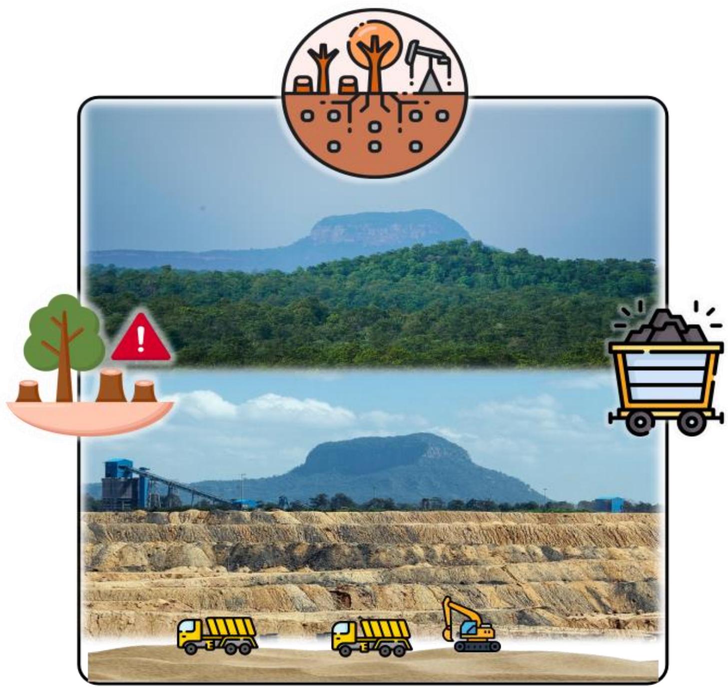
National River Conservation Directorate
Ministry of Jal Shakti,
Department of Water Resources,
River Development & Ganga Rejuvenation
Government of India

Geological Profile

Mahanadi River Basin



March 2025

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National River Conservation Directorate (NRCD)

The National River Conservation Directorate, functioning under the Department of Water Resources, River Development & Ganga Rejuvenation, and Ministry of Jal Shakti providing financial assistance to the State Government for conservation of rivers under the Centrally Sponsored Schemes of 'National River Conservation Plan (NRCP)'. National River Conservation Plan to the State Governments/ local bodies to set up infrastructure for pollution abatement of rivers in identified polluted river stretches based on proposals received from the State Governments/ local bodies.

www.nrcd.nic.in

Centres for Mahanadi River Basin Management Studies (cMahanadi)

The Centres for Mahanadi River Basin Management Studies (cMahanadi) is a Brain Trust dedicated to River Science and River Basin Management. Established in 2024 by NIT Raipur and NIT Rourkela, under the supervision of cGanga at IIT Kanpur, the centre serves as a knowledge wing of the National River Conservation Directorate (NRCD). cMahanadi is committed to restoring and conserving the Mahanadi River and its resources through the collation of information and knowledge, research and development, planning, monitoring, education, advocacy, and stakeholder engagement.

www.cmahanadi.org

Centre for Ganga River Basin Management and Studies (cGanga)

cGanga is a think tank formed under the aegis of NMCG, and one of its stated objectives is to make India a world leader in river and water science. The Centre is headquartered at IIT Kanpur and has representation from most leading science and technological institutes of the country. cGanga's mandate is to serve as think-tank in implementation and dynamic evolution of Ganga River Basin Management Plan (GRBMP) prepared by the Consortium of 7 IITs. In addition to this, it is also responsible for introducing new technologies, innovations, and solutions into India.

www.cganga.org

Acknowledgment

This report is a comprehensive outcome of the project jointly executed by NIT Raipur (Lead Institute) and NIT Rourkela (Fellow Institute) under the supervision of cGanga at IIT Kanpur. It was submitted to the National River Conservation Directorate (NRCD) in 2024. We gratefully acknowledge the individuals who provided information and photographs for this report.

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Preface

In an era of unprecedented environmental change, understanding our rivers and their ecosystems has never been more critical. This report aims to provide a comprehensive overview of our rivers, highlighting their importance, current health, and the challenges they face. As we explore the various facets of river systems, we aim to equip readers with the knowledge necessary to appreciate and protect these vital waterways.

Throughout the following pages, you will find an in-depth analysis of the principles and practices that support healthy river ecosystems. Our team of experts has meticulously compiled data, case studies, and testimonials to illustrate the significant impact of rivers on both natural environments and human communities. By sharing these insights, we hope to inspire and empower our readers to engage in river conservation efforts.

This report is not merely a collection of statistics and theories; it is a call to action. We urge all stakeholders to recognize the value of our rivers and to take proactive steps to ensure their preservation. Whether you are an environmental professional, a policy maker, or simply someone who cares about our planet, this guide is designed to support you in your efforts to protect our rivers.

We extend our heartfelt gratitude to the numerous contributors who have generously shared their stories and expertise. Their invaluable input has enriched this report, making it a beacon of knowledge and a practical resource for all who read it. It is our hope that this report will serve as a catalyst for positive environmental action, fostering a culture of stewardship that benefits both current and future generations.

As you delve into this overview of our rivers, we invite you to embrace the opportunities and challenges that lie ahead. Together, we can ensure that our rivers continue to thrive and sustain life for generations to come.

Centre for Mahanadi River Basin
Management and Studies (cMahanadi)
NIT Raipur & NIT Rourkela

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Abbreviations and Acronyms

cMahanadi	Centre for Mahanadi River Basin Management and Studies
MRB	Mahanadi River Basin
GIS	Geographic Information System
NIT	National Institute of Technology
IIT	Indian Institute of Technology
GSI	Geological Survey of India
DGH	Directorate General of Hydrocarbons
CSPCB	Chhattisgarh State Pollution Control Board
OSDMA	Odisha State Disaster Management Authority
MCL	Mahanadi Coalfields Limited
OSPCB	Odisha State Pollution Control Board
CGWB	Central Ground Water Board

1. Introduction

The Mahanadi River Basin, a vital geographical and hydrological entity on India's eastern coast, originates in the highlands of Chhattisgarh and traverses eastward, culminating in its confluence with the Bay of Bengal in Odisha. This expansive basin encompasses major parts of Chhattisgarh, Odisha, and a minor part of Jharkhand, Maharashtra, and Madhya Pradesh, supporting diverse ecosystems and a substantial population through its agricultural, industrial, and ecological contributions.

The basin holds great geographical and economic importance as it supports millions of people through agriculture, industry, and fisheries. Known for its rich alluvial soil and abundant water resources, the Mahanadi basin plays a vital role in irrigation and hydroelectric power generation, with major projects like the Hirakud Dam harnessing its potential. Additionally, the river and its tributaries contribute significantly to the ecological balance of the region, supporting diverse flora and fauna.

Geologically, the basin's formation is deeply rooted in the ancient breakup of Gondwanaland, with its foundational structure largely composed of Precambrian rocks like granites, gneisses, and khondalites, particularly prevalent in the western regions forming part of the Eastern Ghats. Sedimentary formations from the Gondwana period, including the Athgarh Sandstone, also characterize the basin's geological history, indicating past fluvial and terrestrial environments. The coastal region, especially the Mahanadi Delta, is characterized by alluvial deposits, while the offshore geology exhibits distinct differences from the onshore formations.

Its varied soil composition, including red and yellow, mixed red and black, laterite, and deltaic soils, supports a range of agricultural practices. The river system, with its major tributaries like the Seonath, Hasdeo, and Tel, divides the basin into the Upper, Middle, and Lower sub-basins. The Eastern Ghats significantly influence the basin's topography and hydrology, affecting the river's flow and sediment transport. Thus, the Mahanadi River Basin is a product of complex geological processes spanning millions of years, resulting in a diverse landscape with a rich geological heritage

1.1 Background of the Mahanadi River Basin

Chhattisgarh's diverse geological formations—igneous, sedimentary, and metamorphic—host a rich array of minerals, ranging from substantial economic deposits to localized occurrences. Notably, the state possesses significant reserves of coal, iron ore, limestone, dolomite, and bauxite. Furthermore, the Raipur district's diamondiferous kimberlites hold promise for substantial diamond yields, and moderate tin (cassiterite) deposits are found in pegmatites. Beyond these major resources, medium to small deposits of gold, base metals, quartzite, soapstone/steatite, fluorite, corundum, graphite, lepidolite, and amblygonite exist, with potential for expansion into larger deposits through further exploration. Additionally, occurrences of garnet, amethyst, beryl, andalusite, kyanite, sillimanite, and the rare alexandrite are documented across the state, some of which may prove to be commercially viable. Finally, Chhattisgarh boasts widespread deposits of dimension stones and decorative granites, including grey, pink, red, and black varieties (dolerite, amphibolite, and gabbro), as well as flagstones in grey, black, and purple hues. Crucially, mining these resources is a cornerstone of Chhattisgarh's economy, generating substantial revenue and employment opportunities. The extraction and processing of minerals like coal and iron ore contribute significantly to the state's GDP, fueling industrial growth and infrastructure development. The benefits extend to local communities through job creation and the establishment of ancillary industries, making mining a vital driver of economic prosperity in the region.

Originating in Chhattisgarh, the river enters Odisha and traverses through a region marked by diverse geological formations that date back to the Precambrian era. Odisha's portion of the basin includes ancient crystalline rocks such as granites and gneisses of the Eastern Ghats Mobile Belt, as well as sedimentary formations of the Gondwana period in central parts of the state. The deltaic region near the Bay of Bengal, where the Mahanadi empties, is composed primarily of Quaternary alluvium, which supports fertile soils and dense human habitation. This geological diversity influences the basin's soil types, mineral wealth, and groundwater potential, while also shaping forest distribution and land use patterns across the state. The varied terrain — from upland plateaus to low-lying coastal plains — contributes to the rich biodiversity and complex hydrological dynamics of the Mahanadi basin in Odisha.

1.2 Scope and Objective

This report provides a comprehensive analysis of the Mahanadi River Basin, focusing on its geological characteristics and the environmental impacts of both natural and human activities. The report will examine the effects of deforestation, as evidenced by the distribution of forest cover, fracking zones, sand mining, hill slope changes, and the impacts of excavation, exploration, and mining operations on the basin's ecological integrity. To compile this information, data has been collected from various governmental departments, published articles, and relevant research papers.

By synthesizing geological data with information on these activities, the report seeks to foster general awareness among the public and equip various stakeholders working within the Mahanadi Basin with essential knowledge for sustainable development. This compilation of information will enable informed decision-making, promote responsible resource management, and facilitate the implementation of strategies to mitigate the adverse effects of human interventions on the basin's delicate ecological balance.

1.3 Data Source

Table 1: Datasets Used

S. No	Data	Data Source
1	Mining Activity	Mineral and Mines Department report, Research Papers and Articles.
2	Tunneling Activities	Project Proposal and News Article
3	Fracking Zones	Directorate General of Hydrocarbon reports
4	Deforestation	Commissioner of Land Records report and Research paper
5	River Bed Mining	Chhattisgarh state pollution control board [EIA reports], news articles and google earth images
6	Natural Geological Hazards	Chhattisgarh State Disaster Management Authority report, Research paper

2. Potential Anthropogenic Impacts on Geological Identity

Human activities like extensive tunneling, fracking, deforestation, river bed mining, and hill slope modifications are significantly altering the Earth's geological identity. Tunneling and fracking create subsurface fractures and changes in rock structure, potentially leading to geological instability. Deforestation accelerates soil erosion and alters water flow, impacting sediment deposition. River bed mining disrupts natural fluvial processes, changing river morphology and sediment transport. Hill slope modifications, through construction or mining, increase the risk of landslides and alter local geomorphology. These combined actions leave lasting, often detrimental, imprints on geological formations and processes, contributing to a distinct anthropogenic layer in the Earth's geological record. These changes are so significant that they may define a new geological epoch—the Anthropocene. The various impacts are explained in greater detail below -

- **Transformation of Landforms**

Urbanization & Infrastructure Development like Large-scale excavation, tunneling, and construction reshape natural landscapes. Mining & Extracting minerals and fossil fuels alters topography and can cause land subsidence. Removal of vegetation accelerates soil erosion and disrupts natural sediment flows.

- **Climate Change & Atmospheric Alterations**

Rising global temperatures due to Greenhouse gases emissions accelerate glacial melt, sea-level rise, and desertification, altering Earth's surface. Industrial emissions lead to acid precipitation, which erodes rocks and changes soil and water chemistry. Extreme Weather Events like More frequent storms, floods, and droughts modify landscapes and sediment deposition patterns.

- **Sedimentation & Soil Degradation**

Increased erosion leads to excessive sediment accumulation in rivers, lakes, and coastal areas. Dams & Reservoirs trap sediments, disrupting natural sediment transport and reshaping aquatic ecosystems.

- **Seismic & Geological Instability**

Overuse of underground water sources leads to land subsidence and an increased risk of sinkholes. High-pressure fluid injection for fossil fuel extraction induces seismic activity, causing human-triggered earthquakes.

- **Pollution & Chemical Alterations**

Plastic debris is now embedded in sediment layers, forming a new geological marker. Nuclear activities leave long-lasting isotopic signatures in rock formations. Heavy metals and chemical pollutants alter soil composition and groundwater quality.

Human influence on Earth's geology is undeniable and will leave lasting evidence in the planet's rock record for millions of years. As we continue to alter landscapes and ecosystems, the challenge lies in finding sustainable ways to balance development with environmental preservation.

2.1 Excavations, Explosions and Mining Activities

The Mahanadi River Basin, spanning across Chhattisgarh and Odisha, has been an important region for archaeological excavations, revealing significant insights into ancient civilizations, trade routes, and cultural developments. Various excavations in this basin have unearthed artifacts, structures, and settlements dating back to different historical periods, particularly the Chalcolithic, Early Historic, and Medieval eras.

Major Excavation Sites in the Mahanadi River Basin

Figure 1: Archaeological excavation at Sirpur along the banks of the Mahanadi River

[Source: https://visittotravel.com/sirpur/]

- Sirpur (Mahasamund, CG)

Time Period: 5th to 12th century CE

Findings: Sirpur was a prominent religious and urban center loacted in the banks of Mahanadi, known for its Buddhist viharas, Hindu temples, and Jain structures. Excavations have uncovered over 100 archaeological monuments, inscriptions, and terracotta artifacts, highlighting its cultural and architectural richness.

