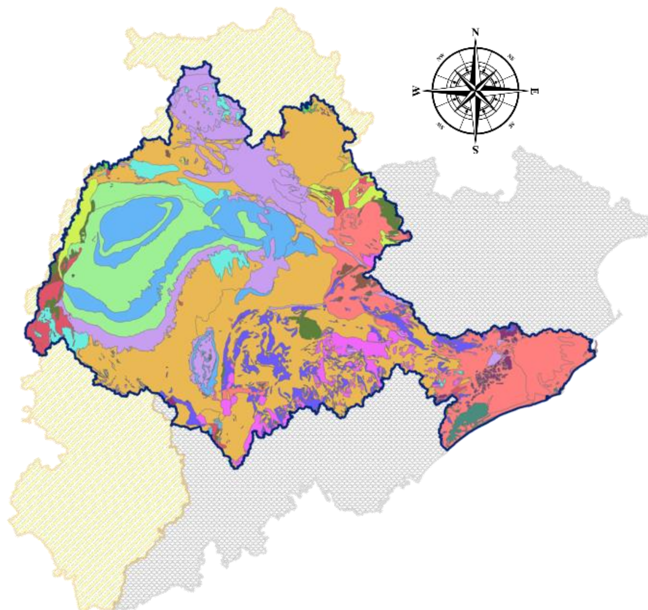
National River Conservation Directorate
Ministry of Jal Shakti,
Department of Water Resources,
River Development & Ganga Rejuvenation
Government of India

Lithological Profile of Mahanadi River Basin



December 2024

cMahanadi

cGanga

Lithological Profile of Mahanadi River Basin

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.

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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 center 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

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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.

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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
ICAR	Indian council of Agricultural Research
NBSS&LUP	National Bureau of Soil Survey & Land Use Planning
CGWB	Central Ground Water Board
GFDRR	Global Facility for Disaster Reduction and Recovery
IGKV	Indira Gandhi Krishi Vishwavidyalaya
OSDMA	Odisha State Disaster Management Authority
GSI	Geological Survey of India
FAO	The Food and Agriculture Organization

1. Introduction

The Mahanadi Basin is a prominent river basin in India, spanning multiple states and characterized by diverse geological features and abundant natural wealth. Its lithological formations trace the basin's evolutionary journey and sedimentary processes. The basin's geological makeup ranges from Precambrian metamorphic rocks to more recent alluvial deposits, offering a glimpse into its stratigraphic and sedimentary complexity.

1.1 Brief Overview

The Mahanadi River Basin, one of India's major river systems, spans approximately 1,41,600 square kilometers across central and eastern India, covering parts of Chhattisgarh, Odisha, Jharkhand, Maharashtra, and Madhya Pradesh. The Mahanadi River, originating from the highlands of Chhattisgarh near the Amarkantak Plateau, flows eastward for about 851 kilometers before emptying into the Bay of Bengal. Once known as the "Sorrow of Odisha" for its devastating floods, the Mahanadi River has been transformed into a lifeline, providing water for irrigation, drinking, and hydroelectric power to millions.

The basin exhibits diverse landscapes, ranging from the rugged terrain of the Chhattisgarh Plateau to the fertile coastal plains of Odisha. This region receives significant rainfall during the monsoon season, making it a vital agricultural hub. It is home to a rich network of tributaries, including the Seonath, Hasdeo, Jonk, Ib, and Tel rivers, which contribute to its expansive drainage system.

Geologically, the basin is a treasure trove of natural resources, hosting a wide array of lithological formations from Precambrian crystalline rocks to Quaternary alluvium. The basin's economic significance is amplified by its abundant reserves of coal, iron ore, bauxite, and fertile soils, which support mining, agriculture, and industrial activities.

The Mahanadi River Basin not only sustains vibrant ecosystems but also holds immense cultural and historical importance, with ancient cities and temples located along its banks. However, challenges such as deforestation, urbanization, pollution, and the impacts of climate change necessitate focused efforts for sustainable development and resource management.

1.2 Importance of Lithological Study in River Basin Management

Canvas painted, layers deep, A basin's story, secrets to keep.
From ancient rocks to modern sands, Geology's wisdom, in nature's hands.
Beneath the surface, treasures reside, A bounty of resources, a natural tide.
Groundwater flows, a life-giving source, Geology's knowledge, of utmost force.
So let us study, the Earth's grand art, to understand its secrets, right from the start.
For in the basin's depths, we'll find the key, To sustainable future, wild and free.
- AI Generated

A lithological study plays a crucial role in understanding the geological, environmental, and economic dynamics of a river basin. It involves analysing the composition, distribution, and characteristics of rocks and sediments within the basin, offering insights that are vital for sustainable development, resource management, and environmental conservation. The Importance of lithological study in River Basin Management is explained in Table 1.

Table 1: Importance of lithological study in River Basin Management

Management Parameters	**Importance**
Understanding Basin Evolution	Lithological studies provide information about the geological history of a basin, including sedimentation patterns and erosion processes. This helps reconstruct the basin's evolution over geological time scales.
Resource Exploration and Management	The lithology of a river basin reveals the presence of valuable resources such as: Minerals and Fossil Fuels: Identifying coal, iron ore, bauxite, and hydrocarbon reserves.
Hydrological Insights	Lithological characteristics influence the permeability, porosity, and water-holding capacity of rocks and sediments, which are critical for understanding groundwater flow, surface runoff, and water resource management.
Infrastructure Planning	Knowledge of lithological features is essential for designing and constructing dams, bridges, tunnels, and other infrastructure. It ensures stability and prevents geotechnical issues such as landslides or structural failures.
Natural Hazard Assessment	Lithology helps assess the risk of natural hazards like floods, landslides, and soil erosion by analyzing the behaviour of rocks and sediments during such events.
Ecological and Environmental Impact	The lithological composition influences soil formation, vegetation patterns, and habitat diversity, making it integral to ecological conservation and sustainable land-use planning.

2 Study Area

2.1 Geographic Overview of the Mahanadi River Basin

The Mahanadi River Basin, covering an expansive area of around 143,687.75 square kilometers, is one of India's significant river systems, geographically spanning central and eastern India. It primarily stretches across the states of Chhattisgarh and Odisha, with additional minor portions extending into Madhya Pradesh, Maharashtra, and Jharkhand as shown in Figure 1. This basin forms a vital lifeline for millions of people, supporting agriculture, industry, and ecosystems across its reach. The basin exhibits a diverse lithological profile, contributing significantly to the hydrological, geomorphological and ecological characteristics of the region.

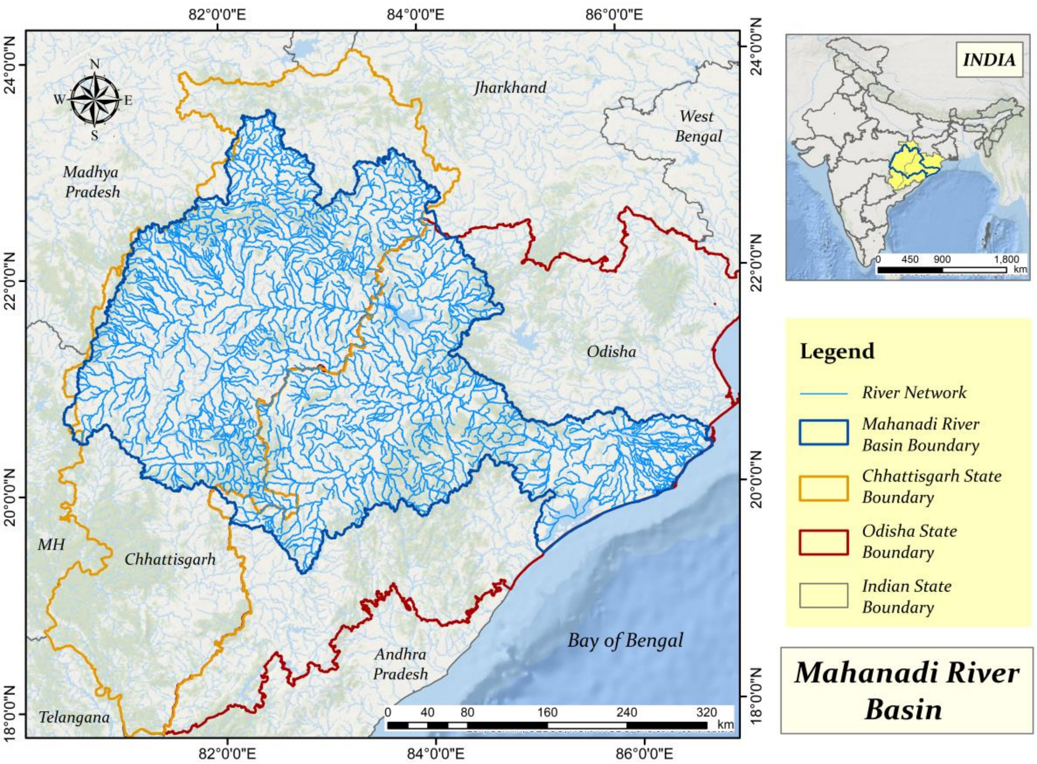


Figure 1: Mahanadi River Basin

2.2 Physiographic Features

The Mahanadi River Basin's physiography is intricately linked with its lithological diversity, which has shaped the landscape, drainage patterns, and soil characteristics across various regions of the basin. The basin's physiography can broadly be classified into the following major units:

Highland Plateaus and Hilly Regions: The northern and western portions of the basin are dominated by highland plateaus and hills, where Precambrian igneous and metamorphic rocks, such as granite, gneiss, and schist, form the underlying lithology. These regions include the Chota Nagpur Plateau and portions of the Eastern Ghats, characterized by rugged terrain, steep slopes, and high elevations. The resistant rocks in these areas withstand erosion, resulting in prominent hill formations and escarpments, especially along the northern boundary of the basin. The lithology here limits soil depth and supports sparse vegetation, with exposed rock surfaces contributing to low permeability and increased surface runoff.

