIC AND ENVIRONMENTAL RISKS

China’s approach to water-sharing agreements is defined by unilateral control, avoiding legally binding treaties with downstream nations like India. This aligns with China’s broader diplomatic strategy, including Wolf Warrior Diplomacy, where it uses upstream control to undermine India’s water security while presenting itself as a responsible global power (Nair, 2023). Similar strategies are observed in the Mekong River, where China’s policies raise concerns about downstream dependence (Zhao, 2021). Additionally, China’s alliances with Pakistan and Bangladesh, rooted in the Kautilya Mandala Theory, employ water control as a diplomatic tool to isolate India, enhancing its regional influence (Rao, 2022).

China's hydropower projects on the Brahmaputra, such as the Medog Dam, not only threaten ecological stability but also destabilise South Asia’s political landscape. By controlling upstream water resources, China consolidates power, using these dams to assert dominance over countries reliant on the river. The ecological, economic, and diplomatic consequences of China’s water policies have already created tensions with India and Bangladesh, and across the region. As China’s expansion through infrastructure projects continues, the international community faces increasing pressure to ensure equitable water sharing and environmental sustainability.

6. INTERNATIONAL WATER COOPERATION AND BILATERALISM

China and India’s water cooperation is primarily bilateral, as reflected in their stances on the 1997 UN Convention on the Law of Non-Navigational Uses of International Watercourses. China voted against, while India abstained (United Nations Treaty Collection, 2014), both highlighting a preference for bilateral rather than multilateral frameworks. Neither country ratified the treaty when it came into force in 2014, and no South Asian nation signed it, revealing reluctance towards multilateral water governance. China’s non-participation in the Mekong River Commission and India’s focus on bilateral treaties like the India-Bangladesh Ganges and India-Nepal Mahakali agreements (1996) further underscores the regional preference for bilateral negotiations.

7. ANALYZING TRANSBOUNDARY RIVER CONFLICTS: A GAME THEORETICAL EXPLORATION OF CHINA-INDIA-BANGLADESH RELATIONS

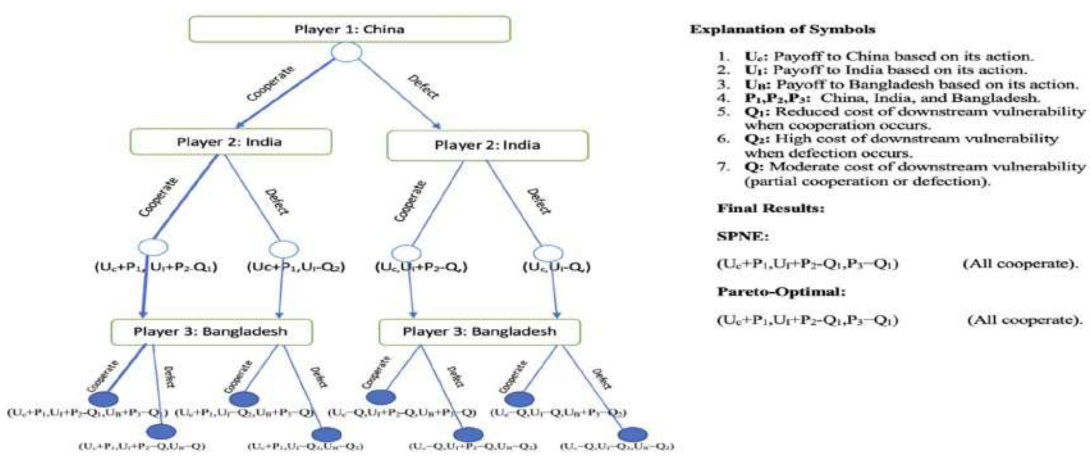

Fig 3: India-Bangladesh Cooperation-Defection Game Tree (modified by the author, with additional branches added).

(Source: Adapted from *Anamika Barua, Tanushree Baruah, and Sumit Vij*)

Figure 4: India-Bangladesh Cooperation-Defection Game Tree (modified by the author, with additional branches added), ***Source:*** Adapted from Anamika Barua, Tanushree Baruah, and Sumit Vij

7.1 GAME OUTCOMES AND HIGHLIGHTS

- **Current Cooperation**

    - India-China MoUs (2002, 2008, 2013) facilitate seasonal data sharing but exclude dry season data.
    - Bangladesh receives similar data for free, exposing unequal agreements.
- **Challenges and Trust Deficit**
    - China's dominance (e.g., Medog Dam) and unilateral actions create mistrust.
    - Past floods and disputes exacerbate tensions.
- **Asymmetric Power Dynamics**
    - China avoids multilateral oversight.
    - India faces security concerns and unequal terms.
    - Bangladesh remains vulnerable with limited influence.

Potential Cooperative Framework

- Year-round multilateral mechanisms (e.g., Lancang-Mekong model) for data sharing and equitable river management.
- Addressing asymmetries through dry-season data sharing and balanced agreements to mitigate ecological and geopolitical risks.

Resolving the trust deficit and fostering equitable cooperation among China, India, and Bangladesh is crucial for sustainable transboundary river governance. A robust multilateral framework integrating technology, transparency, and shared accountability can transform these water conflicts into opportunities for regional stability and resilience.

8. DYNAMIC HYDROPOLITICAL EQUITY FRAMEWORK (DHEF) AND THIRD POLE WATER ALLIANCE (TPWA): A COMPREHENSIVE MODEL FOR TRANSBOUNDARY RIVER GOVERNANCE

8.1 DYNAMIC HYDROPOLITICAL EQUITY FRAMEWORK (DHEF)

The DHEF presents an innovative, technology-driven governance model to address shared river resource management, ensuring equity and sustainability. This decentralised framework incorporates blockchain technology, smart contracts, and real-time environmental sensing to enable transparent water-sharing agreements.

Key features include Blockchain-Based Water Treaty Management, which ensures tamper-proof agreements through immutable records and smart contracts that adjust protocols dynamically based on real-time river flow data. IoT and AI Integration facilitate continuous monitoring via sensors deployed along river basins, capturing flow rates, sedimentation, and dam activity, while AI-driven models forecast flood risks, droughts, and operational impacts. The Environmental Reparations Fund introduces monetary accountability, wherein nations violating agreements face financial penalties channelled into restoration initiatives. Ecosystem Service Credits (ESCs) reward countries adhering to sustainable water management, establishing an incentive-based compliance system. Lastly, Transboundary River Eco-Zones (TREZs) designate protected zones along shared rivers to mitigate risks and foster biodiversity through joint management by riparian states, under international oversight.

Implementation Phases

- **Phase 1:** Pilots on Brahmaputra tributaries with IoT sensors and blockchain systems.
- **Phase 2:** Expansion to Sino-Indian disputes in the Brahmaputra Basin, backed by alliances like the Mekong River Commission model.
- **Phase 3:** Institutionalising the framework under UNFCCC or a new regional body.

8.2 THIRD POLE WATER ALLIANCE (TPWA)

The TPWA aims to counter geopolitical challenges posed by unilateral actions in the Himalayan River systems, focusing on equitable governance and climate resilience. Anchored in the DHEF, it promotes sustainable river management, environmental preservation, disaster preparedness, and data-sharing mechanisms, creating a unified front among lower riparian nations. Core members include India, Nepal, Bhutan, Bangladesh, Myanmar, and Southeast

Asian nations, with observer members like Malaysia and global partners such as the UN and World Bank.

The TPWA's Institutional Pillars include the Council for Hydropolitical Affairs (CHA) for treaty negotiations, a Scientific and Environmental Committee (SEC) for research, and a Disaster Management Task Force (DMTF) for risk mitigation. Mechanisms such as Real-Time Data Sharing Networks, Joint Environmental Monitoring Missions, and Equitable Water Sharing Agreements foster collaboration. Economic instruments like Hydropower Sharing Agreements and Eco-Compensation Funds incentivise cooperation and environmental accountability.

Unique initiatives include a Third Pole Climate Observatory (TCO) for climate impact research, a Glacial Risk Mitigation Programme (GRMP) for managing glacial lake outbursts, and the Blue Peace Initiative to utilise water as a peacebuilding tool.

9. RESULTS AND DISCUSSIONS

9.1 SUMMARY OF FINDINGS

The review revealed that China's unilateral hydropower projects on the Brahmaputra River have exacerbated regional tensions. Key factors contributing to disputes include China's lack of transparency, its strategic use of water as a geopolitical tool, and the absence of binding multilateral agreements. Conversely, successful transboundary river management examples, such as the Indus Water Treaty, highlight the importance of robust institutions, data-sharing mechanisms, and equitable benefit-sharing.

Environmental risks, including sediment starvation, reduced water flow, and flash floods, emerged as significant concerns for downstream nations like India and Bangladesh. The Medog Dam, in particular, has been identified as a critical flashpoint due to its scale and potential impacts on regional water security.