- Sisupalgarh (Bhubaneswar, Odisha)

Time Period: 3rd century BCE to 4th century CE

Findings: Considered one of India's oldest urban settlements, Sisupalgarh was a fortified city during the Mauryan and post-Mauryan periods. Excavations here have revealed massive stone walls, moat systems, pottery, terracotta figurines, and evidence of an advanced drainage system.

Figure 2: Palaeolithic sites in the lower Mahandi Valley

[Source: https://www.telegraphindia.com/my-kolkata/places/the-ruins-of-sisupalgarh-in-odisha-reveal-an-ancient-pre-mauryan-smart-city/cid/1852981]

- Talagada (Cuttack, Odisha)

Time Period: Chalcolithic to Early Historic

Findings: Excavations in Talagada have unearthed a human skeleton reportedly dating back to the iron age,along with an axe and other artifacts. The findings suggest a settled lifestyle,with evidence of agriculture,animal domestication and fishing.

- Asurgarh (Kalahandi, Odisha)

Time Period: 3rd century BCE to 4th century CE

Findings: Asurgarh was an important fortified settlement with evidence of trade and urban planning. Discoveries include iron tools, beads, ceramics, and coins, indicating extensive trade connections with other regions of India and beyond.

Figure 3: Archaeological excavation in Asurgarh Mahanadi River Basin

[Source: https://www.thehindu.com/news/national/other-states/carbon-dating-finds-asurgarh-is-odishas-oldest-fortified-settlement/article65351205.ece]

- Kharligarh (Bolangir, Odisha)

Time Period: Early Historic Period
Findings: The site has yielded evidence of various types of pottery,Semi-precious stone beads,clay beads,Circular huts with post holes,charred animal bones,etc.

- Malhar (Bilaspur District)

Time Period: Around 1000 BCE to the 12th century CE
Findings: Malhar is an ancient settlement with continuous occupation. The site reveals temples, copper tools, coins, and intricate sculptures, indicating its significance as a religious and trade hub in early Chhattisgarh.

- Budhigarh (Chhattisgarh)

Time Period: 1st millennium BCE to early centuries CE
Findings: Excavations at Budhigarh have uncovered stone tools, megalithic structures, and burial sites, indicating early human habitation and burial customs in the region.

Significance of Excavations in the Mahanadi Basin

- **Urban Development:** Discoveries at Sisupalgarh and Asurgarh indicate well-planned settlements with fortifications, suggesting organized governance and trade networks.
- **Cultural Exchanges:** The presence of coins, pottery, and beads from distant regions suggests active trade along the Mahanadi River.
- **Technological Advancements:** Findings such as iron tools and sophisticated drainage systems indicate technological progress in early civilizations.

- **Religious and Artistic Expressions:** The presence of terracotta figurines, sculptures, and temple ruins points to religious and artistic advancements in the region.

The Mahanadi River Basin is rich in mineral resources, leading to extensive mining activities that significantly impact the region's environment and communities. Coal Mining, Unregulated Sand mining, Alluvial gold and diamond recovery are mainly done.

2.1.1 Mineralisation under Mahanadi River Basin (Based on GSI Data)

The Mahanadi River Basin (MRB) hosts a wide range of mineral commodities, reflecting its complex geological makeup. Based on data from the Geological Survey of India (GSI), the basin is mineralogically rich and supports both widespread and localized occurrences of metallic, non-metallic, and strategic minerals. These minerals are often found in association with specific lithological formations such as laterites, Gondwana sediments, schists, and crystalline rocks, making the basin a region of considerable industrial and economic interest. The Table 2 below categorizes the key mineral commodities recorded within the MRB:

Table 2: Key Mineral Commodities in the Mahanadi River Basin

Category	Mineral Commodities
Metallic Minerals	Iron, Copper, Lead, Gold, Columbite, Ilmenite, Molybdenite
Non-Metallic/Industrial	Bauxite, Kaoline, Limestone, Fire Clay, Graphite, Manganese, Limonite, Mica
Strategic/Precious	Diamond, Kimberlite

Several areas across the basin (as shown in Figure 4) exhibit concentrated occurrences of iron, bauxite, manganese, and limestone, which are already under various stages of extraction. Fire clay, graphite, and kaoline are industrially significant and support sectors like refractories, ceramics, and paint.

The presence of columbite, ilmenite, and molybdenite indicates potential for rare and specialty mineral exploitation, although commercial-scale operations for these are still limited. The reported occurrences of diamonds and kimberlite, suggesting the presence of deep-seated igneous activity and possible future exploration prospects in select areas.

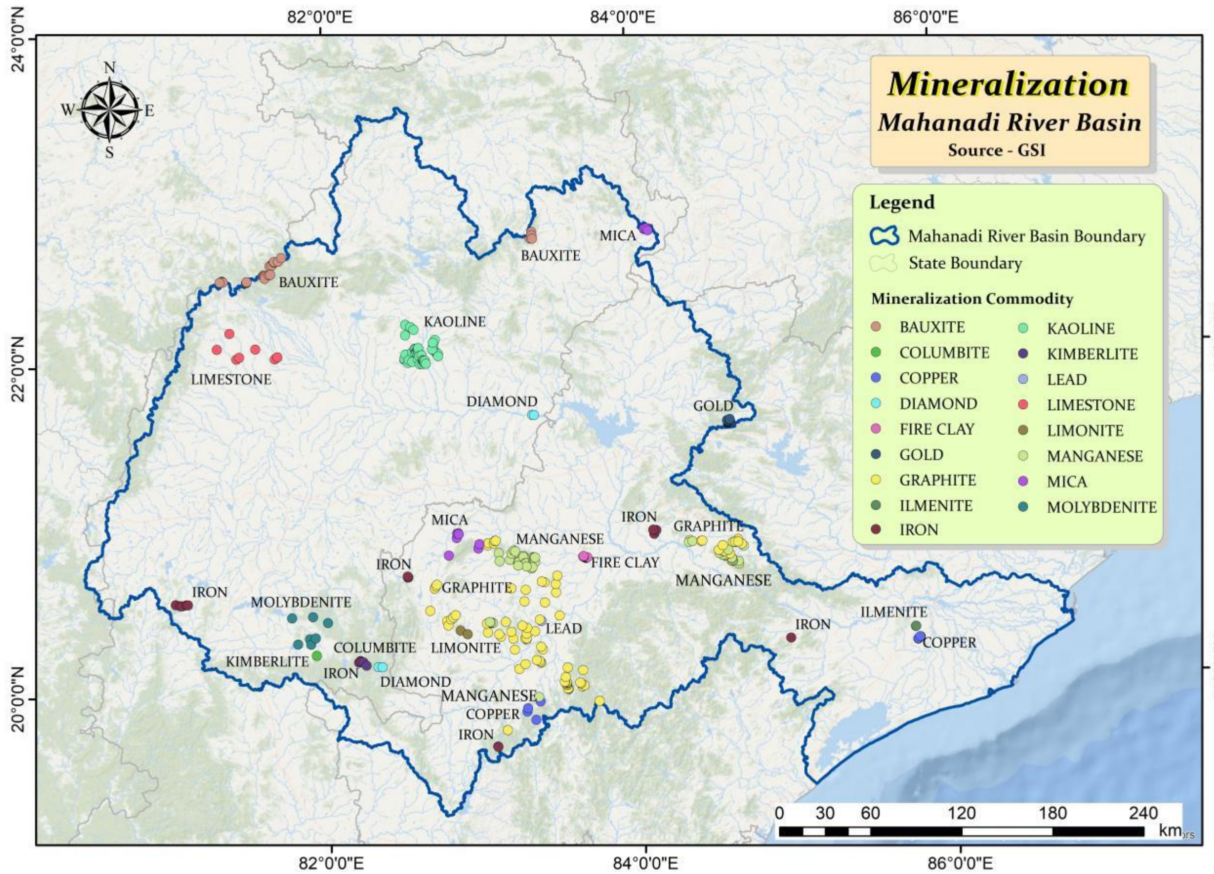


Figure 4: Mineral Resources in the Mahanadi River Basin *(Source: GSI)*

2.1.2 Mining Activities

The Mahanadi River Basin, located primarily in the state of Chhattisgarh and Odisha, India, is known for its rich mineral resources. The mining activities in this region are diverse and have a significant impact on the local economy and environment. The types of mining in the Mahanadi River Basin generally include:

1. **Coal Mining**

The Mahanadi River Basin is rich in coal, with significant coalfields like Ib Valley, Talcher and Mand-Raigarh coalfield.

Table 3: Details of State-wise and category-wise coal resources in Mahanadi River Basin (Billion tonnes)

State	**Measured**	**Indicated**	**Inferred**	**Total Resource**
Odisha	52.05	37.54	4.94	94.52
Chhattisgarh	37.24	42.29	1.24	80.77

Source - https://coal.gov.in/en/major-statistics/coal-reserves

Coal Production in Chhattisgarh
Located across the districts of Korba, Raigarh, and Surguja in Chhattisgarh, this region plays a crucial role in India's coal mining sector. Chhattisgarh ranks among the top two coal-producing states in the country, alongside Jharkhand. It contributes approximately 20% of India’s total coal production, making it the second-largest coal producer nationwide. The major coalfields in Hasdeo-Arand, Korba, and Raigarh significantly bolster the state's output, underlining the strategic importance of this mineral-rich region.

➢ **Hasdeo-Arand Coalfields**:
Located in the Korba district, Hasdeo-Arand is one of the largest coalfields in India. It is a major producer of high-grade coal and plays a central role in the state’s coal industry.

➢ **Korba Coalfields**:
Korba is another prominent coal-producing region in Chhattisgarh. It is home to many operational coal mines, which supply coal to thermal power plants across India.

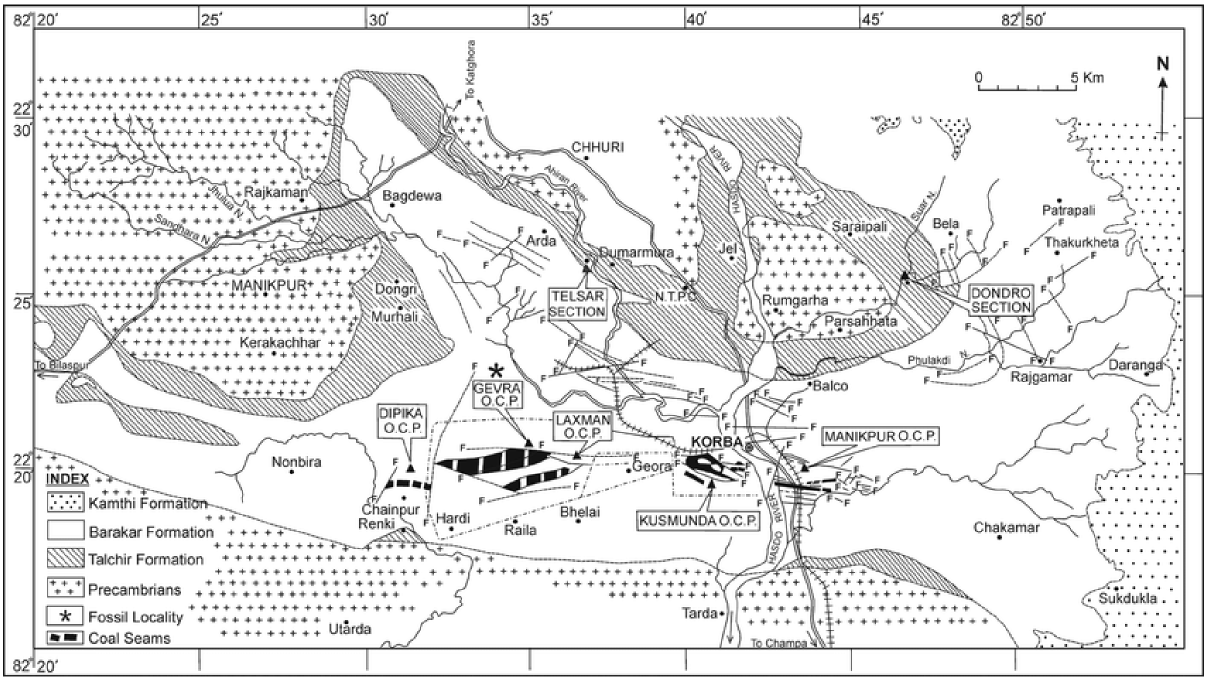


Figure 5: Geological map of Korba Coalfield, Chhattisgarh, showing different collieries (Raja Rao, 1983).

➢ **Raigarh Coalfields**:
Raigarh contributes significantly to the state’s coal output, with mines that produce high-quality coal suitable for power generation.

Figure 6 : Mining operations in Gevra Open Cast Mines, Korba (CG)

[Source: https://pib.gov.in/PressReleaseIframePage.aspx?PRID=2034007]

Coal Production in Odisha

Located in districts such as Angul, Jharsuguda, Sundargarh, and Sambalpur. The state ranks among the top three coal-producing states in the country, following Jharkhand and Chhattisgarh. Odisha contributes around 15% of India's total coal production, making it the third-largest coal producer nationwide. Major coalfields like Talcher and Ib Valley are central to the state's coal output, playing a vital role in meeting the nation's energy and industrial demands.

➢ **Talcher Coalfield:**

According to GSI, the Talcher Coalfield has reserves of 38.65 billion tonnes, the highest in India. Talcher Coalfield covers an area of 500 km². The coal is of lower grade containing only about 35 per cent of fixed carbon, 70 per cent volatile matter and 25 per cent ash content.It is situated in the Brahmani River valley within the Mahanadi River basin in the Angul district, Odisha. Bharatpur, Ananta, Lingaraj,Jagannath, Kaniha, Bhubaneswari, Balaram opencast mines and Talcher,Hingula Underground Mine is located here.