Central Plains and Valleys: The central part of the Mahanadi Basin features broad alluvial plains and river valleys. These low-lying regions are underlain by relatively younger sedimentary deposits, including sandstone, shale, and limestone, particularly around the middle course of the Mahanadi River. The plains are well-drained and have fertile, alluvial soils that support intensive agriculture, with a gradual topographical slope that allows for smooth river flow. This region acts as the principal agricultural zone, benefiting from both riverine deposits and seasonal flooding, which enriches soil nutrients.

Basaltic Terrains of the Deccan Plateau: The southwestern parts of the basin, extending into the Deccan Plateau, are marked by basaltic formations from the Deccan Traps. These terrains, composed mainly of layered basalt flows, have formed through ancient volcanic activity. The basaltic lithology results in undulating terrain with gentle slopes and dark, fertile soils (black soils) that are highly suitable for dryland farming. Basaltic rocks are fractured and porous, facilitating groundwater recharge and forming aquifers that are vital for irrigation and domestic water supply.

Eastern Coastal Plains: As the Mahanadi River approaches the Bay of Bengal, it flows through the expansive coastal plains of Odisha. This region is primarily composed of unconsolidated alluvial sediments, such as sand, silt, and clay, deposited by the river and its distributaries over time. The coastal plains feature flat topography with minor undulations and are frequently subject to coastal flooding, especially during cyclonic events. These alluvial deposits also contribute to the formation of fertile deltaic soils, which support extensive paddy cultivation, aquaculture, and settlements.

Deltaic and Estuarine Zone: The Mahanadi Delta, one of the most prominent physiographic features of the basin, is situated at the river's confluence with the Bay of Bengal. It is formed by a network of distributaries carrying sediments from upstream lithological zones. The deltaic region consists of fine-grained, fertile alluvial deposits that have accumulated over millennia. This area is characterized by flat, low-lying terrain, making it susceptible to both riverine and coastal flooding. The sedimentary lithology here is vital for maintaining coastal ecosystems, with extensive mangrove forests that act as natural flood barriers.

Soil Characteristics: The lithological profile influences soil diversity across the basin's physiographic units. In highland areas with granitic and gneissic rocks, shallow, coarse-textured soils are prevalent, limiting agricultural activities. Central plains and river valleys, with sedimentary rock formations, have deep, fertile alluvial soils supporting intensive cropping. The Deccan Plateau's basaltic regions are associated with rich black soils, which retain moisture well, making them suitable for cotton and oilseed crops. In the coastal and deltaic zones, fine alluvial and clayey soils are ideal for rice cultivation but are vulnerable to saline intrusion.

Overall, the Mahanadi River Basin's physiography is a product of its complex lithological underpinnings, shaping its topography, soil composition, and hydrology. These physiographic features not only define the basin's landscape but also significantly influence its land use, agriculture, water availability, and environmental management.

3 Data Sources and Tools Used

Table 2: Datasets Used

S. No.	Data Theme	Source (Agency/Department)	Data Type
1	Lithology (1:50k)	GSI	Shape File
2	Aquifer System, Litholog	CGWB	Shape File
3	Soil Texture, Depth, Productivity	NBSS&LU	Shape File
4	District-wise Soil Characteristics: (Soil Type, Local Name, Colour, Soil Texture, Infiltration Constant (cm/h), Avg. pH, Avg. EC (dS/m), Avg. Soil Water Holding Capacity (mm/M), Avg. Organic Matter Content (%), Avg. Soil depth (cm), Micro-nutrient Deficiency, Average Available Nutrient Status (kg/ha))	1. Department of Agriculture Development and Farmer Welfare and Bio-Technology, Govt of CG 2. State Agriculture University (IGKV, Raipur) 3. Published Research Articles 4. District Survey Report of each district of Odisha	Reports and Research Articles

Table 3: Tools Used

S. No.	Software	Purpose
1	ArcGIS 10.8	For Geospatial Analysis & Mapping
2	MS Office	For Report Formatting

4 Geological Settings of Mahanadi River Basin

4.1 Tectonic Framework of the Mahanadi River Basin

The Mahanadi River Basin, located in the eastern part of peninsular India, exhibits a complex and tectonically controlled geological setting. Its structural configuration has evolved through multiple tectonic episodes, ranging from the Archean to the Cenozoic, profoundly influencing its geomorphology, drainage patterns, sedimentation, and groundwater regime.

4.1.1 Tectonic Setting:

The basin is situated between two major geological provinces: the Bastar Craton to the west and the Eastern Ghat Mobile Belt (EGMB) to the east. This tectonic juxtaposition results in a transition zone that has experienced long-term crustal evolution and deformation events. The central part of the basin overlays the Chhattisgarh Synclinorium, a Proterozoic sedimentary basin developed over the cratonic basement.

4.1.2 Major Tectonic Elements

Key tectonic features shaping the basin include:

- **Mahanadi Fault (MF):** A major NW–SE to E–W trending fault system that significantly controls the alignment of the Mahanadi River and its tributaries. This fault has influenced sedimentation and river migration patterns throughout geological time.
- **Eastern Ghat Boundary Fault (EGBF):** A prominent fault demarcating the contact between the Eastern Ghat Mobile Belt and the coastal plains. It is considered tectonically active and may be associated with neotectonic uplift and tilting in the deltaic region.
- **Chhattisgarh Syncline:** A broad synclinal structure formed during Proterozoic sedimentation, with overlying sedimentary rocks of the **Chhattisgarh Supergroup**, influencing the hydrogeological regime of the upper basin.
- **Lineaments and Fracture Zones:** Numerous N-S, NE-SW, and E-W trending lineaments act as zones of weakness, guiding river channels and groundwater movement. These are interpreted as manifestations of basement tectonics (Sinha et al., 2002).

4.2 Lithology

The Mahanadi Basin, is characterized by a diverse lithological sequence, primarily composed of Precambrian and Proterozoic rocks. The basin has undergone complex geological processes, resulting in a varied assemblage of geology types. Figure 2 shows the detail lithology of Mahanadi basin the predominant lithological units in the Mahanadi Basin include:

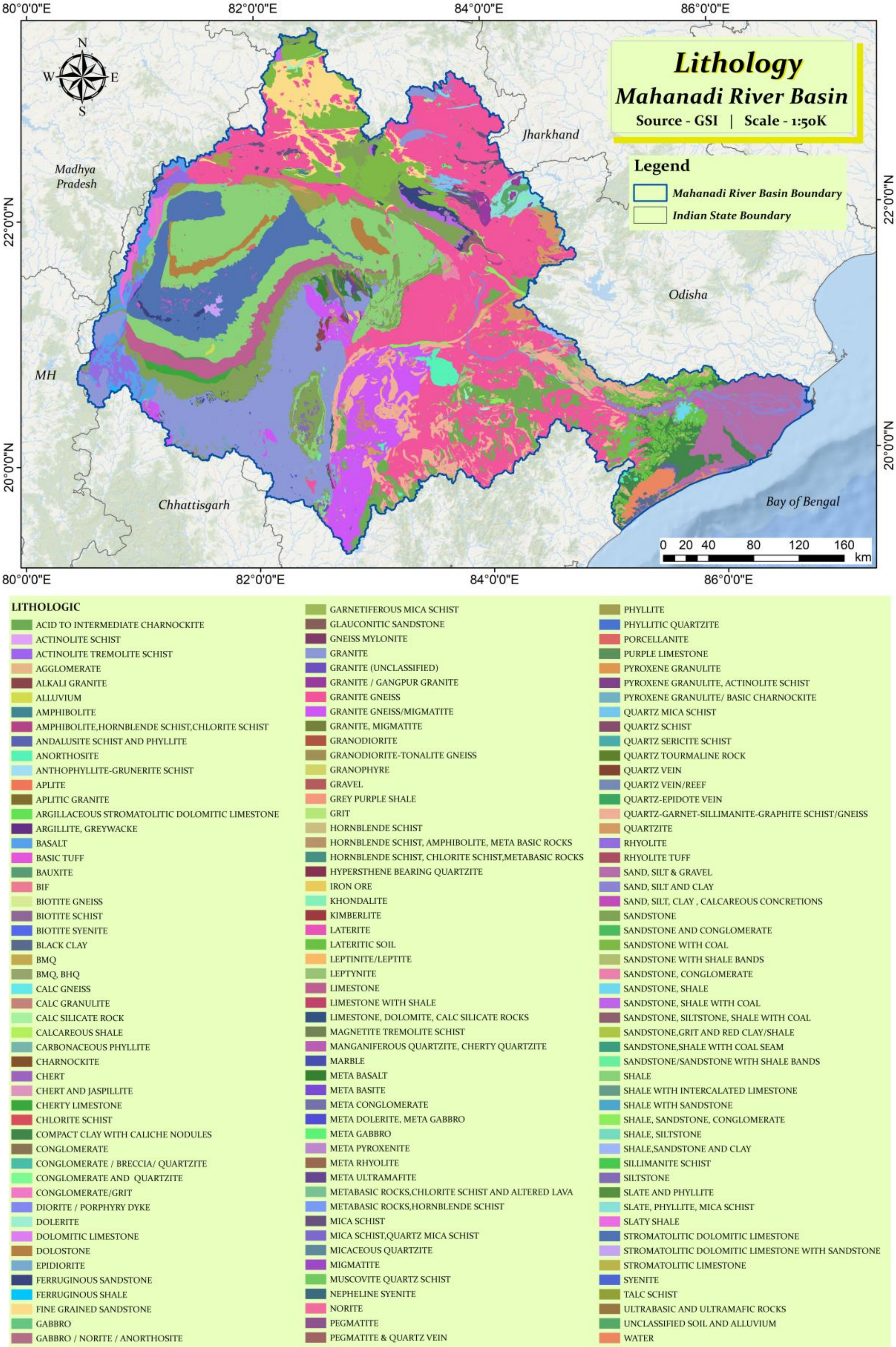


Figure 2: Lithology Map of Mahanadi Basin

- Archaean-Paleoproterozoic Metamorphic Rocks:
    - Lower Bonai Group: Comprising amphibolite, hornblende schist, chlorite schist, quartzite, slate, phyllite, and mica schist. These rocks represent the oldest formations in the basin and are indicative of intense metamorphism and deformation.
    - Gangpur Group: Consisting of quartzite, shale, phyllite, and conglomerate. These rocks are associated with a marine sedimentary environment and subsequent metamorphism.
- Paleoproterozoic Sedimentary Rocks:
    - Kolhan Group: Composed of sandstone and conglomerate, indicating a fluvial or deltaic depositional setting.
- Proterozoic Intrusive Rocks:
    - Granitic Intrusions: These intrusive, such as granite and granite gneiss, are associated with periods of magmatic activity and crustal deformation.
    - Ultramafic and Mafic Intrusions: These rocks, including amphibolite and pyroxenite, represent intrusive events related to tectonic processes.

In Chhattisgarh the lithology is divided into three major grouped detailed in Table 4. The lithological succession, from older to younger, includes the Raipur Group, the Sakoli Group, and the Bhilai Group.

Table 4: Lithology of Chhattisgarh State

Group	Formation	Lithology
Raipur Group	Maniari Shale	Shale, dolomite, gypsum
Raipur Group	Hirri Dolomite	Grey dolomite
Raipur Group	Tarenga Shale	Dolomitic shale, shale-chert beds, purple shale, limestone
Raipur Group	Chandi Limestone	Stromatolitic dolomite, limestone, glauconitic sandstone, shale
Raipur Group	Gunderdehi Shale	Shale with limestone interbeds, arenite-shale, ignimbrite
Raipur Group	Charmuria Limestone	Phosphatic limestone with shale interbeds
Sakoli Group	Daltongunj Formation	Phyllite, schist, quartzite, marble
Sakoli Group	Dongargarh Formation	Granite, gneiss, quartzite
Bhilai Group	Bailadila Formation	Iron ore, shale, quartzite
Bhilai Group	Lohandiguda Formation	Conglomerate, sandstone, shale

(Source: https://www.ndrdgh.gov.in)

These formations exhibit a diverse range of lithologies, including shales, dolomites, limestones, sandstones, and iron ores. The Chhattisgarh Basin is known for its significant iron ore deposits, particularly associated with the Bailadila Formation of the Bhilai Group. The basin's sedimentary sequence provides valuable insights into the geological history of the region and its mineral resource potential.

Spatial Distribution and Geological Significance:

The spatial distribution of these lithological units varies across the basin. Metamorphic rocks, particularly those of the Lower Bonai Group, are widely distributed, forming the basement complex. Sedimentary rocks, such as the Kolhan Group, are found in specific areas, often overlying the metamorphic basement. Intrusive rocks occur as smaller bodies within the sedimentary and metamorphic sequences.

The geological history of the Mahanadi Basin is complex and involves multiple phases of sedimentation, deformation, metamorphism, and magmatism. Understanding the lithological characteristics of the basin is crucial for various applications, including mineral exploration, groundwater resource assessment, and engineering geology.

The lithological diversity of the Mahanadi Basin significantly influences its agricultural, mineral, and coal mining potential explained below:

- Agriculture:
  - Soil Formation: The underlying geology, particularly the weathering of metamorphic and igneous rocks, contributes to the formation of fertile soils. The basin's diverse lithology leads to a variety of soil types, including red and yellow soils, black cotton soils, and lateritic soils, each supporting specific crops.
  - Water Resources: The basin's river system, fed by monsoon rains and groundwater reserves, is crucial for irrigation. The underlying geological formations influence groundwater availability and quality, impacting agricultural practices.
  - Land Use: The basin's topography, shaped by geological processes, determines the suitability of land for different agricultural practices. Hilly terrains are often used for terrace farming, while plains are ideal for mechanized agriculture.
- Mineral Exploration:
  - Metalliferous Minerals: The presence of metamorphic and igneous rocks, particularly in the older parts of the basin, indicates the potential for various metalliferous minerals like iron ore, manganese ore, chromite, and bauxite.
  - Non-Metallic Minerals: Sedimentary rocks, such as limestone and dolomite, are important for cement and steel industries.
  - Industrial Minerals: Clays, silica sands, and other industrial minerals are also found in the basin, supporting various industries.
- Coal Mining:
  - Coal Deposits: The basin is renowned for its extensive coal reserves, primarily associated with the Gondwana Supergroup. The sedimentary rocks of this group, including shale, sandstone, and coal seams, provide the source for coal mining.

- Mining Impact: Coal mining, while contributing to energy production, can have significant environmental impacts, including land degradation, water pollution, and deforestation. Understanding the underlying geology is crucial for sustainable mining practices and environmental mitigation.

The Mahanadi Basin's diverse lithology plays a pivotal role in shaping its agricultural, mineral, and coal mining landscape. The interplay between geology, soil formation, water resources, and mineral deposits influences the region's economic development and environmental sustainability. By understanding the geological context, it is possible to optimize resource utilization, groundwater resource assessment, mitigate environmental impacts, informed decision-making in various sectors and ensure the long-term well-being of the region.

4.3 Litholog

The Chhattisgarh part of the Mahanadi Basin is primarily composed of sedimentary rocks belonging to the Chhattisgarh Supergroup. This Supergroup comprises a thick sequence of predominantly siliciclastic and carbonate formations, deposited in a marine environment during the Mesoproterozoic era. The locations of Litholog taken over the Mahanadi River basin during the period of 1996 to 2005 by the CGWB are depicted in the Figure 3.

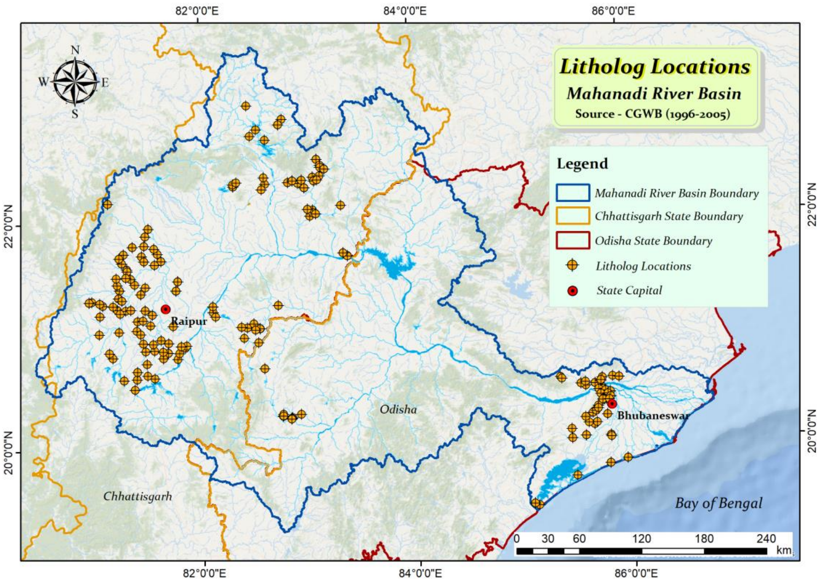
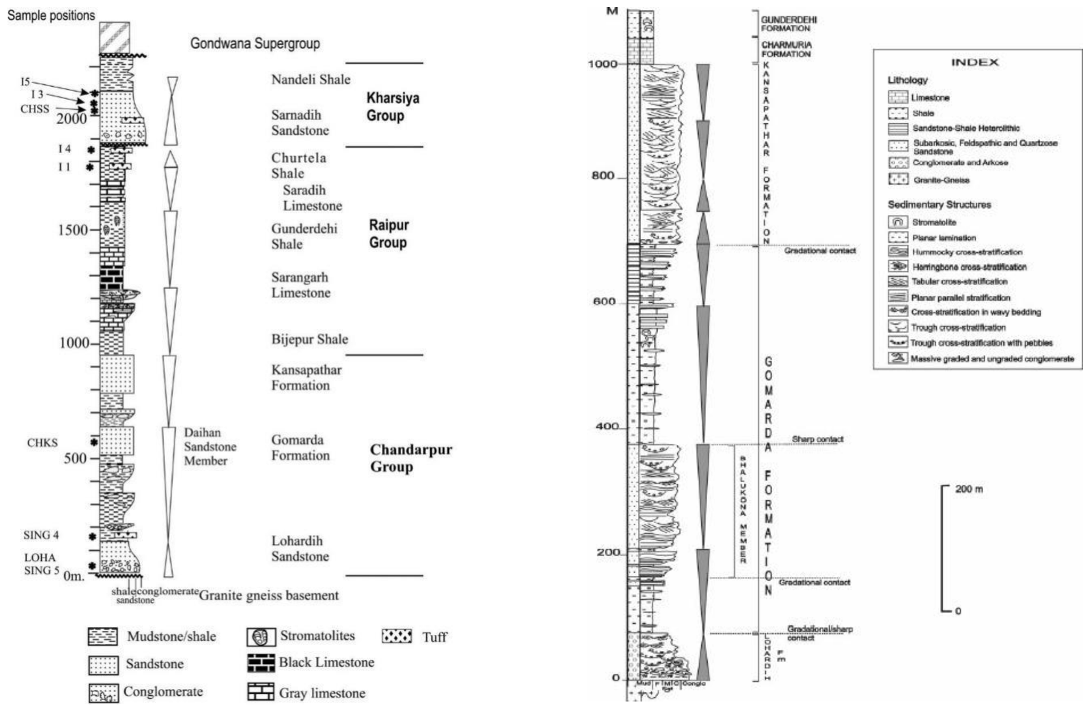