9.2 DISCUSSION

The analysis underscored China's strategic use of its upstream position to exert influence over downstream nations. This aligns with its broader geopolitical strategies, such as the "Palm and Five Fingers" framework. The lack of a multilateral governance framework has left India and Bangladesh vulnerable to China's unilateral actions.

Comparative analysis with other transboundary rivers, such as the Mekong and the Indus, suggests that cooperative frameworks, supported by international mediation and environmental safeguards, are essential for sustainable management. However, the trust deficit between China and its neighbours remains a significant barrier to collaboration.

10. CONCLUSION

The Sino-Indian water-sharing dispute over the Brahmaputra River underscores the complexities of transboundary river governance amidst geopolitical rivalries and environmental vulnerabilities. China's unilateral hydropower initiatives and its strategic use of water as a geopolitical tool have exacerbated regional tensions. This study highlights the critical need for multilateral frameworks that prioritise environmental sustainability, equitable benefit-sharing, and comprehensive data-sharing mechanisms. The proposed Dynamic Hydro political Equity Framework (DHEF) and Third Pole Water Alliance (TPWA) present innovative solutions to these challenges. By fostering transparency, collaboration, and resilience, these frameworks have the potential to transform water conflicts into opportunities for regional stability and sustainable development.

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THE GANGA & SAND MINING: AN ENVIRONMENTAL HISTORY OF RESOURCE EXPLOITATION IN VARANASI

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1. ABSTRACT

The fast economic development and concurrent expansion of building activities in many regions of the world over the past few decades have increased demand for construction-grade sand. This has frequently led to the careless extraction of sand from floodplain and instream regions, seriously harming the ecosystem of the river basin. In the catchment basins of rivers like the Ganga, the situation is fairly concerning. The Ganga has great cultural, spiritual, and ecological significance and is frequently referred to as India's lifeline. The river that flows through Varanasi, one of the oldest towns in the world, is essential to religious rites, commercial activity, and the survival of millions of people. According to a recent study on the environmental consequences of sand mining in Varanasi, certain areas have been identified as highly impacted due to intensive extraction activities. These areas include the riverbanks near Ramnagar, the stretch along the Ganges between Rajghat and Assi Ghat, parts of Adalpura, and the downstream regions near Chunar.

2. INTRODUCTION

The Ganga has great cultural, spiritual, and ecological significance and is frequently referred to as India's lifeline. The river, which runs through Varanasi, one of the oldest towns in the world, is essential to both religious rites and commercial activity, supporting millions of lives. However, extensive sand mining has resulted from the growing need for sand, a vital resource for building, which has raised worries about biodiversity loss, environmental degradation, and the long-term health of the river. The purpose of this essay is to examine the ecological effects and sociopolitical factors that motivate resource exploitation as well as the environmental history of sand mining in Varanasi.

Historical Context of Sand Mining in the Ganga Basin:

2.1 Traditional Use of River Resources

Local people have historically made sustainable use of the Ganga's resources. Very little sand was extracted, mostly for ceremonial and small-scale building uses. Ecological balance was preserved by the river's natural processes, such as the deposition of sediment during monsoons.

2.2 The Rise of Industrial Demand

India's fast urbanization and infrastructure growth after independence spurred a boom in building projects, which raised the country's need for river sand. Due to infrastructural initiatives and real estate booms, Varanasi saw a transition from small-scale sand collecting to large-scale commercial mining by the late 20th century.

3. STUDY AREA

3.1 LOCATION

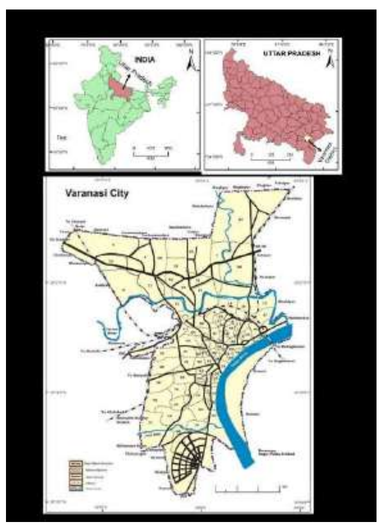

Figure-1: Map showing the location of Varanasi in Uttar Pradesh

One of the world's oldest continuously inhabited towns, Varanasi (also called Kashi or Banaras) is located in the Indian state of Uttar Pradesh on the left bank of the Ganga River. Varanasi, which is famous as a significant cultural, religious, and educational hub and draws millions of pilgrims and tourists each year, is situated between latitudes 25.3176° N and longitudes 82.9739° E.

3.2 Sand Mining Sites in and Around Varanasi

The urban portion of the Ganga in Varanasi is somewhat protected because of its holy significance, but sand mining that is illegal and unregulated flourishes on its fringes, especially in places like:

Ramnagar: Located across the river from the main city, known for extensive sand extraction operations.

Chunar (Mirzapur district): A major site for both legal and illegal mining activities due to its proximity to Varanasi and high-quality sand deposits.

Sarnath and downstream rural belts: Witness scattered mining activities impacting riverbanks and floodplains.

Both physical labour and automated machinery, such as dredgers and boats, are used to remove sand, frequently in violation of environmental laws. To satisfy the needs of the expanding building sector in Varanasi and the surrounding areas, the excavated sand is transported.

COMPARATIVE ANALYSIS:

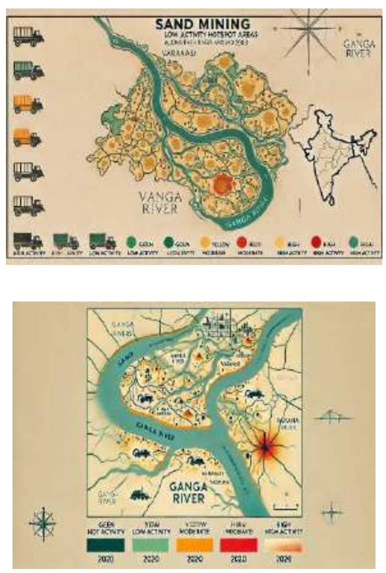

Figure-2: Comparative Analysis of Sand Mining Trends in Varanasi: 2000 Vs. 2020

The Ganga River's sand mining activity clearly increased between 2000 and 2020, according to the simplified maps. Mining activities were more confined and concentrated in easily accessible areas, as evidenced by the 2000 map's hotspots, which are comparatively few and primarily moderate, with a few high-activity areas clustered close to important landmarks. On the other hand, the 2020 map demonstrates a notable rise in the intensity and dispersion of mining operations, with a wider variety of high-activity zones suggesting that mining has increased in scope and geography. According to this comparison, sand mining activities have significantly increased over the past 20 years, indicating rising demand and potentially ineffective enforcement of regulations.

5. METHODS AND MATERIALS

5.1 Methods of Data collection

Government documents, historical research, and observations at significant sand mining locations along the Ganga in Varanasi are all used in this study's mixed-methods methodology. It also examines satellite imagery from 2000 to 2020, emphasizing changes in sediment patterns and river shape. The historical framework was enhanced by archival research, which included records from the colonial past and current legal documents.

5.2 Materials

5.2.1 Environmental Consequences of Sand Mining in Varanasi

Significant environmental damage has resulted from Varanasi's sand mining, including erosion of riverbanks, biodiversity loss, groundwater depletion, and a greater danger of flooding. According to studies, in highly mined places along the Ganga, riverbank erosion rates have increased by 30%. Due to habitat damage, the endangered Ganges River dolphin population has decreased by more than 20% in the past ten years. at addition to endangering ecosystems, these environmental challenges also put Varanasi's livelihoods and cultural legacy at danger.

Environmental Impact	Quantitative Data
Riverbank erosion	Increased by 30 – 50% (Rajghat and Assi Ghat)
Alteration of River Morphology	Riverbed lowering by 1.5 - 2m over the past decade.
Groundwater Depletion	Decline by 0.5 – 1 m/year
Loss of Biodiversity	25 – 30% decline in Fish Diversity
Increased water pollution	Turbidity increased from 50 NTU to over 150 NTU.
Agricultural Productivity	Decreased by 15 – 20%

Table-1: Impact of Sand Mining in Varanasi

5.2.2 Regulatory Framework Governing Sand Mining in Varanasi

Sand mining in Varanasi is regulated by both central and state laws:

MMDR Act, 1957: Provides the national framework for mineral regulation.

Uttar Pradesh Minor Minerals (Concession) Rules, 1963: Governs sand mining permits and leases.

Uttar Pradesh M-Sand Policy, 2024: Promotes manufactured sand to reduce environmental impact.

National Green Tribunal (NGT) Directives: Enforces environmental safeguards and mandates replenishment studies to prevent over-extraction.