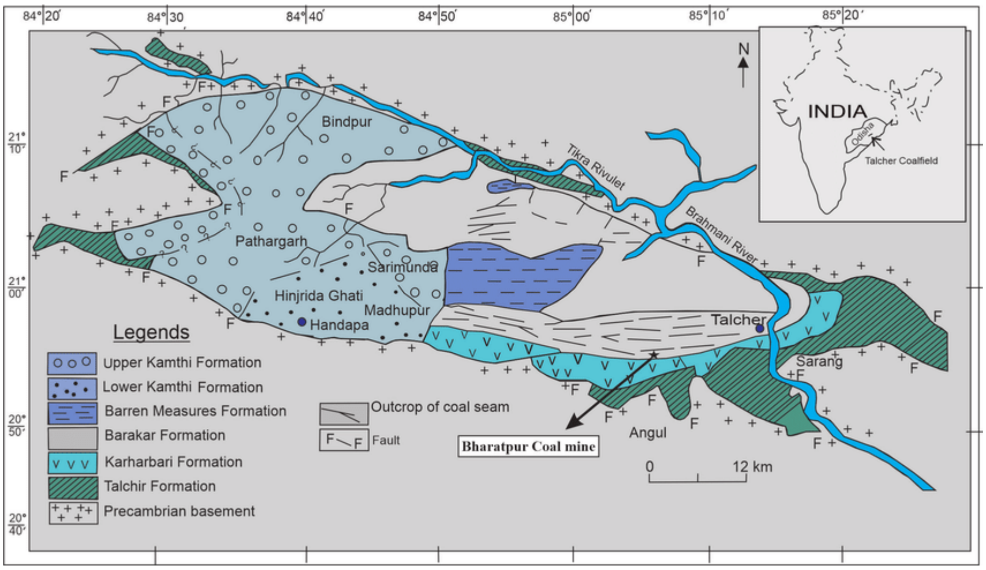


Figure 7: Geological map of the Talcher Coal Field, Mahanadi Basin (Mishra et al. 2021)

➢ Ib Valley Coalfield:

Ib Valley Coalfield lies between latitudes 21° 41′N and 22° 06′N and longitudes 83° 30′E and 84° 08′E.It covers an area of 1,375 square kilometres. According to Geological Survey of India, Ib Valley Coalfield has reserves of 22.3 billion tonnes, the third highest in India. It is located in the southeastern part of the Son-Mahanadi valley in the Jharsuguda and Sambalpur district of Odisha. It is a part of the Gondwana basin and is connected to the Talcher coalfield.

Mahanadi Coalfields Limited (MCL) operates open-cast mines here, including Lilari, Lajkura, Samleswari, Lakhanpur, Belpahar and Kulda opencast mines and Underground mines like Orient Colliery and Hingir Rampur Underground Mine. The area is characterized by Barakar and Karharbari formations, with Barakar being the main coal-bearing formation.

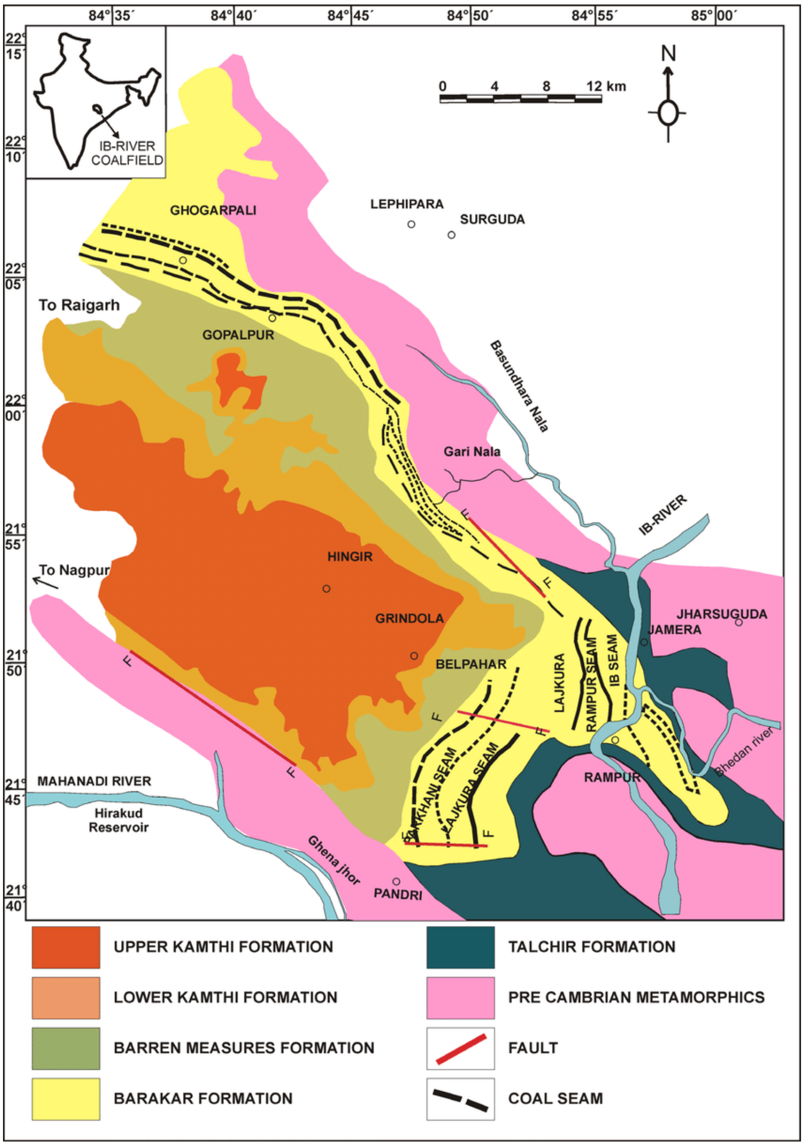


Figure 8: Geological map of the Ib valley coalfield area (Senapaty & Behera, 2015)

Uses of Coal:

- Thermal Power Generation**:** Most of the coal extracted in Chhattisgarh is used for power generation. The state is home to multiple coal-based thermal power plants such as Chhattisgarh State Power Generation Company Limited, which rely heavily on coal from local mines.
- Industrial Use**:** Coal is used in steel manufacturing and cement production. Chhattisgarh's coal reserves support industries like steel plants in Raigarh and cement companies such as Ambuja Cements and Ultratech.
- **Export**: A portion of the coal mined is also exported to other states and countries, contributing to the country's revenue from coal exports.

Figure 9: Balaram Open Cast Mine (Formerly known as Kalinga Open Cast Project) Located in Angul district, Odisha

Figure 10: Lakhanpur Open cast mine, Jharsuguda District, Odisha

Figure 11: Bhubaneswari Coal mine, Angul District, Odisha

Annual Revenue and Economic Contribution:

- **Revenue Generation**: Coal mining is a major revenue generator in Chhattisgarh, both directly through the sale of coal and indirectly through the industries it supports. In the year 2022-23, Odisha registered highest coal production of 218.981 MT (24.52%), followed by Chhattisgarh 184.895 MT (20.70%), Jharkhand 156.445 MT (17.52%) and Madhya Pradesh 146.028 MT (16.35%).
- **Economic Impact**: The coal industry provides thousands of jobs, stimulates infrastructure development, and plays a key role in the energy sector. The state government generates substantial revenue from coal royalties, taxes, and other related activities.

2. **Limestone Mining**

Limestone Mining in Chhattisgarh

Location**:** Raipur, Durg, Bilaspur, Korba districts, Chhattisgarh.

Production Ranking in India:

- Chhattisgarh is one of the top 5 limestone-producing states in India.
- Ranking**:** The state is a significant contributor to India's total limestone production, contributing approximately 9% of the country's limestone output. Chhattisgarh ranks among the top 5 states in terms of production and holds a vital position in the Indian cement industry due to its high-quality limestone deposits.

Major Limestone Mining Areas:

- **Raipur District**:
  - The Raipur region is known for its substantial limestone deposits, particularly around areas like Raipur city, which hosts large-scale limestone mining operations. The limestone from this region is of high quality, suitable for cement manufacturing.
- **Durg District**:
  - Durg has large limestone reserves, with mining activity focused on producing limestone for cement production. It is home to major cement plants like ACC Cements, Ambuja Cements and Ultratech Cement, which rely on limestone from this region.
- **Bilaspur District**:
  - The Bilaspur region also contributes significantly to the state's limestone production, with its high-quality limestone used for both industrial and agricultural purposes.
- **Korba District**:
  - Korba hosts a variety of limestone deposits, supporting both the cement industry and local construction activities.

Uses of Limestone:

- **Cement Production**: Limestone is the primary raw material for the cement industry, which is the most significant consumer of limestone in Chhattisgarh. The state's limestone reserves support the cement plants in Raipur, Durg, and **Korba**.
- **Construction Industry**: Limestone is also used in the construction industry for aggregates and as a raw material for producing lime for construction purposes.
- **Agriculture**: Ground limestone (also known as aglime) is used to neutralize acidic soils in agriculture and provide essential calcium and magnesium to crops.
- **Industrial Use**: Limestone is used as a flux in iron and steel manufacturing and other industrial processes that require high-purity limestone.

Annual Revenue and Economic Contribution:

- **Revenue Generation**: Limestone mining in Chhattisgarh contributes significantly to the state's economy, especially through the cement industry, which is one of the largest consumers of limestone. The state's limestone production supports major cement companies like Ambuja Cements, Ultratech Cement, and ACC.
- **Economic Impact**: Limestone mining plays a key role in employment generation in the state, especially in mining and transportation. Additionally, revenues from royalties and taxes contribute to the state's economic development.

3. **Iron Ore Mining**

Iron Ore Mining in Chhattisgarh

Location: Bastar, Durg, Raigarh, Surguja, Korba districts, Chhattisgarh.

Production Ranking in India:

- Chhattisgarh is one of the top 5 iron ore-producing states in India.
- Ranking: The state plays a pivotal role in India's iron ore production, contributing about 15-20% of India's total iron ore output. Chhattisgarh ranks among the top 5 states in India in terms of iron ore production, with Bastar, Durg, and Raigarh districts being significant contributors to this output.

Major Iron Ore Mining Areas:

- **Bastar Region**:
  - The Bastar district has large reserves of high-quality iron ore. This region is home to several large-scale mining operations, with rich deposits of hematite ore, which is used extensively in the steel-making process.
- **Durg District**:
  - The Durg district is another key iron ore-producing area in Chhattisgarh, with high-grade iron ore deposits that support both domestic and international markets.
- **Raigarh District**:

- Raigarh contributes significantly to the state's iron ore production. The iron ore from this region is used extensively in the steel industry, particularly by integrated steel plants and foundries.

Uses of Iron Ore:

- Steel Production**:** The primary use of iron ore is in the steel industry. Iron ore extracted from Chhattisgarh's mines is processed into sinter and pellets, which are then used in steelmaking furnaces (such as blast furnaces and electric arc furnaces) to produce steel.
- Foundries and Manufacturing: Chhattisgarh's iron ore supports foundries and other manufacturing units that produce cast iron products, machinery parts, and more.
- Export**:** A significant portion of the iron ore mined in Chhattisgarh is exported to countries like Japan, South Korea, and China, contributing to India's foreign exchange earnings.

Annual Revenue and Economic Contribution:

- **Revenue Generation**: Iron ore mining is a crucial contributor to Chhattisgarh's economy. The state generates significant revenue from royalties and taxes associated with iron ore production. In 2022, Chhattisgarh produced over 30 million tonnes of iron ore, making it one of the leading contributors to India's total production.
- **Economic Impact**: The mining of iron ore supports numerous industries in Chhattisgarh, including the steel industry, manufacturing, and construction. It also plays a key role in employment generation in the region, particularly in mining, transportation, and the steel sector.
- Major steel plants in the state, such as SAIL (Steel Authority of India Limited), JSW Steel, and Jindal Steel, rely heavily on local iron ore supplies.

4. **Bauxite Mining**

Bauxite Mining in Chhattisgarh

Location: Korba, Kabirdham (Kawardha), Surguja, Raigarh districts, Chhattisgarh.

Production Ranking in India:

- **Chhattisgarh** is one of the top 5 bauxite-producing states in India.
- **Ranking**: The state ranks among the top 5 bauxite-producing states in India, contributing a substantial portion to the country's total bauxite production. Chhattisgarh is a key player in the Indian bauxite industry, with significant reserves located in Korba, Kabirdham, and Surguja.
-

Major Bauxite Mining Areas:

- **Korba District**:
  - Korba is one of the most prominent regions for bauxite mining in Chhattisgarh. The district is home to large-scale bauxite deposits that are used in the aluminum industry.
- **Kabirdham (Kawardha) District**:

- Kabirdham has substantial bauxite reserves, and mining operations in this district contribute significantly to the state's production of bauxite. This region's bauxite is primarily used in aluminum production.

- **Surguja District**:
  - Surguja also has notable bauxite deposits, with mining activity supporting local industries, especially the aluminum sector. It contributes to both the domestic and export markets for bauxite.
- **Raigarh District**:
  - The Raigarh district is another important area for bauxite mining in Chhattisgarh, contributing to the extraction of this key mineral for aluminum production.

Uses of Bauxite:

- **Aluminum Production**: The primary use of bauxite is in the production of aluminum. Bauxite is refined to produce alumina, which is then processed to produce aluminum metal. This makes bauxite an essential raw material for the aluminum industry.
- **Refractories**: Bauxite is also used in the production of refractory materials (high-heat resistant materials) for industries like steel and cement.
- **Chemical Industry**: Bauxite is used in the production of chemicals, including aluminum sulfate, which has applications in water treatment and as a mordant in dyeing.
- **Glass Industry**: In some cases, bauxite is used as an ingredient in glass manufacturing, especially in the production of specialized glass products.

Annual Revenue and Economic Contribution:

- **Revenue Generation**: Bauxite mining in Chhattisgarh contributes significantly to the state's revenue, especially due to its use in the aluminum industry. Major aluminum smelters, such as the Hindalco Industries smelter in Korba, rely on locally mined bauxite for their production.
- **Economic Impact**: The bauxite mining sector plays a crucial role in employment generation, providing jobs not only in mining but also in the downstream industries such as aluminum production, refining, and transportation. The state earns considerable royalties and tax revenue from bauxite mining.

5. Dolomite Mining

Dolomite Mining in Chhattisgarh

Location: Janjgir-Champa, Bilaspur districts, Chhattisgarh.

Production Ranking in India:

- Chhattisgarh is one of the top 5 dolomite-producing states in India.

- Ranking: The dolomite mines in Janjgir-Champa and Bilaspur make Chhattisgarh one of the leading states in dolomite production, contributing significantly to India's total dolomite output.

Mining Method:

- Open-pit mining is predominantly used for dolomite extraction in Chhattisgarh, given the relatively shallow depth of the deposits.
- Dolomite is extracted for both industrial use and agriculture, with large quantities used in steel manufacturing, cement production, and as a flux in industrial processes.

Uses of Dolomite:

- Steel Industry: Dolomite is used as a flux in steel manufacturing to remove impurities like silica and phosphorus.
- Cement Industry**:** Dolomite is used as a raw material in the production of cement, where it provides calcium and magnesium components.
- Agriculture**:** Dolomite is used in soil conditioning to neutralize acidic soils and supply essential magnesium to plants.