Figure 3: Map Showing Litho-log Locations of Mahanadi River Basin

Detail of vertical sequence of rocks encountered in a two specific within the basin is shown in Figure 4. To overview general Lithology, its age, depositional environment and thickness refer Figure 5.



a. Lithostratigraphic column of the Chhattisgarh Supergroup in the eastern part of the basin (Patranabis-Deb & Chaudhuri, 2008)

b. Stratigraphic column of the Chattisgarh Supergroup around Singhora-Saraipali, Chattisgarh Basin (Dhang & Patranabis-Deb, 2011)

Figure 4: Sample Litho-log of Chhattisgarh part of Mahanadi Basin

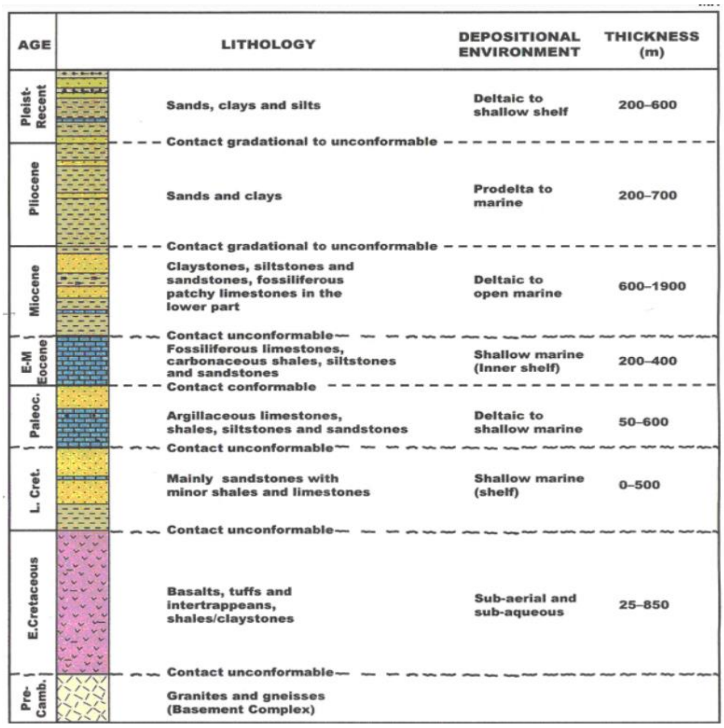


Figure 5: Generalized Lith-stratigraphic Column of Mahanadi Shallow offshore Basin

(Source: https://www.dghindia.gov.in/assets/downloads/56cfd80936b91The_Mahanadi_Basin.pdf)

The litholog of the Mahanadi River Basin in Odisha primarily reflects the geology and sedimentology of the region. The Odisha part of the Mahanadi Basin is primarily characterized by a diverse lithological composition, which includes a variety of sedimentary rocks associated with the Gondwana Supergroup. This region features significant deposits of sandstones, shales, and coal, formed during the Late Paleozoic to Early Mesozoic eras in a predominantly fluvial and deltaic environment. The geological succession in Odisha can be categorized into several groups, including the Talcher Group, which is known for its coal deposits, and the Barakar Group, consisting mainly of sandstones and shales. Additionally, the eastern part of the basin is marked by recent alluvial deposits that have formed in the fertile delta region as the Mahanadi River approaches its confluence with the Bay of Bengal. This geological diversity not only influences the hydrology and soil types within the basin but also contributes to its agricultural productivity and ecological richness.

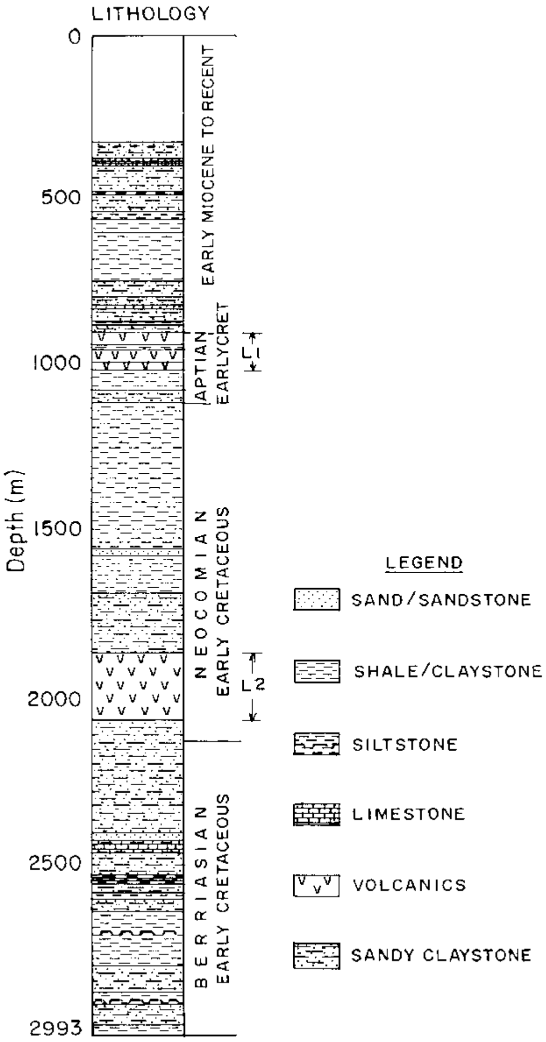


Figure 6: Sample Litho-log of Odisha part of Mahanadi Basin
(Source: CGWB Report, Cuttack Dist., Odisha)

Chhattisgarh: A Mineral-Rich State

Chhattisgarh is renowned for its rich mineral resources, particularly iron ore. The state boasts several major iron ore mines, including those in the Bailadila range. These mines contribute significantly to India's steel production.

Key Mineral Resources of Chhattisgarh:

- **Iron Ore**: Chhattisgarh is one of India's leading iron ore-producing states, 1/5 of indias's total. The Bailadila range is a major iron ore mining hub.
- **Coal**: The state possesses approximately 17% of India's total coal reserves, primarily in the Korba coalfield. Coal is used for power generation and industrial purposes.
- **Bauxite:** Bauxite, the primary ore of aluminum, is mined in several parts of the state. It holds approximately 5% of India's total estimated bauxite reserves.
- **Dolomite:** Dolomite is used in various industries, including steelmaking and cement production.
- **Minor Minerals:** Chhattisgarh also produces minor minerals like limestone, clay, and silica sand.

The mining industry plays a crucial role in Chhattisgarh's economy. However, it is essential to balance mineral extraction with environmental conservation and sustainable development practices.

ODISHA: A Mineral-Rich State

Odisha, located in eastern India, is one of the most mineral-rich states in the country. Its geological diversity and vast natural resources make it a significant contributor to India's mineral production.