6. CONCLUSION

The ecological equilibrium of the Ganga has been severely disrupted by sand mining in the Varanasi basin, which has changed the river's geomorphology, endangered wildlife, and harmed local livelihoods. Both legal and illicit mining have contributed to environmental degradation, which has been fuelled by urbanization and lax implementation of regulations. A balanced strategy that encourages sustainable mining methods, fortifies government, and engages local populations is required to address these issues. Because of the close ties that exist between the Ganga and the Varanasi community, protecting the river is not just an environmental imperative but also a cultural and sociopolitical priority.

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TRANSBOUNDARY WATER DISPUTES: A CASE STUDY OF INDUS RIVER

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1. Abstract

Transboundary water conflicts are a real challenge to international relations, especially in areas where several countries share water resources. The India-Pakistan Indus River conflict is one of the most complicated and longest-standing water conflicts in the world. Regulated by the Indus Waters Treaty (IWT) of 1960, facilitated by the World Bank, the treaty divided the ownership of the six Indus basin rivers, with India being granted the eastern rivers (Ravi, Beas, and Sutlej) and Pakistan granted the western rivers (Indus, Jhelum, and Chenab). While the treaty was successful in averting large-scale confrontations for decades, tensions have flared anew on account of hydroelectric schemes, climate change, and geopolitical tensions. India's construction of dams on the western rivers, including the Kishanganga and Ratle projects, has been accused of treaty violations by Pakistan. Concurrently, population growth, growing water requirements, and climate-related variability have strained the water-sharing treaty further. Attempts to solve these conflicts through bilateral negotiations and international arbitration have been partially successful. The Indus River conflict underlines the imperative for collaborative water management, diplomatic efforts, and sustainable development approaches to avoid intensifying tensions and provide water security for both countries.

2. Introduction

Transboundary water conflicts are now a new normal of international relations, particularly in regions where water resources across national borders. The Indus River system, one of the most significant river systems in South Asia, is a quintessential example of a transboundary water conflict. The river flows through China, India, Pakistan, and Afghanistan and has been a lifeline for millions of people for centuries, supporting irrigation, industry, and domestic water needs. The partition of British India in 1947, however, established a complex and contentious water-sharing regime between India and Pakistan, as the river's headwaters are located in India but Pakistan is heavily dependent on its downstream flow. This geographical asymmetry has made the Indus River a focal point of political and diplomatic competitions between the two countries.

The Indus Waters Treaty (IWT), which was signed in 1960 with the World Bank's mediation, was a landmark agreement to resolve the water-sharing conflict. It allocated the six rivers of the Indus basin between the two countries, giving India the eastern rivers—Ravi, Beas, and Sutlej—and Pakistan the western rivers—Indus, Jhelum, and Chenab. While the treaty has been effective to a significant extent in preventing major conflicts for more than six decades, disputes have erupted anew over India's construction of hydroelectric projects on the western rivers, which Islamabad sees as potential treaty violations.

Beyond such technical and legal distinctions, broader geopolitical competitions, climate change, and increasing water demands have increasingly complicated the dispute. The once-rich Indus River is increasingly stressed today with changed weather, glacial melting, and population pressures. This has heightened stakes for both countries to come to the table in sincere negotiation, seek sustainable management of water, and achieve equitable and efficient utilization of the river's resources. This study discusses the historical context, most contested issues, and the role of international mediation in the Indus River dispute. It also examines the climate change and population pressure concerns, prioritizing long-term cooperation and adaptive water management to prevent future conflicts. The Indus River dispute is an important case study on how water, politics, and diplomacy intersect in transboundary river basins around the globe.

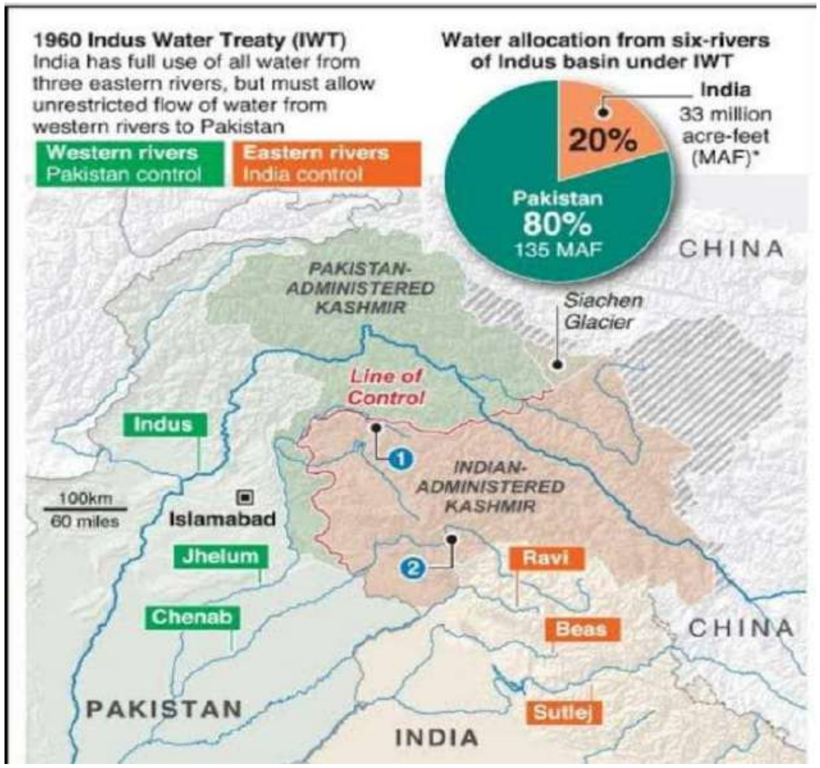

Figure-1: Control of Indus Water (According to Indus Water Treaty)

3. Study Area for the Indus Water Treaty

The area of study of the Indus Water Treaty comprises the regions of India, Pakistan, China, and Afghanistan because the Indus River Basin comprises these countries.

India (upstream region)

1. Jammu & Kashmir (now UTs of J&K and Ladakh): Source of rivers Indus, Jhelum, and Chenab.
2. Himachal Pradesh and Punjab: Source and path of rivers Ravi, Beas, and Sutlej.
3. Haryana, Rajasthan, and Delhi: Irrigate and provide water to these states from the eastern rivers.

Pakistan (downstream region)

1. Gilgit-Baltistan and Khyber Pakhtunkhwa: Receive the waters of the Indus, Jhelum, and Chenab.
2. Punjab: Major agricultural hub to receive waters from the western rivers.

3. Sindh: Relies heavily on the Indus River for agriculture and water supply.
4. Balochistan: Receives the waters of the Indus through inter-provincial water-sharing agreements.

China and Afghanistan

China: The Tibetan Plateau serves as the origin of the Indus River. While not a signatory, China's hydrological activities impact the basin's flow.

Afghanistan: Contributes to the Indus through the Kabul River, a key tributary. Though not part of the treaty, Afghanistan's water management decisions influence water availability downstream.

Significance of the Study Area

1. Hydrological Importance:

The Indus River Basin is among the most important transboundary river basins globally. The river originates in China's Tibetan Plateau, flows through India and Pakistan, and finally drains into the Arabian Sea. The basin receives snowmelt and glacial melt from the Himalayan, Karakoram, and Hindu Kush Mountain ranges and is therefore climate change-sensitive. The study area covers the river's tributaries, the Jhelum, Chenab, Ravi, Beas, and Sutlej, which are vital for agriculture, hydropower, and domestic water supply. The basin's hydrology is known to allow better management of water, particularly in drought and flood situations.

2. Geopolitical Importance:

The Indus Basin is located in a politically volatile area with a history of India-Pakistan conflict. Sharing water has been a contentious issue, especially for infrastructure projects like the Baglihar Dam on the Chenab River and the Kishanganga Dam on the Jhelum River. The treaty provisions help manage such conflicts through established mechanisms of information sharing, inspection, and conflict resolution. The study area is therefore at the forefront of ensuring regional stability and cooperation in the face of existing political tensions.

3. Agricultural and Economic Importance:

The Indus Basin sustains the world's largest contiguous irrigation system, the Indus Basin Irrigation System (IBIS). In Pakistan, almost 90% of the country's agriculture is dependent on the Indus system's water, and the basin is therefore at the heart of food security and livelihood.

Wheat, rice, sugarcane, and cotton are grown on a large scale throughout the basin. Punjab, Haryana, and Rajasthan in India are highly dependent on the eastern rivers' (Ravi, Beas, Sutlej) water for irrigation and economic development. The study area thus sustains agricultural productivity and economic stability for millions of individuals.

4. Environmental and Ecological Significance:

The Indus Basin has varied ecosystems, including glacial areas, rivers, wetlands, and deltaic areas. The Indus Delta in Sindh, Pakistan, has rich biodiversity, including mangrove cover and aquatic fauna. Excessive water abstraction and decreased downstream flows have, however, led to ecological degradation, increased salinity, and loss of biodiversity. Basin analysis enables understanding of the environmental effects of water management practices and encourages sustainable development approaches.