Annual Revenue and Economic Contribution:

- **Revenue Generation**: The revenue from dolomite mining is significant, especially in regions like Raigarh and Korba, where dolomite extraction supports several industries, including cement production (e.g., Ambuja Cements, Ultratech Cement) and steel manufacturing.
- **Economic Impact**: The dolomite industry in Chhattisgarh generates millions of rupees annually, contributing to the state's industrial output, providing employment, and supporting local economies through the associated industries (cement, steel, and agriculture).

6. **Manganese Ore Mining**

Manganese Ore Mining in Chhattisgarh

Location: Bastar, Durg, Raigarh, Kabirdham (Kawardha) districts, Chhattisgarh.

Production Ranking in India:

- **Chhattisgarh** is one of the top manganese ore-producing states in India.
- **Ranking**: The state ranks among the top 5 manganese ore-producing states in India, contributing approximately 15% of India's total manganese ore production. Chhattisgarh's manganese ore is significant for the steel industry, which is a major consumer of this mineral.

Major Manganese Ore Mining Areas:

- **Bastar District**:
  - The Bastar district has substantial deposits of high-grade manganese ore, making it one of the primary regions for manganese mining in Chhattisgarh. The region's mining activities support local industries and steel plants across India.
- **Durg District**:
  - Durg is another key area for manganese mining in Chhattisgarh. The district hosts various mining operations that contribute to the state's production, supplying manganese ore for both domestic and international markets.
- **Raigarh District**:
  - Raigarh has smaller but notable manganese ore deposits that contribute to the state's manganese production. This region supports industries that process manganese for the production of ferroalloys and steel.
- **Kabirdham (Kawardha) District**:
  - The Kabirdham region also has significant manganese ore reserves, with mining activities supporting the growing steel sector and related industries.

Mining Method:

- **Open-pit mining** is predominantly used for manganese ore extraction in Chhattisgarh. Manganese deposits are often found close to the surface, making them suitable for surface mining methods.
- **Mechanized mining** techniques such as drilling, blasting, and crushing are commonly employed to extract and process the ore, ensuring that the manganese ore meets the required grade for industrial use.

Uses of Manganese Ore:

- **Steel Production**: The primary use of manganese ore is in the steel industry, where it is used as a deoxidizer and an alloying agent in the production of ferromanganese and silicomanganese. These alloys are essential for producing high-strength steel.
- **Ferroalloy Production**: Manganese is crucial for producing ferroalloys, which are used in the manufacture of stainless steel and other specialized steel products.
- **Battery Industry**: Manganese is used in the production of batteries, especially in lithium-ion batteries that are used in electric vehicles and electronic devices.
- **Chemical Industry**: Manganese compounds are used in various chemical industries, including as manganese sulfate in fertilizers and as potassium permanganate in water treatment and disinfectants.

Annual Revenue and Economic Contribution:

- **Revenue Generation**: Manganese ore mining contributes significantly to the state's economy, especially due to its importance in the steel and ferroalloy industries. The state generates substantial revenue from royalties, taxes, and exports of manganese ore.
- **Economic Impact**: The manganese mining sector plays a key role in employment generation, particularly in mining, processing, and transportation. The mining activities also stimulate local economies through infrastructure development and support for industries that rely on manganese ore for production.

7. **Graphite Mining**.

Graphite Mining in Chhattisgarh

Location: Balod, Raigarh, Kabirdham (Kawardha), Surguja districts, Chhattisgarh.

Production Ranking in India:

- **Chhattisgarh** is a significant producer of graphite in India, though the state is not one of the top-ranking producers.
- **Ranking**: While Chhattisgarh does not rank among the top 3 states in graphite production, it contributes a notable share of the country's total graphite output. The state plays a key role in supplying raw materials for various industries, particularly in industrial applications such as lubricants, batteries, and steel production.

Major Graphite Mining Areas:

- **Balod District**:
  - Balod is one of the key regions for graphite mining in Chhattisgarh, where high-quality natural graphite deposits are found. Mining operations here support industries that require processed graphite for manufacturing lubricants, batteries, and other products.
- **Raigarh District**:
  - Raigarh is another significant area where graphite mining takes place in Chhattisgarh. The graphite extracted from this region is of high quality and is primarily used in the steel, refractory, and battery industries.
- **Kabirdham (Kawardha) District**:
  - Kabirdham also has deposits of graphite, contributing to the state's overall production. The district's graphite is primarily used for industrial applications, including graphite electrodes, lubricants, and foundries.
- **Surguja District**:
  - Surguja has smaller graphite deposits that support mining activities in the region. The mined graphite is used in refractory materials, batteries, and other high-performance industrial applications.

Mining Method:

- **Open-pit mining** is typically used for extracting graphite in Chhattisgarh, as the deposits are usually found close to the surface.

- The mining process involves drilling, blasting, and crushing the ore to obtain raw graphite, which is then processed into various forms for industrial uses.

Uses of Graphite:

- **Steel Industry**: Graphite is widely used in the steel industry as a refractory material and as a lubricant for various steel processing stages.
- **Batteries**: Graphite plays a crucial role in the production of lithium-ion batteries used in electric vehicles (EVs), consumer electronics, and renewable energy storage solutions.
- **Lubricants**: Due to its low friction properties, graphite is used as a lubricant in industries such as automotive, machinery, and aerospace.
- **Electrodes**: Graphite is used to manufacture electrodes in electric arc furnaces, especially in the steel and foundry industries.
- **Foundry and Refractory Industries**: Graphite is also essential in foundry applications and high-temperature refractory materials, which are crucial for metal casting and heat resistance.

Annual Revenue and Economic Contribution:

- **Revenue Generation**: Graphite mining contributes to Chhattisgarh's economy through royalties, tax revenues, and exports. The mined graphite supports a variety of industries, including steel, automobile, and battery production, which boosts both state and national economies.
- **Economic Impact**: The graphite mining sector generates employment in mining, processing, transportation, and the manufacturing sectors. As the demand for graphite-based products (especially for electric vehicle batteries) grows, it is expected that the economic contribution of graphite mining will increase.

2.1.3 Impact of Mining on Surface and Subsurface Geology of the Mahanadi River Basin

The Mahanadi River Basin, a vital geographical and ecological zone, spans across several states in India. It is rich in mineral resources, leading to extensive mining activities. This document provides an overview of the impact of these mining activities on the surface and subsurface geology of the basin.

Effects of Mining on Surface Geology

- **Land Degradation:**
  - Open-cast mining, used for many minerals, results in large-scale deforestation, soil erosion, and habitat destruction.
  - The removal of topsoil and vegetation reduces land fertility and disrupts ecological balance (Jaiswal & Pandey, 2023).

- **Changes in Topography:**
    - Mining operations alter the natural topography, creating large voids, spoil heaps, and altered landscapes.
    - This leads to changes in drainage patterns, increased surface runoff, and the risk of soil erosion and landslides.
- **Air Pollution:**
    - Mining activities generate dust, particulate matter, and gaseous pollutants, including sulfur dioxide, nitrogen oxides, and methane.
    - These pollutants degrade air quality, contribute to respiratory problems, and contribute to climate change.
- **Land Use Changes:**
    - Mining leads to the conversion of forests, agricultural land, and other natural habitats into mining areas, infrastructure, and industrial sites.
    - This disrupts ecosystems, displaces communities, and impacts livelihoods.

Effects of Mining on Subsurface Geology

- **Groundwater Depletion:**
    - Mining operations often involve the extraction of large volumes of groundwater, lowering groundwater tables.
    - This affects the availability of water for drinking, agriculture, and other uses.
- **Groundwater Contamination:**
    - Leaching of pollutants from mine waste, tailings, and spoil heaps contaminates groundwater aquifers (Pandey et al 2013).
    - AMD can also seep into groundwater, further contaminating it.
- **Subsidence:**
    - Underground mining can cause the ground surface to sink or subside, damaging buildings, roads, and other infrastructure (Mandal 2022).
    - Subsidence can also alter subsurface water flow and increase flood risk.
- **Changes in Subsurface Stratigraphy:**
    - Mining activities can disrupt the natural layering of rock formations and alter the geological structure of the subsurface.

Environmental Considerations:

Mining activities in the Mahanadi Basin, like those in other mineral-rich regions, often raise concerns related to environmental sustainability. Issues like deforestation, water pollution, and land degradation are some of the challenges that need to be addressed. Efforts for better environmental management and reclamation are crucial for maintaining the balance between economic benefits and ecological health.

Mining activities across the Mahanadi River Basin have significantly impacted both surface and sub-surface water quality. The basin, which encompasses a variety of minerals like coal, dolomite, limestone, iron ore, bauxite, manganese ore, and graphite, has seen increasing pressure on its water resources due to various mining-related activities. Below is an assessment of the current status of surface water and sub-surface water in the basin, considering the ongoing mining operations.

Surface Water in Chhattisgarh and Odisha

- **Water Quality**:
  - **Sahu et al. (2021)** highlight that both the Chhattisgarh and Odisha parts of the Mahanadi River Basin have been significantly impacted by industrial and mining activities, particularly in areas like Korba (Chhattisgarh) and Angul (Odisha). Their research discusses increased turbidity, heavy metal contamination, and acidic runoff, which have severely degraded the surface water quality, making it unsafe for direct consumption without extensive treatment.

- **Sedimentation and Siltation**:
  - According to the Chhattisgarh State Pollution Control Board (CSPCB) Report (2019) and the Odisha State Pollution Control Board (OSPCB) Report (2020), mining activities in both states have led to significant sedimentation and siltation in the Mahanadi River. Mining of coal, iron ore, and limestone has contributed to increased sediment load in the river, affecting water flow and aquatic ecosystems. This has particularly impacted areas like Raigarh and Bilaspur in Chhattisgarh and Sambalpur and Dhenkanal in Odisha.

- **Water Availability**:
  - **Mishra et al. (2020)** discusses how mining-related water extraction in both Chhattisgarh and Odisha has reduced water availability in several parts of the Mahanadi Basin. In particular, areas like Raigarh (Chhattisgarh) and Angul (Odisha) have seen water shortages, which are compounded by increasing water demand for industrial and mining activities. The study highlights the challenge of ensuring adequate water for agricultural and domestic purposes due to the over-extraction of water for mining activities.

Sub-Surface Water in Chhattisgarh and Odisha

- **Groundwater Quality**:
  - A study by Bose et al. (2018) explores groundwater contamination in both Chhattisgarh and Odisha due to mining. In Chhattisgarh, coal mining is

responsible for severe degradation of groundwater quality, primarily through acid mine drainage and heavy metal contamination. In Odisha, mining activities in the Angul and Jharsuguda regions have similarly led to contamination of groundwater with heavy metals such as arsenic and mercury, posing a risk to public health and agriculture.

- **Groundwater Quantity**:
  - According to the Central Ground Water Board (CGWB) Report (2018), both Chhattisgarh and Odisha face groundwater depletion due to the over-extraction of water for industrial and mining purposes. In Chhattisgarh, districts like Korba and Raigarh have seen a significant drop in groundwater levels, while in Odisha, areas such as Sambalpur and Dhenkanal are facing similar issues. The depletion of groundwater resources is impacting local communities' access to clean water for drinking and agriculture.

Summary for both Chhattisgarh and Odisha

- Mining activities in both Chhattisgarh and Odisha have led to significant deterioration in the quality of surface water in the Mahanadi River, with increased turbidity, sedimentation, and contamination from heavy metals and acid mine drainage.
- Sedimentation and siltation due to mining have reduced water flow, leading to the degradation of aquatic ecosystems in the river.
- The over-extraction of water for mining in both regions has reduced water availability for agricultural, industrial, and domestic use, particularly in key areas like Korba and Raigarh in Chhattisgarh, and Angul and Sambalpur in Odisha.
- Groundwater quality has been severely impacted by contamination from mining, and groundwater levels have dropped due to over-extraction, affecting local communities' water supply.

These references demonstrate that both Chhattisgarh and Odisha are facing significant challenges related to water quality and availability due to mining activities in the Mahanadi River Basin. These issues arise from both direct mining operations and inadequate management of mining-related infrastructure. These highlights the necessity for stringent regulatory oversight, improved safety protocols, and enhanced coordination between regional authorities to mitigate adverse impacts on the environment and local communities.

2.2 Tunneling Activities

Tunneling in the Mahanadi River Basin is primarily associated with irrigation projects, hydroelectric power plants, and transportation infrastructure. The region's geology, consisting of hard rocks, soft sediments, and groundwater presence, poses engineering challenges for tunnel construction. Existing, Under-Construction, and Proposed Tunnels in MRB (Chhattisgarh) (Till March 2025) are listed below:

2.2.1 Hirakud-Rengali Link Canal Tunnel:

- **Irrigation and Water Management Tunnels**

  Mahanadi Irrigation Projects - Various canal and tunnel systems are constructed for water diversion and irrigation. The Hirakud Dam Project has associated tunnels and channels for water distribution.

  Telengiri Irrigation Project (Odisha)-Includes tunnels for directing water to agricultural lands in the region.

  Lower Suktel Irrigation Project (Odisha)-Includes underground tunnels for water distribution to drought-prone areas.

- **Hydroelectric Power Projects**

  Hirakud Dam Hydropower Tunnels (Odisha)-The Hirakud Dam, one of India's largest earthen dams, has water tunnels to regulate flow for power generation. These tunnels connect the reservoir to powerhouses for hydroelectric generation.

- **Transportation Infrastructure**

  Bhanwar Tonk Tunnel – 1,024 metres length (opened in year 1907), located between Kargi Road and Bhanwar Tonk railway stations.

Figure 12: Bhanwar Tonk Tunnel [Image Source: (NPG News, 2024)]

2.2.2 Under-Construction Tunnels:

Keshkal Valley Tunnel – 2.79 km (9,150 ft): Part of the Bharatmala Project, enhancing connectivity between Raipur and Visakhapatnam. To reduces travel time and improves road safety by bypassing hazardous curves in the Keshkal valley.