Major Minerals Found in Odisha

- **Iron Ore:** Odisha accounts for over 50% of India's iron ore production. Major reserves are located in Barbil-Koira region (Keonjhar and Sundargarh districts), Gandhamardan and Tomka areas.
- **Coal:** Odisha is the second-largest coal-producing state in India. Major coalfields are: Talcher Coalfields (Angul district), Ib Valley Coalfields (Jharsuguda and Sundargarh districts), Talcher Coalfield is one of India's largest reserves.
- **Chromite:** Odisha produces nearly 98% of India's chromite. Major deposits include: Sukinda Valley (Jajpur district), Baula-Nuasahi Belt (Keonjhar district).
- **Bauxite** Odisha holds 50% of India's bauxite reserves. Key areas are: Panchpatmali (Koraput district), Gandhamardan (Balangir and Bargarh districts).
- **Manganese:** Odisha contributes around 40% of India's manganese production. Found in: Keonjhar and Sundargarh districts, Rayagada and Koraput regions.
- **Limestone and Dolomite:** Essential for cement and steel industries. Found in Sundargarh, Bargarh, and Koraput districts.
- **Graphite:** Found in the Malkangiri, Rayagada, and Balangir districts.
- **Beach Sand and Heavy Minerals:** Coastal regions (e.g., Ganjam district) are rich in ilmenite, rutile, and zircon.

Economic Contribution in Mahanadi Basin

The economies of both Chhattisgarh and Odisha are significantly bolstered by their abundant mineral wealth, a direct result of their unique lithology. Chhattisgarh, often called the "Rice Bowl of India," also possesses vast reserves of coal, iron ore, limestone, and bauxite. This geological endowment has fueled the growth of major industries like steel production, aluminum smelting and cement manufacturing, making the industrial sector the dominant force in its economy. Similarly, Odisha's economy thrives on its rich mineral deposits, including iron ore, chromite, bauxite, and coal. These resources have laid the foundation for a robust industrial sector, with significant contributions from steel, aluminum, and power generation.

The very nature of the rocks and their formation processes (lithology) in these states has resulted in the concentration of these valuable minerals. For instance, the presence of ancient sedimentary basins and metamorphic rock formations has led to the accumulation of coal and iron ore deposits. This favourable lithology has not only driven industrial development but also provided employment opportunities and contributed substantially to the states' revenues, highlighting the crucial link between geology and economic prosperity.

Key Industries in Mahanadi Basin

- **Iron and Steel**: Bhilai Steel Plant (BSP), Rourkela Steel Plant (SAIL), Tata Steel, and Jindal Steel.
- **Aluminum**: Bharat Aluminium Company Limited (BALCO). NALCO (National Aluminium Company), Vedanta.
- **Coal**: Korba Coalfield, South Eastern Coalfields Limited (SECL), Mahanadi Coalfields Limited (MCL).

The Mahanadi Basin stands as a testament to Earth's geological history and its abundant mineral wealth. Understanding the basin's complex lithological profile is vital for sustainable resource management and environmental conservation

4.4 Rock Types

The Mahanadi River Basin, a significant hydrological system, is characterized by a diverse lithological makeup. These geological formations significantly influence the various environmental and economic sector of the basin. Understanding rock types is crucial for various applications in basin analysis. It helps identify potential hydrocarbon reservoirs, groundwater sources, mineral deposits, and assess geotechnical and environmental factors.

The basin is underlain by various rock types of different geological ages from Pre-Cambrian to Recent age. These include the Archaean Crystalline, Precambrian Sedimentaries, Gondwanas, Deccan Traps and Unconsolidated Sediments. The major classification of rocks and its importance is detailed in Table 5, by understanding the specific characteristics of these rock types, we can better manage and utilize the resources of the Mahanadi Basin. The Rock Data Parameters of Mahanadi River Basin and detail characteristics are tabulated in Table 5.

Table 5: Different Rock Type in Mahanadi Basin and its Characteristics

Rocks Type	Groundwater Potential:	Mineral Resources	Fertility	Hydrocarbon Resources
Archaean-Paleoproterozoic Metamorphic Rocks:	Low permeability, fractures and weathered zones can act as aquifers, especially in hilly areas.	Contain valuable minerals like iron ore, manganese, and other metallic ores.	low fertility due to their crystalline nature	—
Paleoproterozoic Sedimentary Rocks	Excellent aquifers due to their porosity and permeability.	Sedimentary rocks can host non-metallic minerals like limestone, clay, and silica sand.	Rich in clay minerals, can weather to form fertile soils	Contain significant hydrocarbon reserves, including oil and natural gas.
Recent Alluvium and Deltaic Deposits	Excellent aquifers, providing water for agriculture and domestic use.	—	Highly fertile	—
Lateritic Deposits:	Porous, have low permeability but fractures and weathering can enhance their capacity.	They can contain valuable minerals like bauxite, used in aluminum production.	infertile due to the leaching of nutrients	—

The Chhattisgarh region of the basin is encompassing consolidated, semi-consolidated formations and unconsolidated formation (Table 6). Understanding the distribution and characteristics of these rock formations is crucial for sustainable groundwater management in the Mahanadi River Basin. The Figure 7 Shows the presence of both consolidated and semi-consolidated formations in Mahanadi Basin at Chhattisgarh State.

Table 6: Distribution of Hydrogeological Units in Chhattisgarh

Geological Age		Rock Formations	Districts/ Hydrogeological Characters
Consolidated Formations:			
Upper Cretaceous to Eocene	Deccan traps	Basalts, Dolerits and acidic derivatives of Basaltic magma	Jashpur, Surguja, Kawardha, Bilaspur
Pre Cambrian (Proterozoics)	Chhattisgarh Super Group, Indravati Group, Khariyar Group, Sukma Group and Pakhal Group	a) Consolidated sandstones b) Shales c) Limestones and Dolomites	Raipur, Durg, Dhamtari, Janjgir-Champa, Bilaspur, Mahasamund, Rajnandgaon, Raigarh, Kawardha, Korba, Bastar, Dantewada Karstified and Cavernous, Lime-stones, Recrystallised fractured dolomites and fractured Shales forms the unconfined to confined aquifers.
	Dongargarh Supergroup (Abhujmar Group, Chilpi group, Dongargarh and Kanker Granites, Nandgaon Group)	a) Granites b) Schists and Phyllites c) Arkose and Conglomerate d)Rhyolites and Andesites	Bastar, Kanker, Raipur, Mahasamund, Dhamtari, Rajnandgaon, Kawardha, Durg, Bilaspur, Raigarh, Surguja, Dantewada Unconfined shallow aquifer
Archaeans	Bengpal / Amgaon Group Peninsular Gneiss and unclassified basement	Granites, Gneiss and Metasediments Charnockites and Khondalites	Dantewada, Bastar, Kanker, Raipur, Raigarh, Bilaspur, Mahasamund, Rajnandgaon, Surguja, Jashpur, Kawardha,Champa, Korba, Durg, Koriya Unconfined shallow aquifer
Semi-consolidated formation:			
Carboniferous to Cretaceous	Gondwana Supergroup	Pebbles and boulders Sandstones Shales Coal Seams	Raigarh, Surguja, Koriya, Korba Unconfined to confined aquifers
Unconsolidated formation:			
Quaternary	Alluvium and Laterites	Sand, Silt and Gravels Laterites	All over the State along major drainages. In isolated patches. Unconfined aquifers.

(*Source: Aquifer Systems of India Report - 2012, CGWB*)

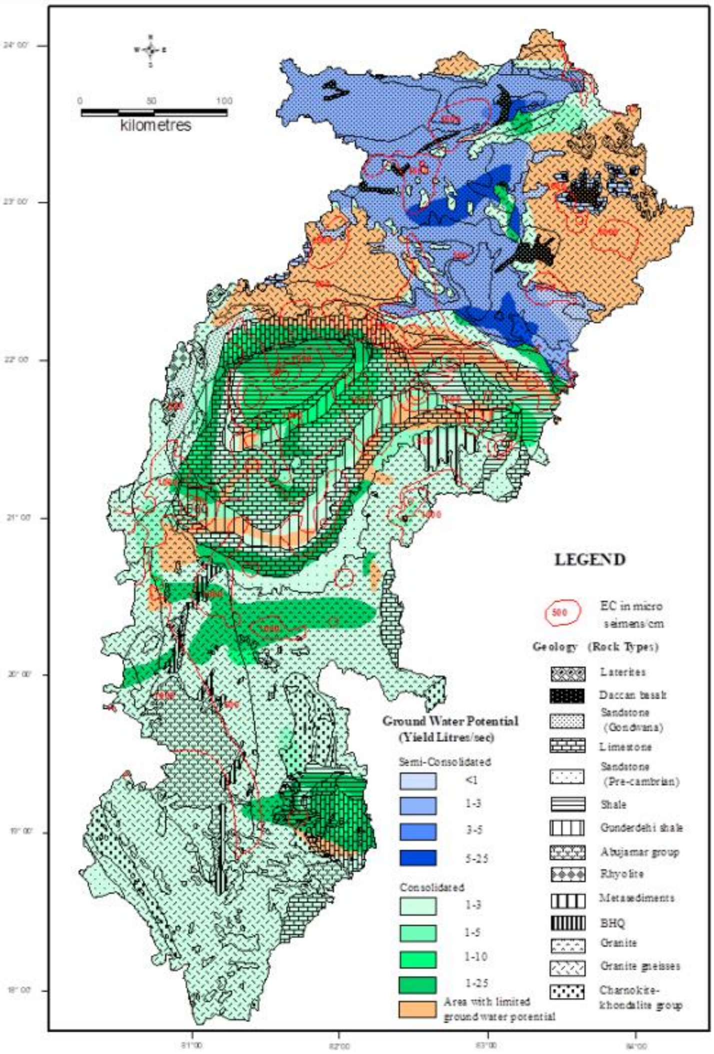


Figure 7: Rock Types in Chhattisgarh
(*Source: Aquifer Systems of India Report - 2012, CGWB*)