5. Socioeconomic Impact:

The basin has a direct impact on the livelihood of millions of individuals involved in agriculture, fisheries, and related industries. Insufficiency of water, unequal distribution, and climate variability create serious challenges for rural communities. The study area of the treaty enables identification of areas prone to water stress and supports measures to enhance water use efficiency, particularly in densely populated and agriculturally intensive regions.

6. Climate Change Resilience:

The glaciers feeding the Indus River are melting due to global warming, which is affecting the river flow regime. Climatic variability, glacier melting, and extreme events like flood and drought have increased. The research area can be utilized to assess the impacts of the climate, and adaptive measures like improved water storage capacity and improved forecasting networks can be adopted.

4. Material And methodology

The 1960 Indus Waters Treaty (IWT) of the World Bank governs the distribution of water between India and Pakistan. The treaty distributes the eastern rivers (Ravi, Beas, Sutlej) to India and the western rivers (Indus, Jhelum, Chenab) to Pakistan with some non-consumptive uses to India. The mechanism involves the Warabandi system of balanced allocation of water and mutual observation by the Permanent Indus Commission. The financial terms guaranteed the development of infrastructure in Pakistan. The treaty focuses on cooperation, dispute resolution, and judicious use of water for regional peace in the background of political rivalry between the countries.

5. Result and Discussion

Result

1. Peaceful Water Sharing: The IWT has kept India and Pakistan from fighting over water in large measure despite recurring political tensions, including wars. By defining water rights and use, the treaty enabled stability in the region and facilitated the two countries to pursue agricultural and industrial growth.

2. Infrastructure Development: India, under the treaty, committed to providing financial assistance to the development of dams, canals, and other infrastructure in Pakistan for the purpose of enabling its utilization of the western rivers. This led to the development of large projects, such as the Mangla and Tarbela dams, increasing Pakistan's irrigation and hydroelectric power.

3. Institutional Mechanism: The establishment of the Permanent Indus Commission (PIC) facilitated the ease of communication and cooperation between the two countries. The PIC holds annual meetings, mutual inspections, and information exchange, promoting transparency and confidence-building.

4. Sustained Cooperation: The treaty has been resilient, enduring many geopolitical crises. Both countries have continued to pursue dialogue through the PIC, testifying to the treaty's status as a confidence-building measure.

Discussion:

Despite its success, the Indus Waters Treaty is facing various challenges:

1. Hydroelectric Disputes: Hydroelectric development in India on the western rivers has caused controversies, with Pakistan worried about the reduction in water flow. The Kishanganga and Baglihar dam projects have led to international arbitration and are indicative of differing interpretations of the treaty provisions.

2. Climate Change and Water Scarcity: Changes in precipitation patterns, glacier melt, and increased water demand because of population increase are impacting water availability in the Indus Basin. The treaty fails to adequately address these, having been created in a different environmental and population context.

3. Political Tensions and Security Issues: Political tensions between India and Pakistan have at times influenced treaty negotiations. Charges of water manipulation have resulted in distrust, with water security emerging as a politically charged concern in both countries.

4. Need for Modernization and Adaptation: The treaty lacks provisions for addressing new challenges like environmental sustainability, groundwater management, and climate change adaptation. Experts support revising the treaty to incorporate modern water management techniques and address changing needs.

6.Conclusion

The Indus Waters Treaty (IWT) of 1960 is a success story of transboundary water resource management, and it has proved that cooperation for common natural resources is possible even during times of political tensions. By allocating the eastern rivers (Ravi, Beas, and Sutlej) to India and western rivers (Indus, Jhelum, and Chenab) to Pakistan, it ensured proportionate water distribution and prevented water-related conflicts between the two nations.

One of the biggest strengths of the treaty is its robust institutional mechanism—the Permanent Indus Commission (PIC)—which ensures continuous dialogue, data sharing, and conflict resolution. This mechanism has ensured that the treaty has remained robust, and it has been able to survive different geopolitical crises to ensure peace on water-sharing terms for more than six decades.

The treaty does have challenges, including hydroelectric project conflicts, the impact of climate change on water availability, and altered water demands due to population growth. These create the need for dialogue and potential treaty modifications to accommodate challenges of the contemporary era.

In conclusion, the IWT has been instrumental in fostering regional stability and cooperation. For continued success, India and Pakistan must engage in proactive discussions to modernize the treaty, incorporating contemporary water management practices and addressing emerging environmental and political challenges.

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किशनगंज, बिहार की कनकई नदी के उफान का सामाजिक-आर्थिक प्रभाव

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संक्षेप

कंकई नदी ने कई महत्वपूर्ण कटावों का अनुभव किया है, जिसके परिणामस्वरूप इस क्षेत्र पर काफी सामाजिक-आर्थिक प्रभाव पड़ा है। यह शोध पत्र नदी के कटाव के कारणों और प्रभावों का गहनता से पता लगाता है और कृषि, बुनियादी ढांचे और स्थानीय समुदायों की आजीविका पर इसके प्रभावों का विश्लेषण करता है। ऐतिहासिक डेटा विश्लेषण, क्षेत्र सर्वेक्षण और भौगोलिक सूचना प्रणाली (जीआईएस) मानचित्रण के संयोजन का उपयोग करके, अध्ययन नदी के बदलते मार्ग से उत्पन्न चुनौतियों का एक व्यापक अवलोकन प्रस्तुत करता है। निष्कर्ष प्रतिकूल प्रभावों को कम करने और प्रभावित क्षेत्रों में सतत विकास को बढ़ावा देने के लिए एकीकृत नदी प्रबंधन रणनीतियों और सक्रिय नीति हस्तक्षेपों की आवश्यकता पर प्रकाश डालते हैं।

कीवर्ड : कंकई नदी, बाढ़, सामाजिक-आर्थिक प्रभाव, किशनगंज, बिहार, नदी प्रबंधन, सतत विकास।

परिचय

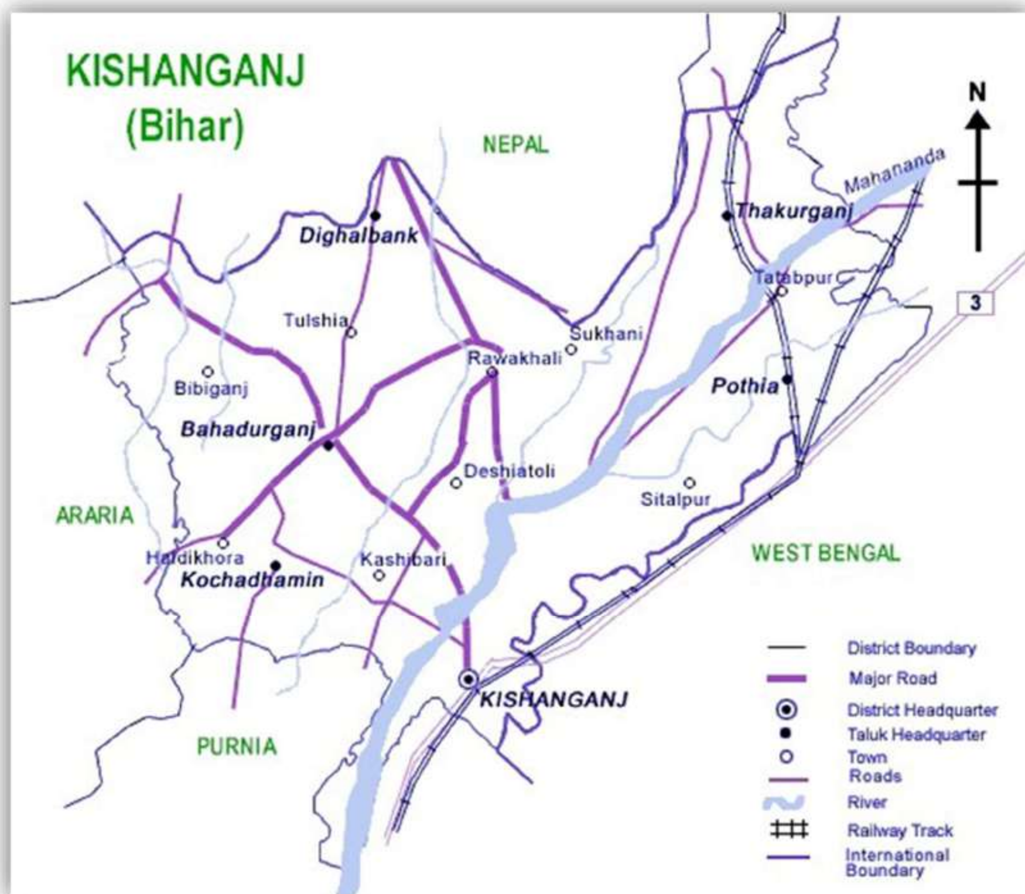
नदी का जलप्लावन, जिसका अर्थ है नदी के किसी चैनल को तेजी से छोड़ना और एक नया चैनल बनाना, एक प्राकृतिक नदी प्रक्रिया है जो परिदृश्यों और मानव बस्तियों को गहराई से बदल सकती है। बिहार में ऐसी घटनाएँ आम हैं, जो पूर्वी भारत का एक राज्य है, जहाँ कोशी और कंकई जैसी नदियाँ अक्सर अपना मार्ग बदल देती हैं। कंकई नदी, विशेष रूप से, जलप्लावन की घटनाओं का एक उल्लेखनीय इतिहास है, जिसके कारण किशनगंज जैसे जिलों में महत्वपूर्ण सामाजिक-आर्थिक व्यवधान उत्पन्न हुए हैं। इस पत्र का उद्देश्य किशनगंज में कंकई नदी के जलप्लावन के सामाजिक-आर्थिक प्रभावों की जाँच करना है, जो कृषि, बुनियादी ढाँचे और स्थानीय निवासियों की समग्र आजीविका पर इसके प्रभाव पर ध्यान केंद्रित करता है।