2.2.3 Planned/Proposed Tunnels

The Mahanadi River basin, spanning several Indian states, is the focus of various water management projects, some of which involve tunnel constructions. Here is an overview of existing and planned tunnels in the region:

- Mahanadi (Barmul)–Godavari (Dowlaiswaram) Link Canal: As part of the National Perspective Plan for inter-basin water transfer, this proposed link canal intends to divert approximately 10,105 million cubic meters (MCM) of water annually from the Mahanadi to the Godavari River. The canal's design incorporates two tunnels: one measuring 0.75 km and another 5.4 km in length, located at specific reaches along the canal's route.
- Hirakud-Rengali Link Canal Tunnel: This proposed canal aims to transfer surplus water from the Hirakud reservoir in the Mahanadi basin to the Rengali reservoir in the Brahmani basin. The project includes a 6 km long tunnel to cross the ridge between the Mahanadi and Brahmani rivers.
- Godavari (Inchampalli/Janampet)–Cauvery (Grand Anicut) Link Canal: This extensive project proposes to transfer 12,165 MCM of water from the Mahanadi River southward through a series of link canals. The plan includes a tunnel of 9.15 km length to cross the ridge between the Godavari and Krishna basins, facilitating the water transfer.

These projects are part of India's broader initiative to interlink rivers for optimal water resource management. It's important to note that while some tunnels are in the planning stages, others are proposed and awaiting further developments.

- Rowghat Rail Tunnel – Part of the Rowghat-Jagdalpur rail line, crucial for iron ore transportation.
- Dulanga-Talaipalli Rail Tunnel – Proposed for coal transport under NTPC's infrastructure expansion.

These tunnels are crucial for improving connectivity, transportation, and economic growth in Chhattisgarh.

2.3 Fracking Zones of Mahanadi River Basin

Hydraulic fracturing, or fracking, is a technique used to extract oil and natural gas from underground rock formations, typically shale. Fracking zones refer to specific rock layers targeted for this process. The Mahanadi Basin contains sedimentary formations with hydrocarbon potential and a structural architecture resembling extensional basins with master bounding faults, indicating possible exploration prospects. However, as of recent reports, no large-scale commercial fracking operations have been documented in the region. While seismic surveys and pilot drilling have been undertaken to assess the feasibility of hydrocarbon extraction from deep shale formations, fracking remains limited. According to the Ministry of Petroleum & Natural Gas (2021), the maturity of conventional hydrocarbon resources in India's sedimentary basins—categorized into three groups by DGH India (2023)—helps explain the limited adoption of fracking in the Mahanadi Basin.

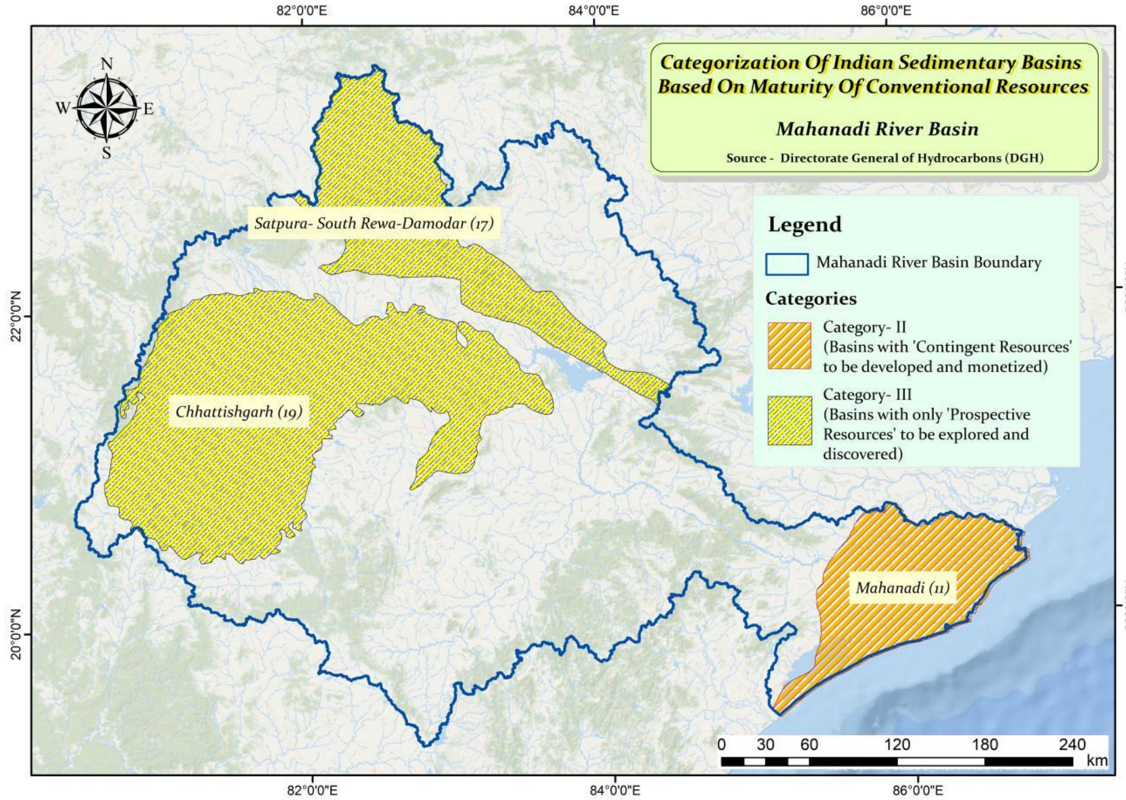


Figure 13: Categorization of Sedimentary Basins under MRB, based on maturity of conventional resources.

Category I: Producing basins (e.g., Mumbai Offshore, KG Basin)

- These basins contribute significantly to India's domestic oil and gas production. For example, the Mumbai Offshore basin alone accounts for nearly 40% of the country's crude oil production.

Category II: Basins with known hydrocarbon accumulations but pending commercial production (e.g., Mahanadi Sedimentary Basin)

- Although hydrocarbon reserves have been identified in these basins, challenges such as technological constraints and economic viability have delayed full-scale production. The Mahanadi Basin has shown promising natural gas reserves, with estimated recoverable resources of over 1.3 trillion cubic feet.

Category III: Basins with geological prospects but no significant discoveries (e.g., Bengal Basin)

- These basins are still under exploration, with geological surveys indicating potential hydrocarbon-bearing formations. However, no commercially viable reserves have been established yet.

The Mahanadi River Basin, includes 3 Sedimentary Basins

Table 4: Sedimentary Basins under MRB

Basin	Category	Area Coverage	Key Features
Chhattisgarh Basin	III	22.45%	- Largest Purana basin (~36,000 sq. km) in the Bastar Craton, bounded by major mobile belts and orogens.
			- Rich in limestone, dolomite, and kimberlite-bearing granites supporting steel and cement industries.
			- Contains up to 2,500 m thick sediments in Hirri and Baradwar sub-basins, separated by the Sonakhan high.
Satpura-South Rewa-Damodar Basin	III	10.11%	- Spindle-shaped basin (~1,200 sq. km) south of the Narmada with complex tectonic trends.
			- Hosts coal-rich Barakar Formation and fossil-bearing layers like Bijori and Denwa.
			- Includes glacial, red clay, sandstone, and fossiliferous formations from the Talchir to Bagra sequence.
Mahanadi Basin	II	7.84%	- Rift basin on India's East Coast, spanning 55,000 sq. km (14,000 sq. km offshore).
			- Estimated hydrocarbon resources: 45 MMt (onshore), 100 MMt (shallow offshore), with deepwater potential.
			- Originated from Gondwana breakup; exploratory wells and geochemical studies support hydrocarbon viability.

2.3.1. Potential Impacts on Subsurface Geology, Seismicity, and River Health

Geological Alterations and Groundwater Contamination

High-pressure fluid injection during fracking induces fractures in deep rock formations, potentially creating unintended pathways for contaminants to reach groundwater aquifers. The Mahanadi Basin, with its interlinked surface and subsurface hydrological systems, faces a heightened risk of aquifer contamination from methane migration and chemical-laden fracking fluids. Studies from other shale basins indicate that such contamination can alter the geochemical balance of freshwater systems, leading to long-term degradation of drinking water sources and aquatic habitats (U.S. Geological Survey [USGS], 2023; Geological Survey of India [GSI], 2022).

Induced Seismicity and River Stability

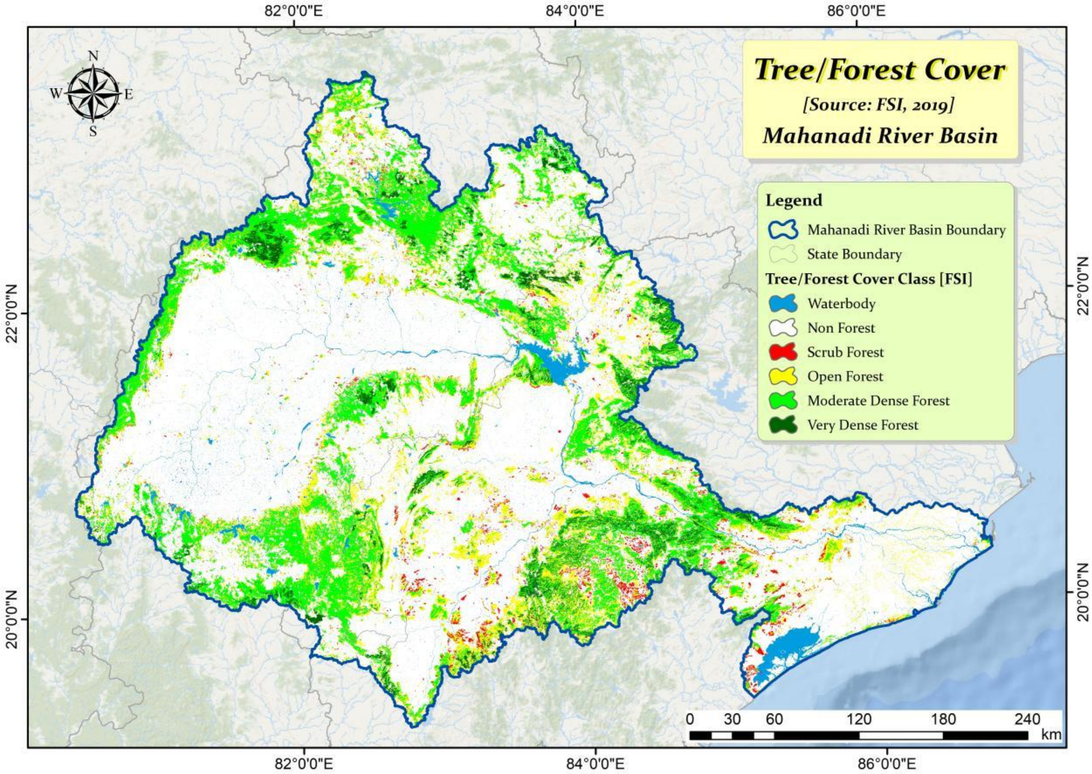
Evidence from hydraulic fracturing operations in the United States and Canada has demonstrated that fracking and associated wastewater disposal can induce seismic events, with some exceeding magnitude 4.0 (Ellsworth, 2013). The Mahanadi Basin, characterized by a complex tectonic framework influenced by the Eastern Ghat Mobile Belt and Gondwana rift structures, may be particularly susceptible to such disturbances. Increased seismic activity could destabilize riverbanks, alter sediment transport dynamics, and contribute to erosion, threatening floodplain stability and aquatic ecosystems. Therefore, comprehensive geotechnical and seismic assessments are essential before large-scale fracking activities commence (GSI, 2023).

2.4 Deforestation

The Mahanadi River Basin, encompassing significant portions of Chhattisgarh and Odisha, features a diverse forest cover that plays a crucial role in the region's ecological balance (Figure 14). These forests, varying from tropical moist deciduous to tropical dry deciduous types, contribute significantly to biodiversity and influence the basin's hydrology. However, the region faces increasing pressure from factors like mining activities, rapid urbanization, and agricultural expansion, leading to deforestation and forest degradation. While substantial forest areas remain, particularly in the hilly regions, monitoring and conservation efforts are essential to ensure the sustainable management of these valuable ecosystems and to mitigate the adverse impacts of human activities on the Mahanadi River Basin.

The geology of the Mahanadi Basin is rich in mineral deposits, making it an attractive region for mining operations. However, these mining activities not only lead to the direct removal of forests but also disturb the soil structure, increase erosion, and reduce the basin’s ability to manage floods. The combination of mining activities and deforestation in the basin is further compounded by the loss of biodiversity and the alteration of local hydrology, making the region increasingly vulnerable to environmental challenges like soil erosion and water management issues. Despite some areas showing slight recovery in forest cover, the overall trend reflects the profound impact of mining on the ecological stability of the Mahanadi Basin.

The forest area data for the Mahanadi River Sub-Basins, sourced from the Commissioner of Land Records (Govt. of CG), reveals a diverse array of changes over the past two decades. Rate of change in forest area at sub-basin Level in the Chhattisgarh Region of the Mahanadi Basin is shown in Figure 13. In the Seonath Sub-Basin, the forest area decreased from 703,516 hectares in 2000 to 682,630 hectares in 2020, reflecting a notable decline in forest cover. Similarly, the Pairi Sub-Basin showed a reduction in forest area, dropping from 288,044 hectares in 2000 to 282,304 hectares by 2020, indicating a continuous loss in forest cover over the two decades. However, the Hasdeo Sub-Basin demonstrated positive changes, with forest cover decreasing from 646,011 hectares in 2000 to 623,843 hectares in 2010, but recovering to 669,053 hectares by 2020. This suggests that afforestation and conservation initiatives may have contributed to the recovery of forest area in this sub-basin. The Jonk Sub-Basin also witnessed an increase in forest area, rising from 99,144 hectares in 2000 to 102,017 hectares in 2020, indicating a positive trend in forest cover. In the Ib Sub-Basin, forest area grew steadily from 151,699 hectares in 2000 to 178,719 hectares in 2020, reflecting successful forest preservation and afforestation efforts.



Class	Description	% Area
Waterbody	Waterbodies	7.15
Non Forest	Any area not included in the above classes	58.12
Scrub Forest	All forest lands with poor tree growth of small or stunted trees having canopy density <10%	2.14
Open Forest	All lands with tree cover (Including mangrove cover) of canopy density between 10% and 40%	14.00
Moderate Dense Forest	All lands with tree cover (Including mangrove cover) of canopy density between 40% and 70%	14.05
Very Dense Forest	All Lands with tree cover (Including mangrove cover) of canopy density of 70% and above	4.55

Figure 14: Overview of Forest Cover in the Mahanadi River Basin [FSI, 2019]

Other sub-basins, such as Tel, Ong, Main Kelo, and Chotta Kelo, showed minor changes in forest area, indicating either slight deforestation or afforestation activities. Overall, while certain sub-basins have experienced reductions in forest area, others have seen improvements, highlighting the ongoing efforts in afforestation and conservation to maintain the forest resources of the Mahanadi River Basin.