Semi-Consolidated Formations:

- **Quaternary Alluvium:** These recent deposits, covering approximately 0.44% of the Chhattisgarh state, form thin, unconfined aquifers with limited extent. They are primarily found along major river courses and are tapped through dug wells, shallow bore wells, and filter point wells.
- **Laterite:** These residual soils, occurring in detached patches, can yield groundwater from weathered zones. They are primarily developed through dug wells and exhibit moderate yields.
- **Gondwana Super Group:** These formations, covering nearly 12% of the state, consist of sandstone, shale, clay, siltstone, and coal seams. The sandstones, particularly the Barakar sandstones, form productive aquifers with yields ranging from 1 to 10 liters per second. Groundwater development in these formations involves dug wells, bore wells, and tube wells

Consolidated Formations:

- **Igneous and Metamorphic Rocks:** These rocks, comprising granites, gneisses, and khondalites, occupy a significant portion of the state. Their groundwater potential is primarily controlled by fractures and weathered zones.
- **Carbonate Rocks:** These rocks, including limestones and dolomites, can form significant aquifers, especially where they are fractured or karstified.
- **Volcanic Rocks:** These rocks, such as basalts, can have varying groundwater potential depending on their degree of fracturing and weathering.

Understanding rock types is crucial for informed decision-making in resource exploration, development, and environmental protection. This knowledge directly contributes to economic growth by enabling efficient resource extraction, sustainable development, and minimizing environmental impact.

Table 7: Rock Data Parameters of Mahanadi River Basin

SL No.	ROCK TYPE	COLOUR	VOLATILE (ORGANIC)	FIXED (ASH/ INORGANIC)	CARBON CONTENT	AN (mg N/ kg)	TKN (mg/L)	CHLORIDE	SULPHATE	CARBONATE	NITRATE	P	K	Na	Ca	Mg	Heavy Metal of highest frequency
1	GRANITE GNEISS	ALTERNATE LIGHT AND DARK COLOUR	-	-	-	250	-	low	few	very low	-	<0.1 %	3-6 %	2-5 %	1-4%	<1 %	Fe,Mn,Zn,Cu,Pb
2	MIGMATITE	BANDED LIGHT AND DARK COLOUR	-	-	-	Very less	-	-	Very low	Very low	-	<0.1 %	-	less	few	2-10 %	Fe,Al,Mn

3	QUARTZITE	LIGHT-GRAY TO YELLOW	very low	90-95%	low	-	-	Negligible	-	-	-	low	very low	less	-	low	Fe,Al,Mn
4	SHALE	GRAY-BLACK	More	50-85%	0.5-10%	0.1-0.2 %	0.05-0.2 %	Few ppm	0.1-1%	Less than 5%	-	less	low	very low	2%	low	Pb,Zn,Cu
5	SLATE	BROWN-BLACK	Less	80-95%	less than 1%	Very low	Negligible	Very low	-	Less	very low	low	-	low	<1%	low	Fe,Zn
6	PHYLLITE	BROWN-BLACK	Less	95%	1%	low	<1%	Low	-	less	<0.1%	less	-	low	<0.1 %	low	Fe,Zn,Mg
7	SCHIST	GRAY-BROWN	Low	90%	<1%	Very less	<0.1%	Low	-	-	<0.1%	less	-	-	0.01 %	low	Zn,Pb
8	CONGLOMERATE	GRAYISH-WHITE	low	>70%	<1%	<1%	0.10%	Low	-	Less	low	less	less	low	-	Low	Mg,Fe,Cu
9	KHONDALITE	GRAYISH BLACK-WHITE	Low	>90%	<1%	Negligible	<1%	Very few	-	Less	low	low	less	low	-	-	Cu,Cd
10	CHARNOCKITE	DARK GREENISH GRAY	Low	>90%	1%	Negligible	<1%	-	<0.1%	-	-	-	-	low	-	-	Mg,Fe
11	COAL SEAM	BLACK	Medium	5-40%	20-90%	0.5-2%	0.1-1.5 %	low	-	<0.1%	-	low	-	-	-	Low	Al,Zn
12	SANDSTONE	LIGHT BROWN	Low	90-95%	0.1-1%	<1%	<0.1%	low	-	Less	-	-	-	-	-	-	Pb,Zn,
13	LEPTYNITE	LIGHT GRAY	low	>90%	<1%	Very low	0.10%	low	-	-	0.50%	less	-	<0.1 %	low	low	Fe
14	LATERITE	REDDISH BROWN	low	70-90%	<1%	low	<0.1%	-	-	-	0.10%	-	<0.1 %	<0.01 %	-	-	Al,Mg
15	FIRE CLAY	PALE GRAY	low	95%	1%	<1%	1%	<0.1%	-	-	-	-	<0.1 %	low	-	-	Cd,Cu

Source: District Survey report, GSI Report

4.5 Aquifers System of the Basin

The map (Figure 8) illustrates the diverse geological formations that constitute the major aquifer systems within the Mahanadi River Basin, spanning parts of Chhattisgarh and Odisha states in India. The basin is characterized by a mosaic of geological units, including Alluvium, Basalt, Charnockite, Gneiss, Granite, Khondalites, Laterite, Limestone, Quartzite, Sandstone, Schist, Shale, and Unclassified formations.

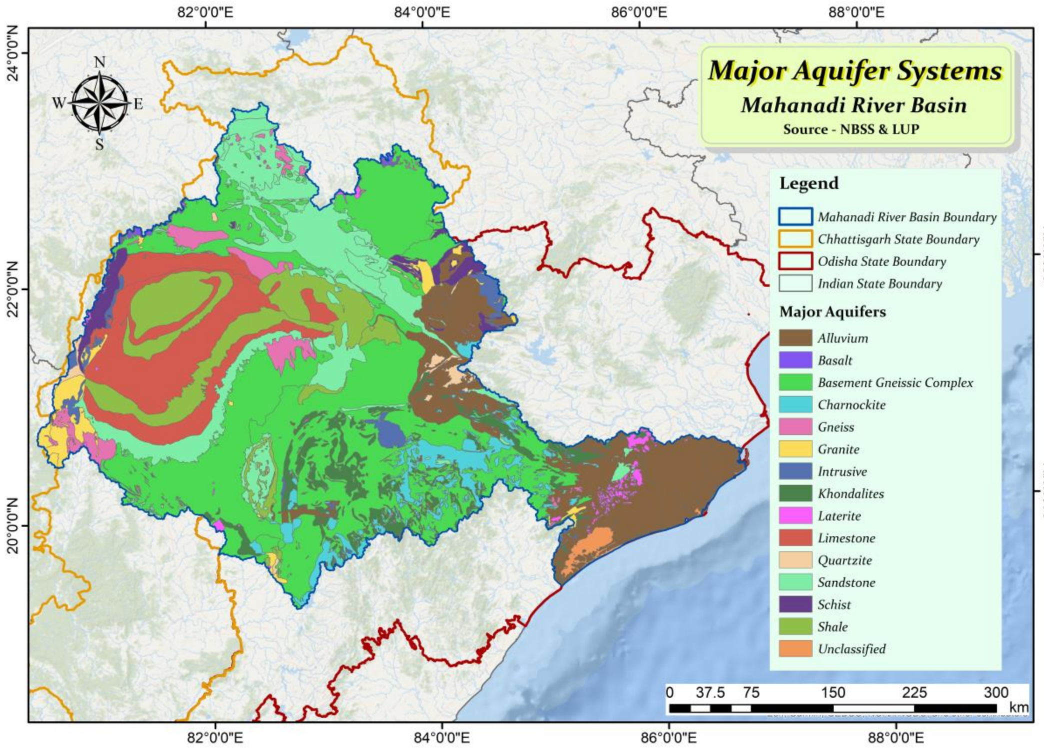


Figure 8: Major Aquifer System of Mahanadi River Basin

The distribution of these aquifer systems is significantly influenced by the underlying geology of the region. Figure 9 illustrates the approximate percentage distribution of these aquifer systems across the basin. The Table 8 presents the characteristics and details of the major aquifer systems found within the Mahanadi River Basin.

Alluvium, for instance, forms a substantial portion of the aquifers, particularly in the deltaic regions where riverine sediments have accumulated over time. These alluvial aquifers are generally considered to be productive due to their high porosity and permeability, making them suitable for both irrigation and domestic water supply.

In contrast, the crystalline rocks, such as granite and gneiss, which dominate the upland areas, typically have lower groundwater potential due to their low porosity and permeability. However, fractures and weathered zones within these rocks can act as conduits for groundwater flow, creating localized zones of higher productivity.