अध्ययन क्षेत्र

किशनगंज ऐतिहासिक रूप से पूर्णिया का एक महत्वपूर्ण उपखंड था। सत्रह वर्षों तक चले एक लंबे और चुनौतीपूर्ण संघर्ष के बाद, जिसमें सामाजिक कार्यकर्ताओं, राजनेताओं, पत्रकारों, व्यापारियों और किसानों

सहित किशनगंज के लोगों के प्रयास शामिल थे, 14 जनवरी 1990 को किशनगंज जिले की स्थापना की गई।

भूगोल :- किशनगंज जिला 1,884 वर्ग किलोमीटर में फैला हुआ है । किशनगंज जिला पश्चिम में अररिया जिले, दक्षिण-पश्चिम में पूर्णिया जिले, पूर्व में पश्चिम बंगाल के उत्तर दिनाजपुर जिले और उत्तर में पश्चिम बंगाल और नेपाल के दार्जिलिंग जिले से घिरा हुआ है। पश्चिम बंगाल की लगभग 20 किमी चौड़ी एक संकरी पट्टी इसे बांग्लादेश से अलग करती है। किशनगंज जिला 25.20 और 26.30 उत्तरी अक्षांशों और 87.7 और 88.19 पूर्वी देशांतरों के बीच स्थित है। जिले से होकर बहने वाली प्रमुख नदियाँ महानंदा, कंकई , मेची , डोंक, रतुआ और रमजान सुधानी हैं ।



(स्रोत- https://kishanganj.nic.in/)

जनसांख्यिकी- 2011 की जनगणना के अनुसार किशनगंज जिले की कुल जनसंख्या 107,076 है। इसमें से 55,688 पुरुष और 51,388 महिलाएँ शामिल हैं। जनगणना के आंकड़ों के अनुसार, पुरुषों

की साक्षरता दर 71.7% और महिलाओं की साक्षरता दर 56.3% है, जबकि औसत साक्षरता दर 64.24% है। यह जिले उन कुछ स्थानों में से एक है जहाँ मुसलमानों की जनसंख्या प्रमुखता में है।

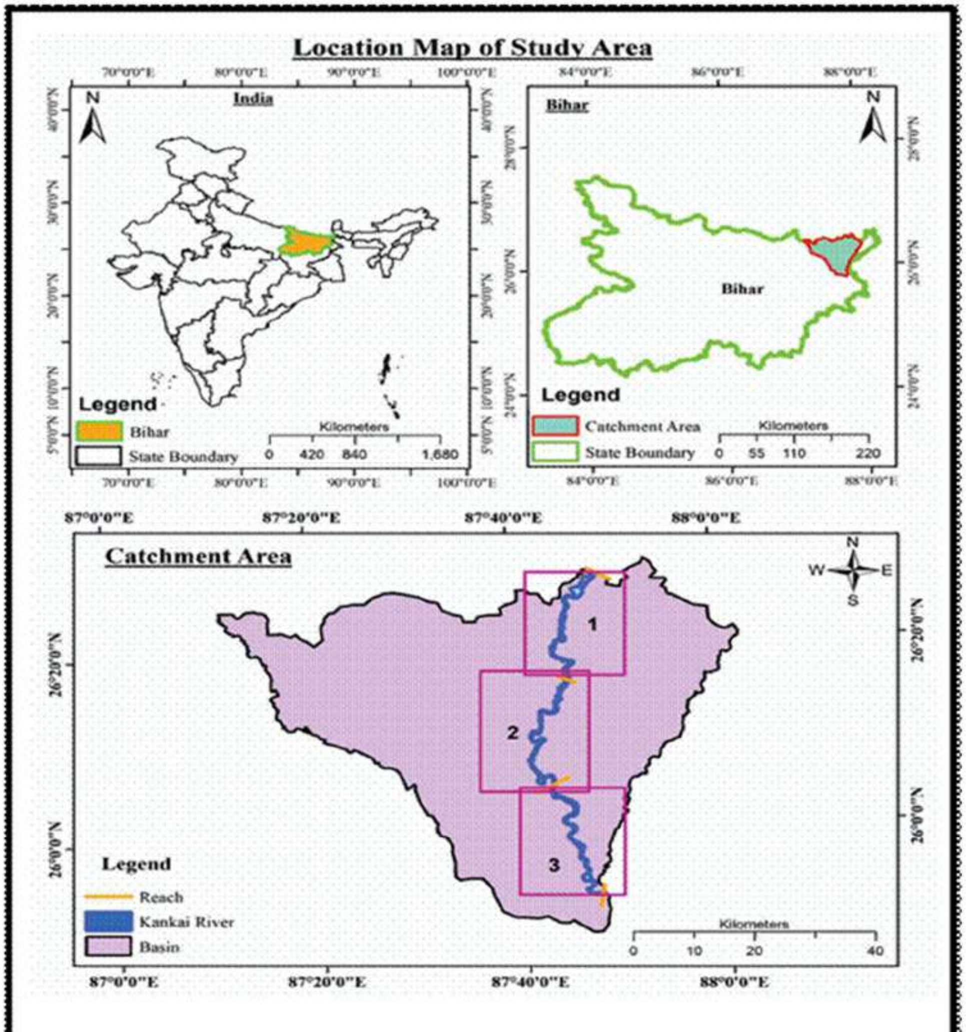


Fig. 1. Location map of study area

(स्रोत - जर्नल ऑफ वॉटर इंजीनियरिंग एंड मैनेजमेंट में लेख · जनवरी 2021)

क्रियाविधि

इस लेख में डेटा संग्रह के लिए मुख्यतः द्वितीयक डेटा स्रोतों का उपयोग किया गया है। द्वितीयक डेटा से तात्पर्य उन जानकारियों से है जो पहले से ही विभिन्न स्रोतों, जैसे सरकारी रिपोर्ट, शैक्षणिक अनुसंधान और प्रतिष्ठित संस्थाओं द्वारा एकत्रित और प्रकाशित की जा चुकी हैं। शोधकर्ता ने सरकारी वेबसाइटों,

अनुसंधान पत्रों, आपदा प्रबंधन योजनाओं, समाचार लेखों और आपदा जोखिम न्यूनीकरण तथा ग्रामीण विकास से संबंधित संगठनों की रिपोर्टों से सामाजिक-आर्थिक प्रभावों, अनुकूलन रणनीतियों और सफल हस्तक्षेपों पर महत्वपूर्ण डेटा एकत्र किया। इसके बाद, एकत्रित डेटा का विश्लेषण किया गया ताकि रुझानों, चुनौतियों और प्रभावी उपायों की पहचान की जा सके।

परिणाम और चर्चा

(स्रोत: क्रिएटेड बाय ऑथर गूगल अर्थ इमेज 2003 और 2024)

किशनगंज, बिहार में कंकई नदी ने 2003 से 2024 के बीच भूमि उपयोग में महत्वपूर्ण परिवर्तन किए हैं, जो व्यापक कटाव और निक्षेपण की प्रक्रिया के परिणामस्वरूप हुए हैं। हर वर्ष मानसून के समय नदी का प्रवाह बदलता है, जिसके कारण कई गांवों और कृषि भूमि का कटाव होता है। हजारों एकड़ उपजाऊ भूमि नदी में समाहित हो गई, जिससे किसान विस्थापित हो गए। दूसरी ओर, कुछ क्षेत्रों में नदी द्वारा नए जमाव (नदी के तल में मिट्टी और रेत का संचय) के कारण भूमि का निर्माण भी हुआ है। यह प्रक्रिया किसानों और स्थानीय निवासियों के लिए निरंतर चिंता का विषय बनी हुई है।