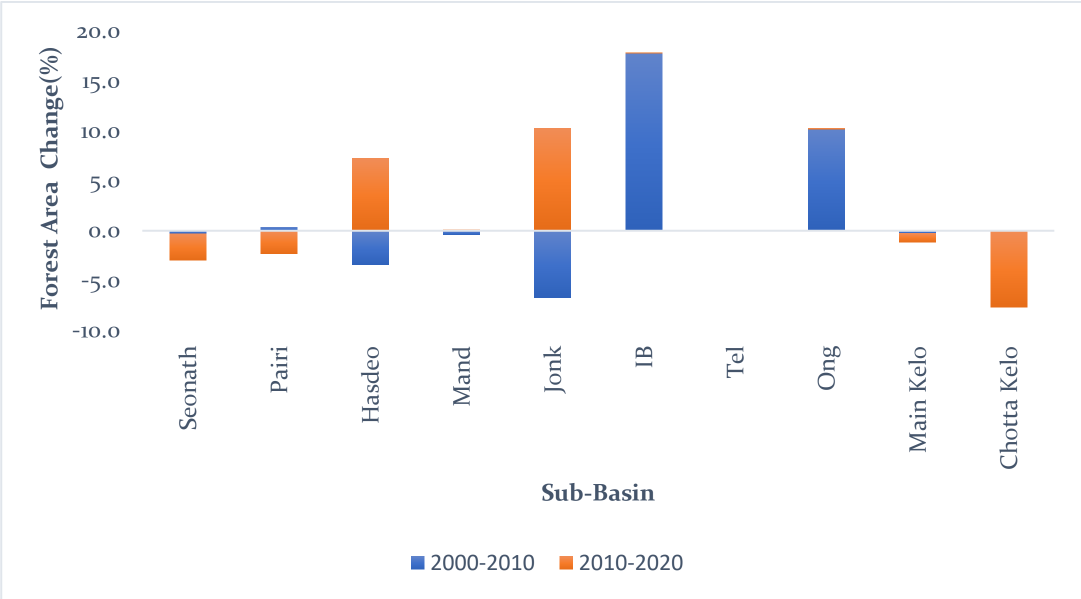


Figure 15: Rate of Change in Forest Area at Sub-Basin Level in the Chhattisgarh Region of the Mahanadi Basin

Odisha experienced a notable increase in its forest and tree cover between 2013 and 2023, , as detailed in the India State of Forest Report (ISFR) 2023 by the Forest Survey of India. The state's green cover expanded by 1,889 sq.km over the decade, with 133.14 sq. km within the Recorded Forest Area (RFA) and 1,755.71 sq.km outside it. This growth was primarily attributed to extensive plantation initiatives and active forest protection efforts, including the involvement of over 16,000 Van Suraksha Samiti member.

Table 5: Decadal change in forest cover of Odisha between 2013 and 2023 assessments (Source-FSI, 2023)

State	Geographical area (sq km)	Forest cover (2013)	Forest cover (2023)	Change in forest cover	Change (%) w.r.t. 2013
Odisha	1,55,707.00	50,544.71	52,433.56	1888.85	3.74

Despite this overall positive trend, certain tribal districts such as Kalahandi, Nabarangpur, Sundargarh, and Malkangiri reported declines in forest cover. These losses were often linked to factors like forest fires, mining activities, and encroachments. Additionally, Odisha's mangrove cover grew by 1.55 square kilometers, with Kendrapara district leading in mangrove area. Overall, while Odisha made significant strides in enhancing its green cover, addressing localized losses in specific districts remains crucial for sustaining long-term ecological balance.

Impact of Deforestation basin Hydrology

Deforestation within the Mahanadi River Basin presents a complex environmental challenge, with measurable impacts backed by research:

- **Land Use/Land Cover Changes:**
  - Studies utilizing remote sensing data have documented significant land use/land cover (LULC) changes within the Mahanadi Basin, with a notable decline in forest cover. This deforestation is driven by a combination of factors, including agricultural expansion, urbanization, and industrial activities such as mining.
  - Research indicates that the conversion of forest land to agricultural land is a major driver of deforestation in the Mahanadi basin (Behra et al. 2017).
- **Increased Flood Vulnerability:**
  - Deforestation reduces the basin's natural capacity to absorb rainfall, leading to increased surface runoff and heightened flood risks. The loss of forest cover contributes to soil erosion, which in turn increases sediment loads in rivers, reducing their capacity and exacerbating flooding.
  - Research shows that increased extreme rainfall events, combined with deforestation, is increasing flood risks in the Mahanadi delta region (India water portal).
- **Impact on Hydrological Cycle:**
  - Deforestation disrupts the natural hydrological cycle, affecting groundwater recharge and streamflow. This can lead to decreased water availability during dry periods and increased vulnerability to droughts.
  - The document, "Nature-Based Solutions for Mahanadi River Basin Protection and Conservation", shows the importance of maintaining natural forestry, for the hydrological cycle (Mishra et al. 2025).

2.5 River Bed Mining

Riverbed mining in the Mahanadi River basin has been a significant environmental and socio-economic issue. The extraction of sand, gravel, and other minerals from the riverbed is common, but unregulated mining has led to serious ecological consequences. This is the most common form of sand mining and involves the extraction of sand directly from riverbeds and floodplains. It often leads to the erosion of riverbanks and can have a significant impact on river ecosystems. The extracted sand is primarily utilized for construction purposes, including the building of embankments, bridges, and other infrastructure projects.

2.5.1 Methods of River Bed Mining

Riverbed mining in the Mahanadi River basin involves various methods, ranging from traditional manual extraction to large-scale mechanical operations. The key methods used include:

1. Manual Extraction

It involves local communities extracting sand and gravel using hand tools like shovels and baskets. It is usually practiced in shallow river sections and floodplain areas. It is Considered as a low-impact method but is labour-intensive and limited in scale.It is often preferred over mechanized methods for smaller operations or in areas where technology is limited.

Cuttack

Jagatsinghpur

Figure 16: Extraction of sand manually from the river bed, Odisha

2. Open Cast Mining

A large-scale method where riverbed materials are extracted using excavators and bulldozers. It is Common in areas where sand and gravel deposits are easily accessible. It can cause riverbed degradation and erosion if not managed properly.

Figure 17: Excavation of sand from the Mahanadi River basin at Cuttack, Odisha

3. Instream Mining

It is the Direct extraction of sand and gravel from within the river channel. It is often conducted using boats and dredging machines. It Can lead to habitat destruction, sediment imbalance, and water quality issues.

4. Bar Scalping (Dry Season Mining)

It is the Mining from exposed river bars and floodplains during the dry season. It Can disturb groundwater recharge and alter river morphology.

5. Mechanical Dredging

It Uses suction or bucket dredgers to remove sand and sediments from deeper river sections. It is mostly used for large-scale commercial sand mining. It can significantly alter river flow, aquatic ecosystems, and sediment transport.

Jagatsinghpur

Balianta, Khurdha

Figure 18: Sand mining using Mechanical dredgers, Odisha

Sand is a fundamental component of riverine ecosystems, acting as a natural filtration system for water, habitat for aquatic species, and a crucial factor in maintaining sediment balance. The growing demand for sand due to rapid urbanization, construction, and industrialization has led to excessive extraction, resulting in riverbed degradation, loss of biodiversity, and groundwater depletion.

2.5.1 Extent and Drivers of Sand Mining Activities

Increasing Demand for Sand

With rapid urban expansion in Chhattisgarh and Odisha, the demand for sand has surged. According to The Times of India (2024), sand extracted from Mahanadi's riverbed is widely used for construction in cities like Raipur, Bhubaneswar, and Cuttack. This demand has fueled both legal and illegal sand mining operations.

2.5.2 Key Hotspots of Sand Mining in the Mahanadi Basin

According to official reports and environmental studies, major sand mining zones in Chhattisgarh and Odisha include (shown in Figure 19):

- Baloda Bazar, Dhamtari, and Janjgir-Champa districts (Chhattisgarh)
- Banki, Kendrapara, and Jagatsinghpur districts (Odisha)
- Sambalpur and Subarnapur regions also report increasing extraction rates.

Studies indicate that over 1.5 million metric tons of sand are extracted annually from the Mahanadi River and its tributaries (Mishra & Rout, 2021).

Figure 19: Sand Mining Hotspots/Zones (*As per Google Earth Imagery*)

Dhamtari [Dec, 2019]

Kurud (Dhamtari) [Oct,2021]

Rajim [April, 2024]

Champaran [April, 2024]

Arang [April, 2021]

Sirpur [May, 2020]

Baloda-Bazar [April, 2022]

Seorinarayan (Janjgir-Champa) [June, 2022]

Banki (Cuttack) [Nov, 2017]

Cuttack [Mar, 2025]

Kendrapara [April, 2024]

Jagatsinghpura [Jan, 2019]

2.5.3 Illegal Sand Mining and Its Growth

Despite regulations, illegal sand mining continues due to weak law enforcement, corruption, and involvement of organized crime groups. Reports by India Rivers Forum (2023) highlight that sand mafias operate with impunity, often using heavy machinery, unregistered boats, and night time operations.

2.5.4 Environmental Impacts of Sand Mining

- **River Morphology Alteration and Erosion**

Sand mining alters the natural flow of rivers, affecting sediment transport and riverbank stability. Studies by Kumar et al. (2022) show that the removal of sand has led to:

- Widening of river channels, causing bank erosion.
- Deepening of riverbeds, leading to the destruction of riparian vegetation.

- Increased flood risks due to changes in river hydrodynamics.

Hydrological Changes in the Mahanadi River Due to Sand Mining Activities (Das & Sahu, 2021) have studied analyzing how extensive sand extraction has altered the hydrology of the Mahanadi River, affecting water flow, sediment transport, and flood patterns

➢ **Decline in Sediment Supply to the Mahanadi Delta**

The Mahanadi Delta, which serves as a natural buffer against coastal erosion and cyclones, is shrinking due to sediment loss (Ghosh et al., 2021). This has resulted in:

- Increased coastal vulnerability to sea-level rise and storm surges.
- Salinity intrusion into freshwater ecosystems, affecting agriculture and drinking water sources.

➢ **Impact on Aquatic Biodiversity**

Sand mining negatively impacts aquatic flora and fauna by:

- Destroying the breeding grounds of fish such as Indian carp and catfish.
- Disrupting benthic organisms (small organisms living in the riverbed), which are vital for nutrient cycling (Das et al., 2021).
- Increasing water turbidity, reducing photosynthesis in aquatic plants.

Singh & Sharma (2022) report a 30% decline in fish populations in sand-mined stretches of the Mahanadi over the last decade.

➢ **Groundwater Depletion and Water Scarcity**

Sand regulates groundwater recharge by slowing down percolation and preventing rapid runoff. Overextraction of sand has led to:

- Lowering of the water table, causing seasonal water shortages in villages.
- Drying up of traditional wells and ponds in Raigarh, Baloda Bazar, and Dhamtari (Mishra et al., 2021).
- Increase in arsenic and fluoride contamination in groundwater due to disturbance of natural filtration systems.

➢ **Pollution from Mining Operations**

Mining activities often involve the use of diesel-powered machines, which release:

- Oil and grease pollutants, contaminating water bodies (Sinha et al., 2023).
- Suspended sediments, leading to increased siltation in reservoirs and irrigation canals.

2.5.5 Socio-Economic Impacts of Sand Mining

➢ **Loss of Livelihoods for Fishermen and Farmers**

- Fishermen face reduced fish catch due to habitat destruction.

- Farmers dependent on river-fed irrigation report declining yields due to soil degradation and water shortages (Roy & Patel, 2021).

- **Rise of Sand Mafias and Conflicts**
  - Illegal sand mining has led to violent conflicts between sand mafia groups, villagers, and enforcement agencies (Indian Kanoon, 2022).
  - Government loses millions in revenue annually due to illegal trade.

- **Community Resistance and Legal Battles**
  - In 2023, villagers in Banki, Odisha, halted mining operations after months of protests (India Rivers Forum, 2023).
  - The National Green Tribunal (NGT, 2023) has intervened in multiple cases, imposing fines on illegal operators.

2.5.6 Regulatory Measures and Challenges

Despite the presence of regulatory frameworks such as the Environmental Protection Act (1986), the Sustainable Sand Mining Management Guidelines (2016), and the National Green Tribunal Orders (2023), the issue of unsustainable riverbed mining in the Mahanadi River Basin persists. Weak enforcement mechanisms and a lack of effective surveillance have allowed illegal extraction activities to flourish, leading to severe environmental consequences. The depletion of sand and other riverbed materials disrupts natural sediment transport, alters river flow patterns, and degrades aquatic habitats, posing a serious threat to the ecological balance of the basin.

Furthermore, corrupt practices at local administrative levels exacerbate the problem, enabling unauthorized mining operations and making regulatory interventions ineffective. The absence of comprehensive scientific assessments before issuing mining permits leads to unchecked extraction rates that exceed the river's natural replenishment capacity. As a result, excessive sand mining accelerates riverbank erosion, reduces groundwater recharge, and increases the vulnerability of nearby communities to floods and water scarcity, further emphasizing the need for stringent conservation measures and sustainable resource management policies.

2.5.7 Recommendations for Sustainable Sand Mining

Stricter Law Enforcement: Strengthening monitoring mechanisms and increasing penalties for illegal mining are crucial to controlling unsustainable riverbed extraction. Implementing real-time surveillance technologies, such as GPS tracking of sand-laden trucks and drone monitoring, can enhance regulatory oversight. Additionally, imposing stricter legal consequences for violations can serve as a deterrent to unlawful mining activities.

Community Involvement & Sustainable Alternatives: Establishing River conservation committees with active participation from local communities, environmental groups, and researchers can improve transparency and accountability in mining activities. Simultaneously, promoting the use of alternative materials like manufactured sand (M-sand) can reduce dependence on natural river sand, thereby mitigating the environmental impact of excessive extraction.

Scientific and Eco-Friendly Approaches: Conducting regular sediment balance studies before granting mining licenses ensures that extraction does not exceed the river's natural replenishment rate. Additionally, restricting the use of heavy machinery and encouraging manual extraction in low-risk areas can minimize ecological disruption, prevent excessive erosion, and support sustainable resource management.

2.6 Hill Slope Changes

The hill slope changes in the Mahanadi River Basin are influenced by natural processes like erosion, weathering, tectonic activity, and human interventions such as deforestation, mining, and urbanization.