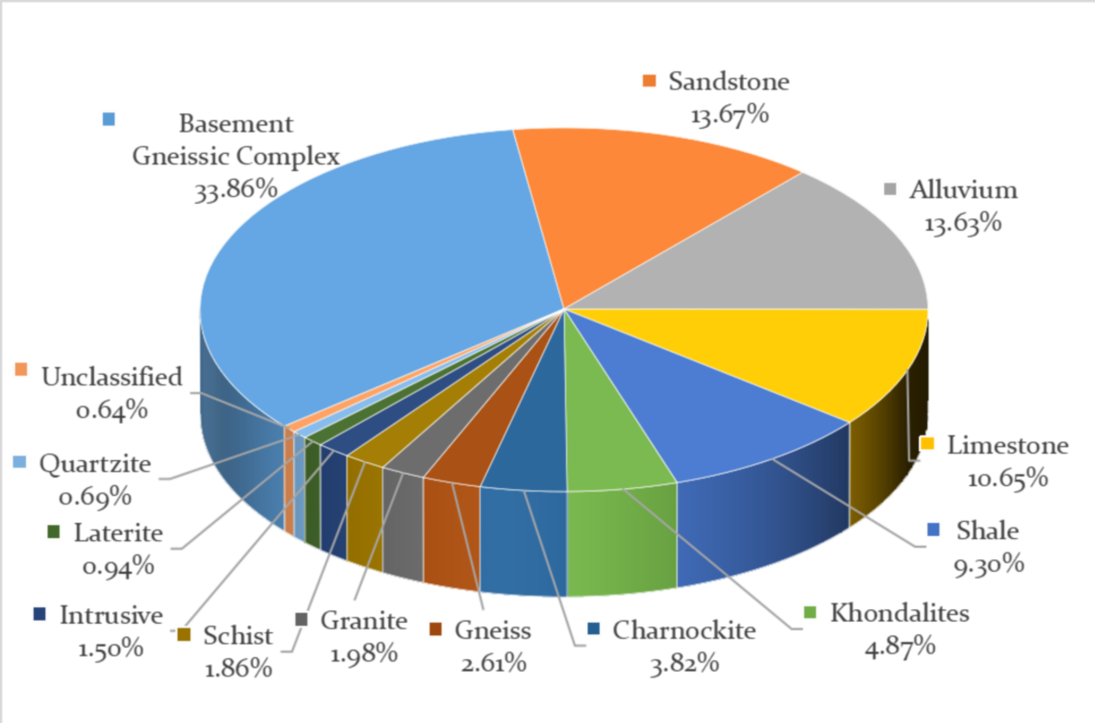


Figure 9: Distribution of Aquifer system in Mahanadi River Basin

Table 8: Detail of Major Aquifer System of Mahanadi River Basin

Aquifer System	Distribution		Geology	Yield	Recharge	Vulnerability Level and Source
Alluvial	17.5%	Deltaic regions, river valleys	Unconsolidated sediments (sand, gravel, clay)	High	Rainfall, baseflow from rivers	High Over-exploitation, agricultural runoff, industrial effluents
Fractured Rock	17.5%	Areas with crystalline rocks (granite, gneiss, schist)	Fractures, joints in hard rocks	Moderate to low	Rainfall, surface water infiltration	Moderate Point-source and non-point source pollution, over-exploitation
Coastal	17.5%	Coastal areas	Unconsolidated sediments influenced by marine processes	High	Rainfall, infiltration from coastal water bodies	High Saltwater intrusion, coastal pollution, sea-level rise
Karst	17.5%	Areas with limestone and dolomite formations	Interconnected caves, fissures	Very high	Rainfall	Very High Rapid contamination, over-exploitation, saltwater intrusion
Basement Gneissic Complex	30%	Upper and middle reaches of the basin (30% of the basin)	Gneissic rocks, granite, schist	Low to moderate	Rainfall, surface water infiltration	Moderate to Low Point-source and non-point source pollution, over-exploitation, mineral dissolution

The sedimentary formations, including sandstone, shale, and limestone, exhibit varying degrees of groundwater potential. Sandstone aquifers, in particular, can be highly productive, especially in regions with favourable recharge conditions. However, the presence of shale layers can act as barriers to groundwater flow, limiting the extent of aquifer systems.

Figure 8 also highlights the presence of laterite formations, which are often associated with groundwater scarcity. Laterites are characterized by their high iron and aluminum content, which can reduce their porosity and permeability. However, weathered zones within laterite profiles can sometimes yield significant amounts of groundwater.

It is important to note that the groundwater potential of any aquifer system is influenced by a variety of factors, including rainfall patterns, recharge rates, discharge rates, and human activities. Therefore, a comprehensive understanding of the hydrogeological characteristics of each aquifer system is crucial for sustainable groundwater management in the Mahanadi River Basin.

Aquifer systems are vital for basin development. They provide a reliable water source for agriculture, industry, and domestic use, boosting economic growth. Additionally, healthy aquifers support ecosystems, maintain water quality, and contribute to overall environmental sustainability

4.6 Groundwater Occurrence/Scenario of the Basin

The Mahanadi River Basin, covering parts of Chhattisgarh, Odisha, and adjoining states, shows a generally sustainable groundwater scenario with pockets of emerging stress. The basin receives moderate to high rainfall, averaging between 1,200 and 1,400 mm annually, which contributes significantly to groundwater recharge through infiltration and surface runoff.

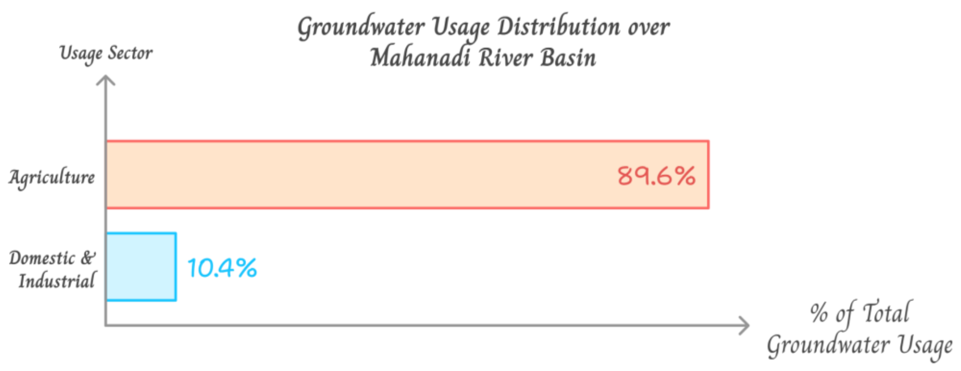


Figure 10: Groundwater usage scenario over MRB

As per the Central Ground Water Board (CGWB, 2022), the net annual groundwater availability of 17.55 BCM. The groundwater usage pattern is highly skewed toward agriculture, with irrigation accounting for nearly 89.6% of the total extraction, while domestic and industrial use together comprise only 10.4%. This dependence on groundwater for irrigation is particularly evident in intensively farmed districts of Chhattisgarh and western Odisha.

Although the majority of assessment units in the basin are classified as “Safe,” a few areas, especially in urbanizing and peri-urban zon es such as Raipur and Bhubaneswar, are categorized as “Semi-Critical” due to increasing pressure on groundwater resources (Figure). Most blocks in central Chhattisgarh and western Odisha showing groundwater extraction within sustainable limits. However, emerging stress is evident in several semi-critical blocks such as Kotma (83 %), Balod (84 %), Dhamtari (76 %), Durg (85 %), and Rajnandgaon (85 %). A few blocks—including Bemetara (90.8 %), Berla (96.7 %), Gurur (93.7 %), and Nawagarh (97 %)—fall in the critical category, nearing over-extraction levels. No block currently exceeds 100 % extraction, while select coastal areas (e.g., Ersama, Rajnagar) are marked saline due to water quality concerns rather than overuse. This distribution indicates that although groundwater use in the MRB is broadly sustainable, localized extraction pressures are emerging and warrant timely attention.