सामाजिक आर्थिक प्रभाव

कृषि प्रभाव

कंकई नदी कृषि सिंचाई को प्रोत्साहित करती है, जिससे किसान हर वर्ष कई प्रकार की फसलें उगा सकते हैं। फिर भी, अचानक आने वाली बाढ़ अक्सर फसलों को क्षति पहुंचाती है, जिससे आर्थिक हानि होती है। बाढ़-प्रतिरोधी फसल किस्मों और उन्नत सिंचाई प्रणालियों का उपयोग इन समस्याओं को कम करने में सहायक हो सकता है। क्षेत्र की पारंपरिक कृषि पद्धतियों पर निर्भरता इसे जलवायु परिवर्तन के प्रति अधिक संवेदनशील बना देती है। जबकि नदी मिट्टी को आवश्यक पोषक तत्व प्रदान करती है, अत्यधिक जलभराव समय के साथ मिट्टी की उर्वरता को घटा सकता है। आधुनिक सिंचाई तकनीकों जैसे ड्रिप सिंचाई और वर्षा जल संचयन को अपनाने से जल के उपयोग को बेहतर बनाने और उपज की स्थिरता को बढ़ाने में सहायता मिल सकती है।

(स्रोत- विज्ञान प्रत्यक्ष वेबसाइट)

बुनियादी ढांचे और सार्वजनिक सेवाओं पर प्रभाव

कंकई नदी के उफान ने बुनियादी ढांचे को गंभीर क्षति पहुंचाई है, जिसके परिणामस्वरूप आवश्यक सार्वजनिक सेवाओं में बाधा उत्पन्न हुई है। अनेक सड़कें, पुल और पुलिया बह गई हैं, जिससे नागरिकों के लिए बाजार, विद्यालय और अस्पतालों तक पहुंचना कठिन हो गया है। शैक्षणिक संस्थानों को भी भारी नुकसान हुआ है, कुछ विद्यालय पूरी तरह से नष्ट हो चुके हैं या उपयोग के योग्य नहीं रहे हैं।

(स्रोत- किशनगंज बिहार कॉम लेख ठाकुरगंज और पोठिया ब्लॉक 2012)

केस स्टडी विश्लेषण: किशनगंज पुल ढहना (जून 2024): जून 2024 में किशनगंज में हाल ही में हुए पुल के ढहने की घटना, जो कंकई नदी की सहायक नदी में जल स्तर के बढ़ने के कारण हुई, संभावित सामाजिक-आर्थिक प्रभावों के अध्ययन के लिए एक समकालीन केस स्टडी के रूप में कार्य करती है। इस केस स्टडी के विश्लेषण में निम्नलिखित पहलुओं को शामिल किया जाएगा:

- **समाचार मीडिया विश्लेषण:** पुल के ढहने की तिथि, स्थान, कारण और तात्कालिक परिणामों के संबंध में जानकारी एकत्र करने के लिए प्रमुख राष्ट्रीय और क्षेत्रीय मीडिया स्रोतों (जैसे, एनडीटीवी, द हिंदू, द न्यू इंडियन एक्सप्रेस) की समाचार रिपोर्टों का विश्लेषण करें। यह बुनियादी ढांचे, कनेक्टिविटी और संभावित रूप से आजीविका तथा दैनिक जीवन में प्रारंभिक व्यवधानों के ठोस प्रभावों को समझने में सहायक होगा।

(स्रोत- अलग-अलग समाचार लेखों से ली गई तस्वीर जैसे - एनडीटीवी, द हिंदू, द इंडियन एक्सप्रेस, हिंदुस्तान टाइम्स)

बाढ़ और आपदा प्रबंधन

नदी के बार-बार उफान से बाढ़ जैसी समस्याएँ उत्पन्न होती हैं, जो जीवन और बुनियादी ढांचे में व्यवधान डालती हैं। वर्तमान बाढ़ नियंत्रण उपायों, जैसे तटबंधों, की अपनी सीमाएँ हैं। नुकसान को कम करने के लिए प्रारंभिक चेतावनी प्रणाली, बेहतर जल निकासी योजनाएँ और समुदाय-आधारित आपदा प्रतिक्रिया कार्यक्रमों की आवश्यकता है। शहरी नियोजन में बाढ़-प्रतिरोधी आवास मॉडल और जलवायु-अनुकूल बुनियादी ढाँचे को प्राथमिकता दी जानी चाहिए। आपदा प्रतिक्रिया एजेंसियों और स्थानीय प्रशासन के बीच समन्वय को मजबूत करने से तैयारी और पुनर्प्राप्ति प्रयासों में सुधार संभव है।

(स्रोत -इंडियन एक्सप्रेस समाचार लेख ,बाढ़ -2017)

विस्थापन और प्रवास

कंकई नदी के कटाव के चलते हजारों लोग अपने स्थानों से विस्थापित हो चुके हैं, जिससे उन्हें सुरक्षित स्थानों पर जाने के लिए मजबूर होना पड़ा है। नदी के किनारे स्थित कई गांव कटाव और रेत के संचय के कारण या तो बह गए हैं या फिर रहने के लिए अनुपयुक्त हो गए हैं। इस विस्थापन के मुख्य प्रभाव निम्नलिखित हैं:

- परिवारों के लिए घरों का नुकसान: कई परिवारों ने अपने पूर्वजों के घरों को खो दिया है, और अनेक लोग अस्थायी आश्रयों, सरकारी कैंपों या निकटवर्ती शहरों में अपने रिश्तेदारों के साथ निवास करने के लिए विवश हो गए हैं।
- शहरी क्षेत्रों की ओर प्रवास: बाढ़ से प्रभावित गांवों में आर्थिक अवसरों की कमी के चलते, अनेक निवासी रोजगार की खोज में निकटवर्ती कस्बों और शहरों की ओर चले गए हैं, जिससे वहां जनसंख्या का दबाव बढ़ गया है और शहरी अवसंरचना पर अतिरिक्त बोझ पड़ गया है।

निष्कर्ष

कंकई नदी के कटाव के कारण किशनगंज के निवासियों पर दीर्घकालिक सामाजिक-आर्थिक प्रभाव पड़े हैं। इस अध्ययन का मुख्य उद्देश्य संभावित खतरों को कम करने के लिए निवारक उपायों का सुझाव देते हुए प्रभाव की गहराई का मूल्यांकन करना है। नदी के किनारों की सुरक्षा को सुदृढ़ करना, प्रारंभिक चेतावनी प्रणाली का विकास करना, स्थायी भूमि-उपयोग योजना को लागू करना और आपदा की तैयारी को बढ़ावा देना भेद्यता को कम करने के लिए आवश्यक कदम हैं। जीवन और आजीविका की सुरक्षा के लिए सरकारी संस्थाओं, स्थानीय समुदायों और गैर-सरकारी संगठनों के बीच एक समन्वित प्रयास की आवश्यकता है। वैज्ञानिक अनुसंधान, नीतिगत हस्तक्षेप और सामुदायिक भागीदारी को एकीकृत करके, किशनगंज एक अधिक लचीले और टिकाऊ भविष्य की दिशा में आगे बढ़ सकता है।

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MORPHOMETRIC ANALYSIS OF TAWA WATERSHED IN SOUTHERN MADHYA PRADESH, USING G.I.S AND REMOTE SENSING

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1. ABSTRACT

Attempt has been made to understanding the geomorphological and hydrological characteristics of a river basin is crucial for effective watershed management and flood risk assessment. This study analyzes key morphometric parameters of the Tawa watershed, including stream order, bifurcation ratio, stream length, drainage density, stream frequency, basin area and perimeter, elongation ratio, circulatory ratio and relief ratio. For detailed study we used Shuttle Radar Topographic Mission (SRTM) data for preparing Digital Elevation Model (DEM) was used in evaluation of linear, areal and relief aspects of morphometric parameters. These findings will provide valuable insights on the hydrological behavior of the Tawa watershed, in southern Madhya Pradesh assisting in sustainable water resource management and flood mitigation strategies.