2.6.1 Causes of Hill Slope Changes

The hill slope changes in the Mahanadi River Basin are caused by a combination of natural factors and human activities. These changes affect soil stability, erosion patterns, and overall landscape dynamics.

- **Natural Causes**
  - Erosion & Weathering

    Water erosion: Heavy monsoon rains cause surface runoff, leading to soil loss and slope modifications.

    Wind erosion: In exposed hill slopes, strong winds gradually wear down the surface.

    Chemical weathering: The high humidity in some areas leads to the breakdown of rock formations, changing slope structures.
  - Tectonic Activity

    The Mahanadi basin lies on an ancient tectonic plate with occasional minor seismic activities. Slow but continuous land movements can alter slopes over time.
  - River Meandering & Sediment Transport

    The Mahanadi River and its tributaries cut through hill slopes, causing natural slope adjustments. Deposition and erosion cycles reshape slopes, especially in flood-prone areas.
  - Landslides & Mass Wasting

    In hilly regions of Chhattisgarh and the Eastern Ghats, landslides occur due to gravity, soil saturation, and weak rock structures.

- **Human-Induced Causes**
  - Deforestation & Agriculture

Tree removal weakens slope stability, making it prone to erosion. Expanding agriculture on slopes leads to soil loss and changes in gradient.

- Mining & Quarrying
  Coal and bauxite mining (Odisha, Chhattisgarh) cause artificial slope modifications. Open-pit mining leads to land subsidence and soil degradation.

2.6.2 Impact of Hill Slope Changes on Landslides, Erosion and Sedimentation

The changes in hill slopes due to natural and human-induced factors have significant impacts on landslides, erosion, and sedimentation. These changes affect not only the stability of the terrain but also the hydrology and ecology of the region.

- **Impact on Landslides**
  Hill slope modifications, particularly in steep and deforested areas, make them vulnerable to landslides.

  Causes of Increased Landslides:

  Slope Instability: Deforestation, mining, and road construction weaken the soil structure.

  Heavy Rainfall & Water Saturation: Monsoons trigger landslides by increasing pore water pressure in the soil.

  Soil Loosening: Quarrying and excavation disturb natural compaction, leading to mass movements.

  Seismic Activity: Minor earthquakes or ground vibrations from human activities (e.g., blasting in mining) can trigger landslides.

  Effects of Landslides:

  Loss of Agricultural Land: Landslides bury fertile lands, reducing productivity.

  Infrastructure Damage: Roads, bridges, and settlements in hilly areas are at risk of destruction.

  River Blockages: Landslides can obstruct rivers, forming temporary dams that may burst, causing floods.

- **Impact on Erosion**
  Erosion is accelerated by hill slope changes, especially where vegetation has been removed.

  Causes of Increased Erosion:

  Loss of Vegetative Cover: Without trees, roots cannot hold the soil, increasing surface runoff.

  Steeper Slopes: Slope modifications from construction or mining increase water velocity, carrying more soil downhill.

Rainfall & Climate Change: Intense rainfall events cause sheet, rill, and gully erosion on exposed slopes.
Agricultural Expansion: Overgrazing and poor farming practices lead to topsoil loss.

Effects of Erosion:
Soil Fertility Decline: Topsoil loss reduces nutrients, impacting crop yields.
Desertification Risk: Continuous erosion can turn land barren and unsuitable for vegetation.
Increased Sediment Load in Rivers: Eroded material is carried into rivers, leading to sedimentation problems.

- **Impact on Sedimentation**
  Sediment movement and deposition patterns are altered due to hill slope changes, affecting rivers, reservoirs, and wetlands.

  Causes of Increased Sedimentation:
  Higher Soil Erosion: More eroded material from slopes enters water bodies.
  Deforestation in Catchment Areas: Without trees, more sediment is washed into rivers.
  Mining and Construction Debris: Loose soil from excavation and quarrying contributes to sediment load.
  Dam and Reservoir Construction: Water flow changes lead to sediment deposition in reservoirs, reducing their capacity.

  Effects of Sedimentation
  Reduced Water Storage Capacity: Reservoirs like Hirakud Dam face reduced efficiency due to sediment buildup.
  River Course Alteration: Excess sediment can cause rivers to change course, increasing flood risks.
  Loss of Aquatic Habitats: Sedimentation affects fish and other aquatic species by reducing water quality.

2.7 Stream Sediment Geochemistry of Mahanadi River Basin

The Geological Survey of India (GSI) employs a standardized methodology for stream sediment sampling under its National Geochemical Mapping (NGCM) initiative. Fine-grained sediments (<180 µm) are collected from active streambeds, primarily along first- to third-order streams, to capture upstream geochemical signatures. Each sample is a composite drawn from multiple points across the stream width to ensure representativeness and minimize local variation. Sampling is carried out at a density of one sample per 2–4 km^2, with each location georeferenced using GPS. The geochemical data is then integrated with spatial datasets in a GIS environment to identify elemental anomalies and guide mineral exploration and environmental assessments.

For the Mahanadi River Basin (MRB), the stream sediment dataset spans 33,018 grid locations. A total of 65 elemental and oxide parameters were analyzed, offering high-resolution insight into sediment chemistry. These elements are organized into eight functional categories based on their geochemical properties, environmental relevance, and economic significance as shown in Table 6.

Table 6: Geochemical Elements Identified in MRB Stream Sediments Data

(Source : GSI - Bhukosh)

1.1

Group	Elements
Major Oxides	SiO_2, Al_2O_3, Fe_2O_3, TiO_2, CaO, MgO, MnO, Na_2O, K_2O, P_2O_5, LOI
Alkali/Alkaline Earth	Ba, Sr, Rb, Cs, Li
Transition/Base Metals	V, Cr, Co, Ni, Cu, Zn, Pb, Mo, Cd, Hg, W, U
HFSEs	Zr, Nb, Hf, Ta, Th
REEs	La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Y
Precious/PGE	Au, Ag, Pt, Pd
Volatile/Toxic	As, Sb, Bi, Se, Te, Tl
Strategic/Tech	Ga, In, Sn, Ge, Sc, Be, F

Major Oxides

These oxides constitute the bulk geochemistry of sediments and represent primary lithological indicators:

- SiO_2, Al_2O_3: Reflect silicate and clay mineral content.
- Fe_2O_3, MnO: Trace iron and manganese oxides/hydroxides.
- TiO_2: Heavy mineral content, notably ilmenite.
- CaO, MgO, Na_2O, K_2O: Associated with feldspars, carbonates, and alteration zones.
- P_2O_5: Linked to phosphates or organic detritus.
- LOI (Loss on Ignition): Represents volatiles, carbonates, and organics.

1.2 Alkali and Alkaline Earth Metals

These elements are sensitive to weathering processes and feldspar alteration:

- Sr, Ba: Derived from plagioclase and carbonates.
- Rb, Cs: Associated with mica and clay minerals.
- Li: Indicates hydrothermal processes and clay-rich environments.

1.3 Transition and Base Metals

These metals are relevant to both mineralization zones and environmental health:

- Cr, Ni, Co: Common in mafic/ultramafic terrains.
- Cu, Zn, Pb: Markers of sulfide mineralization or anthropogenic inputs.
- Mo, Cd, Hg, W, U: Trace metal enrichment; potentially hazardous or ore-forming.

1.4 High Field Strength Elements (HFSEs)

HFSEs are geochemically immobile and indicate tectonic provenance:

- Zr, Hf: Related to zircon content.
- Nb, Ta: Enriched in alkaline/felsic igneous terrains.
- Th: Associated with radioactive minerals and granite-derived sediments.

1.5 Rare Earth Elements (REEs)

REEs are essential for identifying magmatic fractionation and REE-bearing deposits:

- LREEs (La to Sm): Derived from crustal processes.
- HREEs (Gd to Lu, +Y): Highlight fractionated felsic sources or heavy mineral concentration.

Eu anomalies provide insights into plagioclase retention or loss.

1.6 Precious and Platinum Group Elements (PGE)

These elements are of high economic interest, often linked to placer and sulfide mineralization:

- Gold (Au): Key for placer deposit evaluation in MRB tributaries.
- Pt, Pd: May indicate ultramafic-mafic intrusive associations.

1.7 Volatile and Toxic Trace Elements

These are potential environmental contaminants and may also occur in hydrothermal zones:

- As, Sb, Se: Often associated with sulfide mineralization.
- Bi, Te: Common in gold and polymetallic veins.
- Tl: Toxic, typically associated with altered felsic rocks.

1.8 Strategic, Indicator, and Technology Elements

These trace components are linked to strategic and high-tech applications:

- Ga, Ge, In: Associated with sphalerite and silicate-hosted rare metals.
- Sn, Sc, Be: Indicators of specialized granites, greisens, and pegmatites.
- F: Reflects fluorite or phosphate minerals; useful in geochemical mapping of hydrothermal systems.

To facilitate interpretation and decision-making, a subset of environmentally and ecologically relevant elements can be selected (from the list of 63) and grouped based on their geochemical behavior, environmental impact, and toxicological thresholds following guidelines from CPCB (2019), CCME (2001), USEPA (2002), and peer-reviewed literature (MacDonald et al., 2000). These elements are classified into five concentration categories (Very Low to Very High) in terms of ppm, reflecting their potential risk to river health and suitability for basin management as given in Table 7.

Table 7: Concentration Ranges of Key Elements in Stream Sediments (ppm)

Element	Relevance	Very Low	Low	Moderate	High	Very High	Source
Pb (Lead)	Toxic to aquatic life; bioaccumulative	<10	10–25	26–50	51–100	>100	USEPA (2002)
Cd (Cadmium)	Highly toxic, carcinogenic	<0.3	0.3–0.5	0.6–1.0	1.1–3.0	>3.0	USEPA (2002)
Zn (Zinc)	Essential but toxic at high levels	<50	50–90	91–200	201–400	>400	USEPA (2002)

Cu (Copper)	Essential; toxic to fish at high levels	<25	25–50	51–100	101–250	>250	USEPA (2002)
Cr (Chromium)	Hexavalent form is toxic	<40	40–75	76–150	151–300	>300	USEPA (2002)
Ni (Nickel)	Toxic, carcinogenic	<20	20–40	41–80	81–150	>150	USEPA (2002)
As (Arsenic)	Toxic, carcinogenic	<5	5–10	11–20	21–40	>40	USEPA (2002)
Hg (Mercury)	Extremely toxic; bioaccumulates	<0.05	0.05–0.1	0.11–0.3	0.31–1.0	>1.0	USEPA (2002)
Fe_2O_3	Influences sediment chemistry	<1,500	1,500–3,000	3,001–5,000	5,001–10,000	>10,000	GSI (2018)
MnO	Essential micronutrient; toxic in excess	<250	250–500	501–1,000	1,001–2,000	>2,000	GSI (2018)
Al_2O_3	Influences metal adsorption	<5,000	5,000 – 10,000	10,001–15,000	15,001–20,000	>20,000	GSI (2018)
P_2O_5	Nutrient; causes eutrophication	<150	150–300	301–500	501–800	>800	GSI (2018)
U (Uranium)	Radioactive; toxic at elevated levels	<1	1–3	3.1–7	7.1–15	>15	GSI (2018)
Ag (Silver)	Toxic to microbes and aquatic life	<0.1	0.1–0.5	0.6–1.0	1.1–2.0	>2.0	USEPA (2002)
F (Fluoride)	Affects bone health; toxic at high levels	<100	100–250	251–500	501–800	>800	BIS (2012)

Based on the above classified concentration ranges, hotspot mapping for Arsenic (As) and Lead (Pb) in the Mahanadi River Basin (MRB) is shown as example in Figure 20 to provide critical insight into areas of potential ecological and public health concern. The following points summarize the key geochemical and anthropogenic factors contributing to the observed arsenic and lead hotspots in the Mahanadi River Basin.

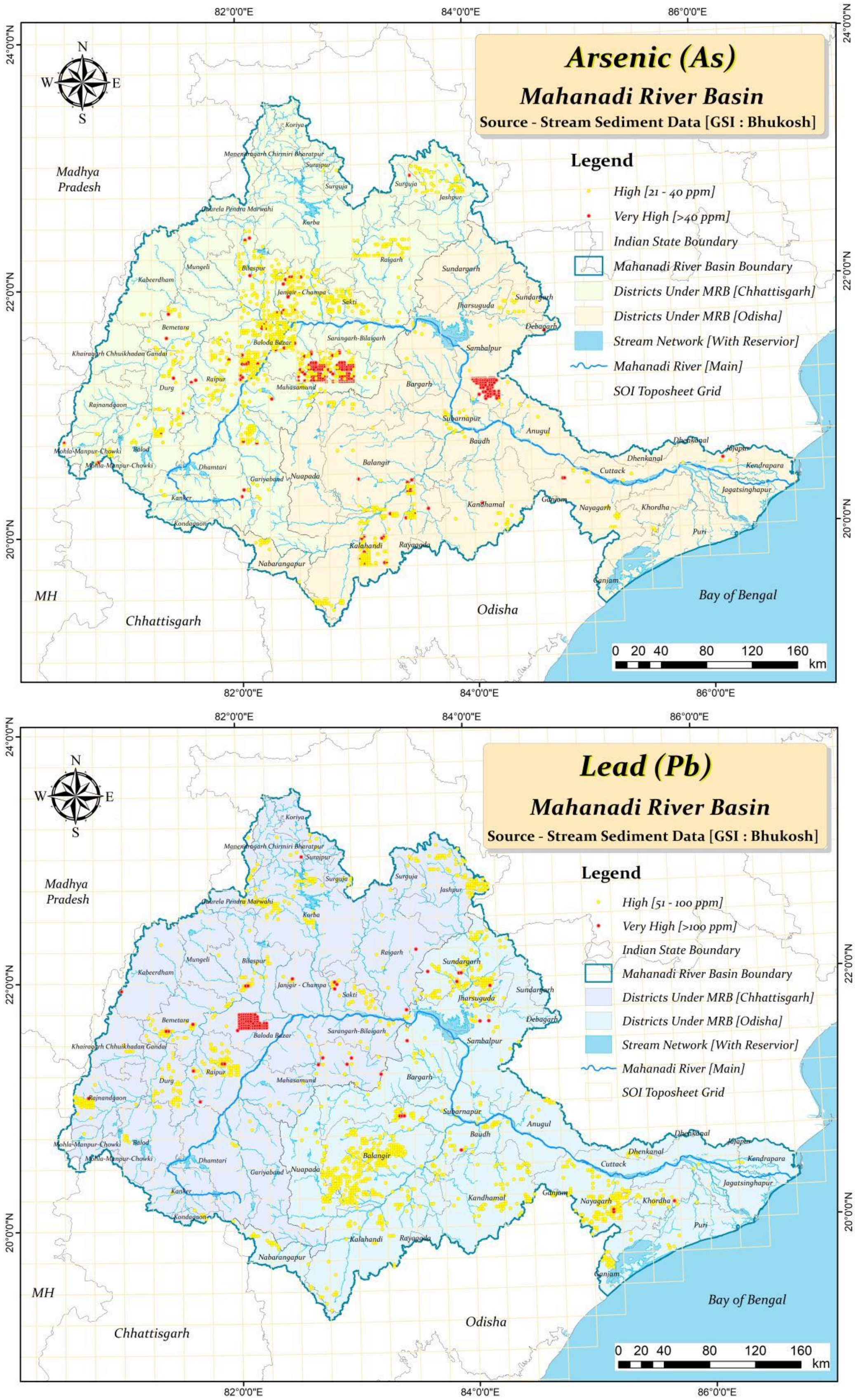


Figure 20: Hotspot mapping for Arsenic (As) and Lead (Pb) in the Mahanadi River Basin (MRB)

For Arsenic (As)

- High Organic Matter Content: Organic-rich sediments enhance microbial activity, which promotes reducing conditions favorable for arsenic mobilization.
- Paddy Cultivation Practices: Alternating wet and dry cycles in rice fields cause geochemical fluctuations that trigger arsenic release from sediments.
- Alluvial Geology: Sediments derived from arsenic-bearing source rocks in alluvial plains can naturally contain elevated As levels.
- Groundwater-Surface Water Interaction: In areas with high hydraulic connectivity, arsenic from groundwater or deep sediments may migrate into surface sediments.