Keywords: Morphometric analysis, SRTM and DEM data, GIS, Tawa watershed, Madhya Pradesh

1. INTRODUCTION

Water is essential for everyone on Earth, but we specifically need freshwater to survive and thrive. Unfortunately, the amount of freshwater available is limited. As the population grows, industries expand, and living standards improve, the demand for water keeps rising. This puts a lot of pressure on our freshwater sources, like rivers, lakes, and groundwater. Rainfall is the natural way freshwater is replenished, but it's not always enough. To ensure there's enough water for everyone's needs—like food production and daily life—we need to plan and manage our water resources wisely and scientifically. It's the only way to keep up with the growing demand. The drainage characteristics of Tawa Basin and sub-basins were studied to describe and evaluate their hydrological characteristics from SRTM DEM data. To prepare a comprehensive watershed development plan, it becomes necessary to understand the topography, erosion status and drainage pattern of the region. For detailed morphometric analysis, we used SRTM data for preparing DEM map slope and aspect maps. GIS was used in the evaluation of linear, areal and relief morphometric parameters. Using and managing groundwater sustainably is crucial today because water shortages are becoming more common. Tools like remote sensing and GIS (Geographic Information Systems) are incredibly helpful for studying and managing groundwater. They allow us to analyse and work with data effectively, making it easier to develop and manage groundwater resources wisely. (Krishnamurthy et al.,2000).

The main goal of this study is to understand different drainage features to get a clearer picture of the drainage basin. It also helps in accurately mapping the landscape of the watershed, which is useful for reducing risks when planning and managing water resources.

2. STUDY AREA

The Tawa River originates in the Mahadeo hills of Chindwara district flows via Betul and Narmadapuram (Hoshangabad) District in the southern part of Madhya Pradesh. Lies approximately between 22°1' to 22°36½' North and longitude of 77°58' to 37.83" East between Vindhyachal Mountains in the north and the Satpura in the south. It is the Narmada's largest tributary, covering an area of around 176.275 kilometres. The area forms a part of Deciduous Forest Region and experiences a tropical climate. The average annual rainfall is 1000 -1500 mm (40-60), most of which falls during the southwest monsoon from June to September. The temperature reaches its high in April and May and low in January, with the mean maximum of 45°C in May and a mean minimum of 10°C in January.

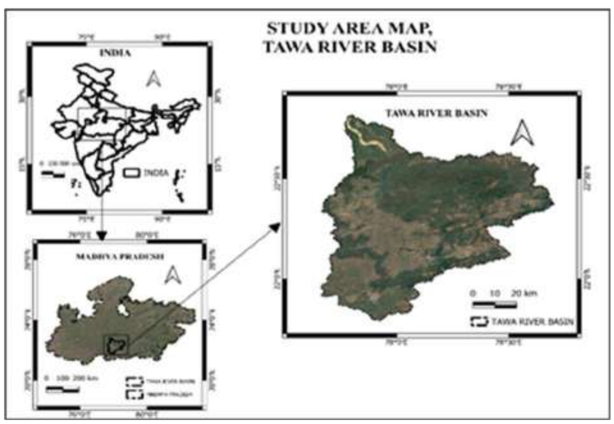

Fig.1 *Study Area map of Tawa basin*

Drainage:

The Tawa River, a tributary of the Narmada River, exhibits a dendritic drainage pattern.

Reason: The river and its tributaries form a tree-like branch pattern, parallel the veins of a leaf. This pattern is common in regions that have homogeneous rock structure, where water channels develop without structural control. the Tawa River flows through the Satpura Range in Madhya Pradesh, where the terrain allows for this natural branching.

Geomorphology:

Geomorphologically, it exhibits a dendritic drainage pattern, influenced by the region's structural and lithological characteristics. The upper course of the Tawa River is characterized by steep slopes, rugged terrain, and deep valleys, formed due to erosion in the Satpura hills. When it moves downstream, river flow through oscillate plateaus and alluvial plains, where sediment deposition becomes remarkable. The middle course is marked by tributary confluences and the Tawa Dam, which may change in the river’s flow and sediment transportation. In the lower course, the river enters the Narmada valley, where its geomorphology transitions into a broader floodplain with meandering patterns before joining the Narmada River.

Overall, the Tawa River’s geomorphology reflects a combination of fluvial erosion, sediment transport, and deposition, shaped by the Satpura range's landscape.

Hydrogeology:

The river exhibits a monsoonal flow pattern, with high discharge during the rainy season (June–September) and significantly reduced flow in the dry season. The dam helps regulate water supply throughout the year. The Tawa basin supports groundwater recharge, sustaining wells and borewells in nearby villages. The alluvial and basaltic formations in the region influence the groundwater flow and storage capacity. 80% of the annual rainfall acquired from monsoonal rainfall, the river supports rich biodiversity, including aquatic life, migratory birds, and dense forests around the reservoirs. The Tawa Dam, constructed on the river in 1978 near Ranipur, is a significant hydrological structure. It forms the Tawa Reservoir, which serves multiple purposes, including irrigation, flood control, hydroelectric power generation, and drinking water supply. This reservoir spans approximately 27,000 hectares and supports agricultural activities in the surrounding districts.

Geology and Structure:

Geologically, the whole Tawa catchment area comprises different lithological formations in which basalt, Vindhyan sandstones, recent alluvium deposits and some patches of Banded Gneisses Complex (BGC) range 80% of the annual rainfall acquired from monsoonal rainfall in age from Archean to Quaternary are exposed in the area.

The banks of the Tawa River are covered by recent alluvium deposits of red, yellow, brown, and grayish clays intercalated with beds of sand, gravel, and pebbles that occasionally contain iron rust fragments

Parameter	**Formula**	**Reference**

Stream Order (SO)	Based on Strahler's method: stream segments are assigned orders.	Strahler (1957), "Quantitative analysis of watershed geomorphology"
Stream Number (N)	N=∑NiN = \sum N_i (where NiN_i is the number of streams at each order)	Strahler (1957), "Quantitative analysis of watershed geomorphology"
Stream Length (SL)	Length of the stream	Horton (1932), "Drainage basin characteristics"
Mean Stream Length Ratio (MSLR)	Lsm = Lu/Nu Stream Length Ratio (RL) Where, Lsm = Mean Stream Length Lu = Total stream length of order 'u'	Schumm (1956), "Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey"
Stream Frequency (SF)	Fs=Mu/A Where Fs=Stream Frequency Nu=Total no. of streams of all orders A= Area of the Basin (km^2)	Horton (1932), "Drainage basin characteristics"
Mean Bifurcation Ratio (MBR)	bm = Average of bifurcation ratios of all order	Strahler (1957), "Quantitative analysis of watershed geomorphology"
Basin Area (BA)	BA=Total area of the watershed BA = {Total area of the watershed}	O'Callaghan & Mark (1984), "The extraction of drainage networks from digital elevation models"
Basin Perimeter (BP)	BP=Total perimeter of the watershed BP = {Total perimeter of the watershed}	O'Callaghan & Mark (1984), "The extraction of drainage networks from digital elevation models"
Circulatory Ratio (CR)	$Re=4*Pi*A/p^2$ Where, Re=Circulatory Ratio Pi='Pi ' value i.e. 3.14 A=Area of the Basin (km^2) P = Perimeter (km)	Miller (1953), "Spatial Analysis in Geomorphology"
Elongation Ratio (ER)	Re=2v (A/Pi/Lb) Where, Re=Elongation Ratio A=Area of the Basin (km^2) Pi='Pi ' value i.e. 3.14 Lb=Basin length	Schumm (1956), "Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey"

Drainage Density (DD)	D-Lu/A Where, D=Drainage Density Lu=Total stream length of all orders **Relief (**A= Area of the Basin (km^2)	Horton (1932), "Drainage basin characteristics"
Relief (R)	Highest Elevation – Lowest Elevation	Goudie & Viles (2017), "The Geomorphology of Desert Environments
Relief Ratio (RR)	Rh = H/Lb Where, Rh=Relief Ratio H=Total relief (Relative relief) of the basin in Kilometer Lb= Basin length	Horton (1932), "Drainage basin characteristics"

Table.1 Morphometric parameters, their formula and references

3. METHODOLOGY

Morphometric analysis:

This paper is organized around a method of involved morphometric analysis. Morphometric analysis of catchment is important and used for developing the regional-scale hydrological models for solving various hydrological problems such as drought, food, and soil erosion. The various parameters that deteriorate the watershed have been worked out from the respective Tawa watershed by using the "Remote Sensing and GIS" approach by using Processing Saga NextGen Provider plugin in QGIS.

The research utilizes the watershed boundary and drainage lines that are automatically extracted from DEM using Saga NextGen Provider plugin in QGIS.