For Lead (Pb)

- Industrial Discharges: Emissions from smelting, battery recycling, and metal processing introduce lead into streams via surface runoff and wastewater.
- Urban Runoff and Vehicular Emissions: Lead particles from vehicle exhaust (legacy sources) and urban dust accumulate in street runoff and settle in streambeds.
- Low Mobility in Environment: Lead tends to adsorb strongly to fine particles and organic matter, causing it to accumulate and persist in sediment.
- Atmospheric Deposition: Emissions from industrial stacks or fossil fuel combustion deposit Pb over large areas, contributing to diffuse sediment contamination.
- Mining and Coal-based Power Generation: Tailings, fly ash, and leachates from coal and metal mines release lead into adjacent water bodies and sediment layers.

These findings highlight the critical need for continuous monitoring of trace metal concentrations in stream sediments, particularly in identified hotspot zones. Integrating geochemical insights with land-use and industrial activity data will strengthen basin-wide strategies for pollution control, ecological protection, and sustainable river basin management.

3. Natural Geological Hazards

The Mahanadi River Basin has witnessed several significant natural geological hazard events over the years, particularly flooding, erosion, and droughts. The Environmental Impact Assessment (EIA) Report, Government of India, 2010, highlights the significant impact of mining and deforestation on flooding in the Mahanadi River Basin. Sand mining, particularly along the riverbed, disrupts natural barriers, reducing the river's ability to manage and store floodwaters, which in turn heightens the risk of flooding. In addition, the extraction of coal and other minerals in the upper catchment areas alters water flow patterns, contributing to sudden surges of water downstream during periods of heavy rainfall. Concurrently, deforestation in the catchment areas exacerbates flooding by diminishing the soil's capacity to absorb rainwater, resulting in increased surface runoff. The loss of vegetation, which typically helps to stabilize the soil, accelerates erosion and further amplifies flooding, as observed during the devastating floods of 2008 and 2011 in the basin. These activities, combined with the region's natural topography, underscore the need for sustainable management practices to mitigate flooding risks and protect the ecological balance of the Mahanadi River Basin.
Below are some of the specific events in the basin, along with references to their occurrence:

- **Flooding Events:**
  - **2008 Mahanadi Floods**: One of the most significant flooding events occurred in 2008 when heavy rains in the catchment areas of Chhattisgarh and Odisha resulted in the Mahanadi River overflowing its banks. This led to extensive flooding, particularly in the downstream areas of Cuttack, Sambalpur, and other parts of Odisha. The flood caused significant damage to crops, homes, and infrastructure.
  - **2011 Floods**: Another major flood event occurred in 2011 when the Mahanadi experienced high discharge due to a combination of heavy rainfall in the upper catchments of Chhattisgarh and release of water from Hirakud Dam. This event impacted areas in Odisha, including the capital, Bhubaneswar, and led to significant agricultural and infrastructural losses (CWC, 2011).

- **Landslides:**

Landslides in river catchments contribute to sediment overload, disrupt flow regimes, and pose direct threats to infrastructure and life. In Odisha, parts of the Mahanadi basin covers undulating terrains, forested slopes, and plateau edges prone to shallow and deep-seated landslides, especially during monsoon. Table 5 provides the list of landslide prone area in Odisha (According to OSDMA Report). According to the Chhattisgarh State Disaster Management Plan (SDMP, 2019), landslides have been reported in specific districts including Kondagaon, Kanker, Dantewada, Sarguja, and Kabirdham. Among these, Kanker, Sarguja, and Kabirdham are partially covered under the Mahanadi River Basin (MRB). These areas, characterized by hilly terrain, lateritic soils, and dense forests, are particularly susceptible to slope instability during intense rainfall events.

Table 8: Landslide Prone area in Odisha (According to OSDMA Report)

District	**Landslide Area**
Sambalpur (along NH 53, which connects Kolkata and Mumbai)	• Lakshmidunguri Hill (Along NH 53) • Burla (Along NH 53)
Bargarh	• Hilly areas near the Gandhamardhan Hills • Barapahar Range
Bolangir	• Gandhamardhan Hills • Khaparakhol Block • Patnagarh Subdivision
Nuapada	• Sunabeda Plateau • Khariar Hills
Kalahandi	• Niyamgiri Hills • Thuamul-Rampur Block
Nabarangpur	• Jharigam Block • Raigarh and Chandahandi Block
Kandhamal	• Phulbani • Daringbadi • Belghar • Kotagarh Block • Tumudibandha Block

➢ **Erosion and Riverbank Instability:**

- **Chilika Lake and Mahanadi River Erosion**: The river's downstream regions, particularly near Chilika Lake, face significant erosion due to seasonal flooding, resulting in shifting of river channels and loss of agricultural land. Erosion is exacerbated by human activities such as sand mining and deforestation.
- This study revealed the coastal erosion trend of Mahanadi delta and based on the predicted coastlines it can be inferred that the coastal communities in near future would be facing substantial threat due to erosion particularly in areas surrounding (Mukhopadhyay et al. 2018)

➢ **Sedimentation and River Siltation**:

- Hirakud Dam Siltation: The Hirakud Dam, built across the Mahanadi River, faces ongoing challenges from sedimentation. The upstream regions carry large amounts of sediment during the monsoon, which is deposited in the reservoir, reducing its water storage capacity. This issue has been a concern since the dam's construction in the 1950s.

These events highlight the ongoing geological hazards and natural challenges in the Mahanadi River Basin. They also emphasize the importance of monitoring and managing these risks to safeguard both the environment and the livelihoods of people living in the basin.

3.1 Potential Impacts on Geological Structures, Groundwater and Infrastructure.

1. **Impact on Geological Structures**
   Erosion & Sedimentation can alter riverbanks, hillslopes, and floodplains, leading to changes in landforms.
   Landslides: Cause mass movement of soil and rock, reshaping hills and valleys, especially in Chhattisgarh's hilly terrain.
   Earthquakes: (Though rare) Can lead to faulting, fractures, and displacement of rock layers.
   Riverbank Collapse weakens geological formations, leading to loss of fertile land.

2. **Impact on Groundwater**
   Flooding increases groundwater recharge temporarily but can also contaminate it with sediments and pollutants. Droughts Lower the groundwater table, leading to water scarcity. Siltation affects aquifer recharge by clogging pores in riverbeds. Land Subsidence (due to erosion or over-extraction) Can permanently reduce groundwater storage capacity.

3. **Impact on Infrastructure**
   Flooding can damage to bridges, roads, and buildings, especially in low-lying areas like Odisha. Landslides block highways and railways, disrupting transportation and connectivity. Droughts can affect irrigation systems, hydropower generation, and drinking water supply.

4. Data Gap

While detailed official data on sand mining is not currently available, we have formally requested this information from the concerned department and will update the report upon receipt of any official data. In the meantime, available online sources, research articles and satellite imagery from Google Earth have been compiled and analyzed to provide indicative insights into sand mining activities in the study area. However, it is important to note that data on hill slope changes is not available with any department and remains a gap in the current assessment.

5. Conclusion

The geological profile of the Mahanadi River Basin (MRB) reveals a region of significant geological diversity and resource richness. The basin's complex lithological formations, encompassing ancient crystalline rocks, Gondwana sediments, and extensive alluvial plains, have fostered the development of various mineral resources, including coal, iron ore, bauxite, and limestone. These resources have been instrumental in driving regional economic activities, particularly in the states of Odisha and Chhattisgarh.

However, the MRB's geological integrity faces increasing challenges due to both anthropogenic activities and natural hazards. Intensive mining operations, including open-cast mining and riverbed extraction, have led to land degradation, alteration of natural drainage patterns, and increased sedimentation in river systems. Tunneling and potential fracking activities pose risks to subsurface stability, while deforestation and hill slope modifications exacerbate soil erosion and reduce the land's natural resilience to environmental stresses.

Sand mining in the Mahanadi River Basin presents a serious environmental and socio-economic challenge. While it contributes to economic development, its unregulated expansion threatens river health, biodiversity, and local livelihoods. Addressing this crisis requires stronger policy enforcement, scientific research, and community-driven conservation efforts to ensure sustainable river management.

In light of these findings, it is imperative to adopt an integrated approach to managing the MRB's geological resources and hazards. This includes:

- Sustainable Resource Management: Implementing best practices in mining and land use to minimize environmental degradation.
- Hazard Mitigation: Developing early warning systems and infrastructure to reduce the impact of natural disasters.
- Stakeholder Engagement: Involving local communities, industry stakeholders, and policymakers in decision-making processes to ensure inclusive and effective management strategies.
- Research and Monitoring: Conducting ongoing geological and environmental studies to inform adaptive management and policy development.

By addressing these areas, the MRB can balance the exploitation of its geological resources with the preservation of its environmental integrity, ensuring long-term sustainability and resilience for the region.

6. Recommendation

1. Safeguarding the Geological Identity of River Landscapes.

Geo-Spatial Monitoring and Assessment:

- To develop a GIS-based geological inventory and identity map to detect landscape alterations.
- Use satellite imagery and UAV (drone) surveys to map topographic changes.
- Integrate temporal geospatial datasets to assess long-term anthropogenic impacts.

Community and Academic Involvement:

- Encourage partnerships with universities and research institutes for periodic geological assessments.
- Promote citizen science initiatives for recording local geological changes.

2. Managing Excavation, Blasting, and Mining Activities with Ecological Sensitivity

Remote Sensing and Sensor Integration:

- Use InSAR (Interferometric Synthetic Aperture Radar) to detect ground displacement due to underground mining or blasting.

Regulatory Enforcement:

- Mandate Environmental Impact Assessments (EIAs) prior to approval of mining/explosive activities near rivers.
- Designate buffer zones where such activities are prohibited near sensitive river stretches.

3. Sustainable Tunneling Practices for River Basin Stability

Predictive Modelling and Risk Assessment:

- Use geological modeling and simulation tools to assess risks to aquifers and riverbeds before tunneling begins.
- Employ groundwater flow modeling (e.g., MODFLOW) to predict alterations in subsurface hydrology.

Monitoring Infrastructure Integrity:

- Install structural health monitoring (SHM) sensors in tunnels near rivers to detect subsidence or leakage.
- Develop early warning systems using AI-based anomaly detection.

4. Conserving Riparian Forests and Watershed Vegetation

Remote Sensing and Vegetation Indexing:

- Utilize NDVI (Normalized Difference Vegetation Index) from satellite imagery to monitor riparian and hill slope vegetation loss.
- Encourage reforestation through GIS-based prioritization of degraded areas.

Community Forest Governance:

- Involve local communities in afforestation drives and protection of river buffer zones.
- Promote agroforestry and sustainable land-use practices.

5. Promoting Responsible Riverbed Resource Utilization to Control Sand Mining:

Use of Remote Sensing and Satellite Imagery:

- Satellite images can be used to detect changes in river morphology, sandbar locations, and excavation patterns over time.
- High-resolution DEMs (e.g., from LiDAR, TanDEM-X, or CartoDEM) can help estimate volume change in the riverbed.
- Drone Survey can be done to get high-resolution imagery and 3D surface models (Small stretches where illegal mining is suspected)
- Combine satellite-based estimations with ground-based GPS surveys to improve accuracy.

Real-time Monitoring using IoT & AI:

- Install CCTV cameras, RFID tags on trucks, and AI-based movement tracking to ensure sand transport is monitored. Use AI to analyze satellite data and raise alerts for suspicious activity.

Strengthening Governance:

- Establish a Sand Mining Monitoring Cell with trained staff.
- Involve local communities and NGOs in reporting and oversight.

Policy and Legal Action:

- Enforce mandatory geotagging and GPS tracking of licensed mining areas.
- Penalize transporters and buyers of illegally mined sand.

6. Building Resilience Against Natural Geological Hazards in the Basins

Multi-Hazard Mapping and Preparedness:

- Develop a hazard susceptibility map for landslides, earthquakes, and floods using geological and historical data.
- Install river-level sensors, seismometers, and real-time alert systems integrated with a centralized dashboard.

Disaster-Resilient Infrastructure:

- Promote climate- and hazard-resilient designs for bridges, embankments, and water infrastructure.
- Train local disaster response teams in geologically vulnerable areas.

7. Protecting Subsurface Integrity: Geological Structures, Groundwater, and Infrastructure

Integrated Monitoring and Data Sharing:

- Establish a centralized digital platform for geological and hydrological data sharing between agencies.

Legal and Regulatory Measures:

- Mandate buffer zones between heavy construction activities and known geological structures or aquifers.
- Include geotechnical clearances as part of all major infrastructure project approvals near river systems.

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