RESULT AND DISCUSSION

Morphometric characteristics have been calculated for the entire river basin under the following three headings:

- *Linear Aspects*
- *Areal Aspects (2-D)*
- *Relief Aspects (3-D)*

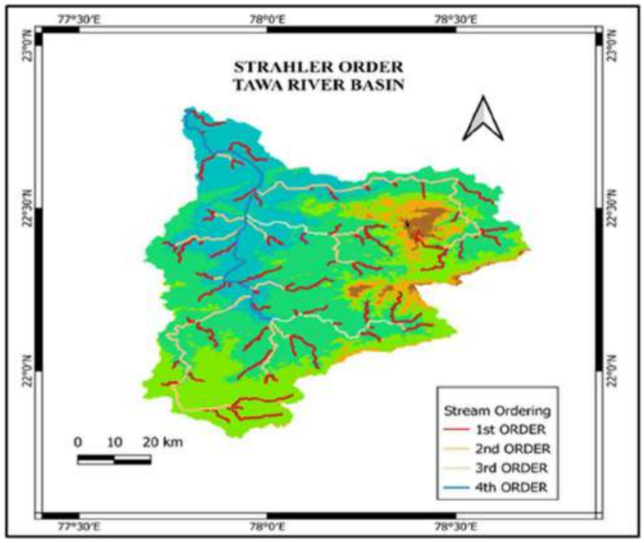

Fig.2 *Strahler order of Tawa River basin*

Linear Aspects

Strahler Stream Order:

Strahler's system, which is a slightly modified version of Horton's system, has been followed here because of its simplicity. The smallest, unbranched fingertip streams are designated as 1st order; the confluence of two 1st order channels gives a channel segment of 2nd order; two 2nd order streams join to form a segment of 3rd order, and so on. When two channels of the same smaller order join, then the next higher order is maintained (Wiejaczka, 2019). The trunk stream is the stream segment of highest order. Based on the method proposed by Strahler (1952). In Tawa Basin, 1st order has 58 streams, 2nd order has 11 streams, 3rd order has 2 streams, and 4th order have 1 stream.

Stream Order	Number of Streams	Total Length (km)
1st Order	58	595
2nd Order	11	336
3rd Order	2	78
4th Order	1	112

Table.2 Stream order, number & length

Stream Number:

Stream Number is the total number of stream segments at each order. In Tawa Basin, 1st order has 58 streams, 2nd order has 11 streams, 3rd order has 2 streams with and 4th order has 1 stream. The total number of streams is 72 in this basin.

Stream Length:

Stream length refers to the total distance a stream or river travels from its source to its mouth. It is usually measured along the centerline of the stream, following its natural course. You can measure stream length using several methods, depending on the tools available. Stream length is an important hydrological parameter used in geomorphology and watershed analysis, influencing factors such as water flow, sediment transport, and drainage basin characteristics. The Stream length of the Tawa watershed is 176.275 km, which makes it the third largest river basin in the region.

Mean stream length:

Mean stream length is the average length of all the stream segments of a particular order within a watershed or basin. The mean stream length is approximately **15.58 km,** and the mean stream length of each stream order is in the following table:

Stream Order	Total Number of Streams	Total Length (km)	Mean Stream Length (km)
1st Order	58	595	10.26
2nd Order	11	336	30.55
3rd Order	2	78	39.00
4th Order	1	112	112.00

Table 3. Mean Stream Length

Stream Length Ratio:

The stream length ratio (Rl) is a dimensionless parameter in geomorphology and hydrology that helps analyze the characteristics of a river basin. It is the ratio of the mean length of a given stream order to the mean length of the next lower order. The stream length ratio of the study area is 2.44. Rl between 1.5 and 2.5, suggesting a mature stage of basin evolution & influence of geological and structural controls.

Stream Frequency (Fs):

The number of streams per unit area is expressed as stream frequency (Fs). The Fs of the whole basin is 0.011. It mainly depends on the lithology of the basin and reflects the texture of the drainage network.

Mean Bifurcation Ratio:

The term 'mean bifurcation ratio (Rbm) was introduced by Horton (1932) to express the ratio of the number of streams of a given order to the number of streams of the next higher order. It is an important parameter in geomorphology and hydrology, indicating the drainage pattern and structural control of a river basin. According to Nag (1998), a lower bifurcation ratio (Rb) suggests a partially disturbed watershed with an intact drainage pattern. A higher Rb value indicates significant overland flow, leading to increased soil erosion and reduced groundwater recharge in the sub-watershed. When Rb falls between 3 and 5, it signifies that the drainage system is shaped by a combination of structural controls and natural erosion process ratio. In this study, the value of the bifurcation ratio of 4.256 suggests that the river basin is moderately affected by geological structures, has a well-developed drainage system, and could experience moderate to high flood risks.

Areal Aspects

Basin Area and Perimeter:

Basin area: refers to the total area of a basin where water drains into a particular stream or river.

Basin perimeter: it is the total length of the boundary line of the basin. The basin area of the Tawa River is 6477 km^2. Perimeter is 739.78 km.

Circulatory Ratio:

The Circulatory Ratio (Rc) is a dimensionless parameter used in geomorphology and hydrology to describe the shape of a drainage basin and its tendency to flood. A circulatory ratio close to 1 would mean the basin is nearly circular, indicating a compact shape. In the present case, the circulatory ratio for the watershed is 0.148, suggesting the basin is much longer than it is wide, resembling a stretched or narrow shape.

Elongation Ratio:

The Elongation Ratio (Re) is a simple way to measure the shape of a drainage basin, like a river's catchment area. Imagine you have a circle that covers the same area as the basin. The elongation ratio compares the width of that circle to the longest length of the basin. A higher ratio means the basin is more circular, while a lower ratio means it's more elongated. It's a handy tool in geography and water studies to understand the shape and behavior of drainage areas. Generally, the value of the elongation ratio (Re) varies from 0.6 to 1.0 associated with a wide variety of climates and geologies. The (Re) of the watershed is 1.45, which shows a circular basin and efficient hydrological response.

Drainage Density:

Drainage density (D) refers to the proximity of stream channels within a given area, calculated as the total length of all stream segments divided by the unit area. It is influenced by many factors that determine the typical length of streams, such as the resistance of materials to weathering, the permeability of rock formations, climatic conditions, and vegetation cover. A drainage density of 0.175 km/km^2 in the Tawa watershed is considered incredibly low, showing that the streams are widely spaced within the basin. This suggests minimal surface runoff, effective groundwater recharge, and a reduced risk of flooding.

Relief Aspects

Relief: *It is the difference between the heights of two points, which are generally the highest and the lowest points of the landscape. The relief of this is approximately 945 meters.*

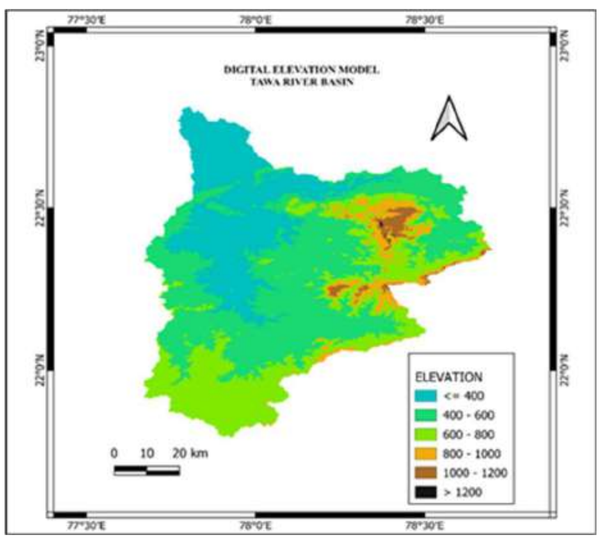

Fig.3: *Digital Elevation Model of river basin*

Relief Ratio:

The total relief of a sub-watershed is simply the difference in elevation between the highest and lowest points on its valley floor. It tells you how much the land rises or falls within that area. The Relief Ratio (Rh) is a way to measure how steep or gentle the basin is. It's calculated by dividing the maximum relief (the elevation difference) by the horizontal distance along the longest part of the basin, measured parallel to the main river or drainage line. A high Relief Ratio means the basin is relatively steep, with a sharp drop in elevation over a short distance and a low Relief Ratio means the basin is more gradual, with a gentle slope over a longer distance, In the present study, Rh is 0.0095.

5. CONCLUSION

The Tawa watershed has a well-developed but balanced drainage system, shaped by both natural erosion and the underlying geological structures. Its bifurcation ratio of 4.256 reflects this balance. Spanning 176.275 km in stream length, Makes it the largest tributary of Narmada river. The watershed's stream length ratio of 2.44 suggests it has reached a mature stage of development. With a low drainage density of 0.175 km/km² and a stream frequency of just 0.011, surface runoff is minimal, meaning most of the water seeps into the ground, contributing to efficient groundwater recharge. The watershed has a slightly elongated yet circular shape, as indicated by an elongation ratio of 1.45 and a circulatory ratio of 0.148. This shape influences flood risks, but the overall gentle slope (relief ratio: 0.0095) reduces the chances of sudden, intense flooding. The Tawa watershed is a stable system with moderate flood risk, good groundwater replenishment, and clear structural influences that have shaped its evolution over time. This Research paper will help to give a mutual understanding about the morphometry of the area and carve out the problems like water scarcity, land degradation, and etc faced by the locals nearby basin area and find suitable solutions for them.

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