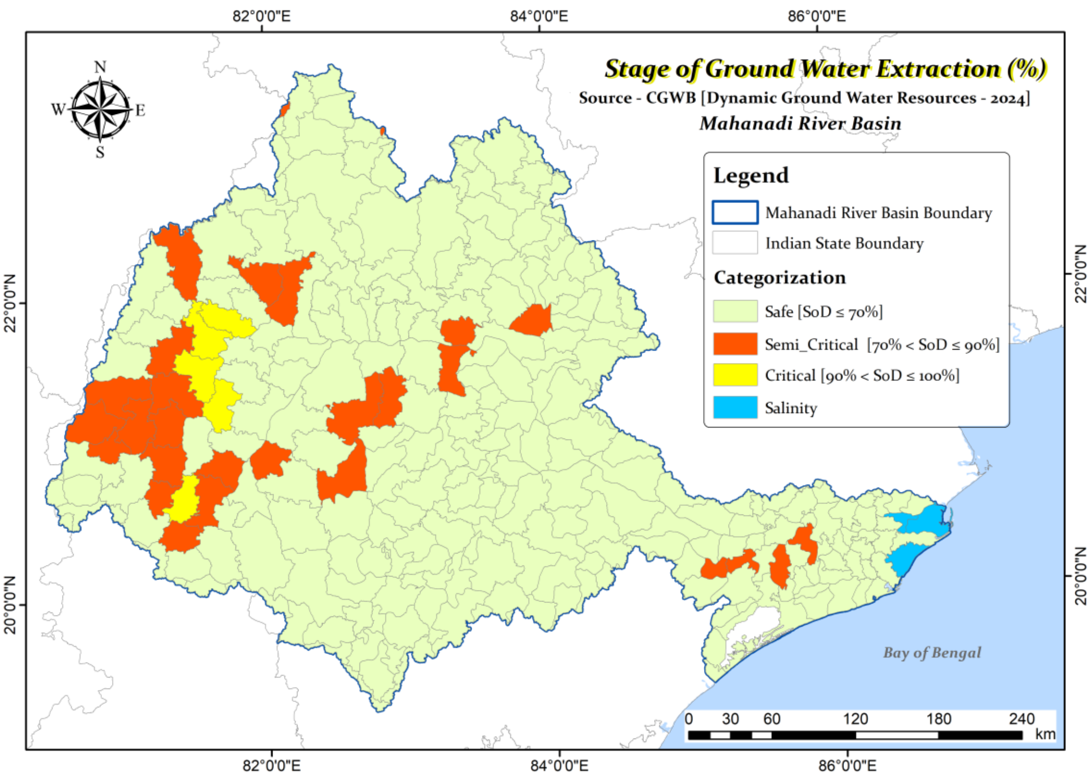


Figure 11: Stage of Groundwater Extraction in the Mahanadi River Basin

The Stage of Ground Water Extraction (SOD%) is a key parameter used by the Central Ground Water Board (CGWB) to categorize groundwater assessment units (typically blocks or taluks) in India. Based on the Dynamic Ground Water Resources Assessment – 2024, CGWB utilizes the official classification thresholds, as presented in the Table , to categorize groundwater assessment units.

Table 9:Groundwater Categorization in Mahanadi River Basin

Category	Stage of Extraction (SOD%)	Condition	Policy Implications	No. of Blocks under MRB
Safe	**≤ 70%**	Groundwater development is within sustainable limits.	Groundwater development can continue with regular monitoring.	265
Semi-Critical	**> 70% and ≤ 90%**	Groundwater extraction is significant; caution needed.	Caution required; promotion of water-saving techniques recommended.	28
Critical	**> 90% and ≤ 100%**	Extraction is approaching the total availability.	Immediate steps needed to reduce extraction; new schemes discouraged.	5
Over-Exploited	**> 100%**	Extraction exceeds recharge; unsustainable.	No new wells permitted; mandatory groundwater recharge and regulation required.	-
Saline	**Any % (in poor quality areas)**	Groundwater is unfit for most uses due to salinity.	Special focus on quality treatment; often excluded from quantitative management zones.	4

To ensure long-term sustainability, a targeted groundwater management strategy is essential—focusing on recharge enhancement, demand regulation, and community-based governance, particularly in semi-critical and critical zones under agricultural and industrial stress. Such proactive measures will help safeguard the basin's water security for the future.

4.7 Landslide Assessment

Landslides are a significant geological hazard, but their occurrence and impact vary across regions due to differences in topography, geological composition, climatic conditions and various anthropogenic factors. Key Factors Contributing to Landslides in Mahanadi Basin

1. **Geological and Lithological Factors:**
   Weak and Weathered Rocks: The presence of weathered or fractured rocks, such as sandstone and shale in sedimentary areas, can lead to slope failures.
   Loose Sediments: Quaternary alluvial deposits near riverbanks and floodplains are prone to erosion and destabilization.
2. **Topographical Features:**
   Hilly and undulating terrains in areas like western Odisha (near the basin's upland reaches) are susceptible to landslides, especially along steep slopes.

Riverbank erosion by the Mahanadi and its tributaries contributes to slope instability in some locations.

3. **Rainfall Patterns:**
   Odisha experiences heavy monsoonal rainfall, which saturates soils and rock formations, reducing cohesion and increasing the likelihood of landslides. Intense short-duration rains often trigger rapid slope failures.
4. **Human Activities:**
   Mining and Quarrying: Extensive mining of coal and other minerals in parts of the basin can destabilize slopes and trigger landslides.
   Deforestation and Land Use Changes: Vegetation loss in catchment areas reduces slope stability and increases erosion.
5. **Seismic Activity:**
   Although Odisha is in a relatively low seismic zone, occasional tremors can weaken slopes and exacerbate landslide risks.

4.7.1 Landslide Conditions in the MRB

Historically, the MRB has not recorded significant large-scale landslide disasters. The physiography of the basin, dominated by flat plains, minimizes the natural drivers of mass-wasting processes. However, localized slope failures have been documented in specific physiographic niches:

- Keshkal Ghat (near Pidhapal, Kanker district, Chhattisgarh): The hilly terrain, characterized by lateritic plateaus and forested slopes, has shown minor localized slope instabilities.
- Eastern Ghats uplands (Odisha): Hill ranges with structurally weak lithologies occasionally witness shallow slips and erosional failures.
- Plateau fringes and escarpments (Raigarh, Gariaband, adjoining areas): Steep scarps and weathered rock exposures are prone to minor failures, particularly during high-intensity rainfall events.

These conditions align well with the susceptibility model results, which also identify such localized hotspots as high to very high susceptibility areas.

A) **Landslide Conditions in Chhattisgarh**

Although Chhattisgarh is not widely recognized as a high-risk state for landslides, the Chhattisgarh State Disaster Management Plan (SDMP, 2019) documents slope instability in select districts, including Kondagaon, Kanker, Dantewada, Sarguja, and Kabirdham. These regions, marked by hilly terrain, lateritic soils, and forest cover, are prone to slope failures during episodes of intense monsoonal rainfall. The SDMP underscores the need for monitoring in these districts, particularly in the context of climate variability, deforestation, and mining, which exacerbate slope instability.

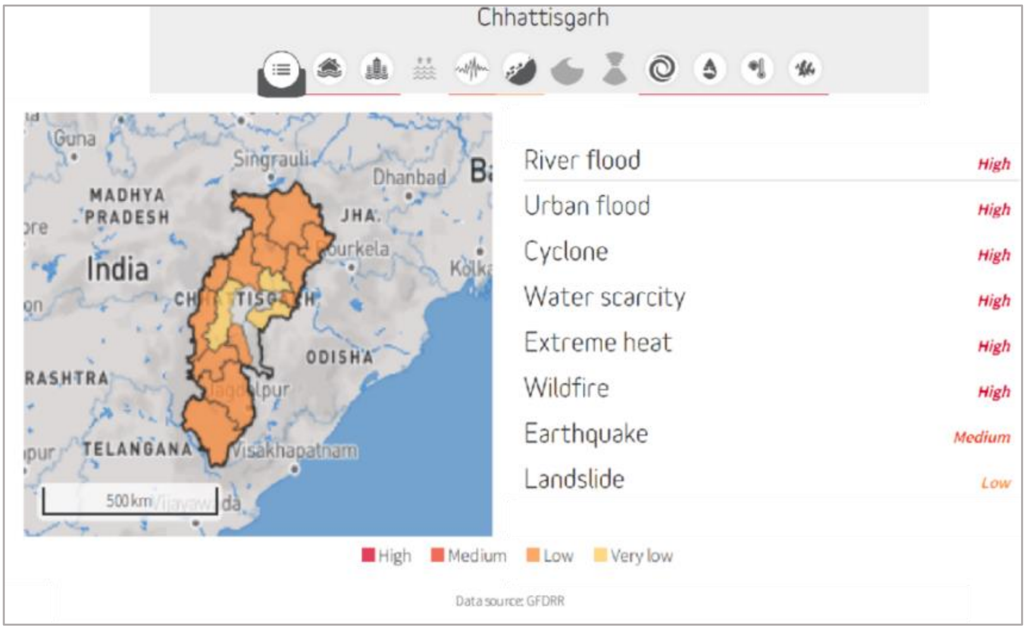


Figure 12: Status of landslide susceptibility of CG state (GFDRR)

At the regional scale, the Global Facility for Disaster Reduction and Recovery (GFDRR) classifies Chhattisgarh as a low landslide-prone or susceptible state, primarily due to its stable geological setting and relatively low seismicity. This differentiates the region from the highly landslide-prone Himalayan and Western Ghat states. Nonetheless, localized landslides linked to anthropogenic pressures and rainfall-induced slope saturation remain a concern.

B) Landslide Conditions in Odisha

In Odisha, landslides are less common in Odisha compared to mountainous regions, can occur in areas with specific geological and geomorphological conditions. In the Mahanadi Basin within Odisha, landslide occurrences are primarily influenced by a combination of factors such as lithology, slope instability, deforestation, mining activities, and rainfall. Assessing these risks is crucial for disaster mitigation and sustainable development in the region. Table 10 shows Documented vulnerable areas in the MRB within Odisha under the Mahanadi River Basin**.**

Table 10: Landslide occurrence area of Mahanadi River Basin Odisha

Districts	**Landslide Area**
Sambalpur	Lakshmidunguri hill (NH-53) Chandlidungri hill Burla
Bargarh	Barapahar Range Hilly areas near Gandhamardhan Hills
Bolangir	Patnagarh sub division Khaprakhol Block Gandhamardhan Hills
Nuapada	Sunabeda plateau Khariar Hills

Kalahandi	Niyamgiri hill Thamul Rampur Block
Nabrangpur	Jharigam Block Raigarh and Chandahandi Block
Kandhamal	Belghar Kotagarh and Tumudibandha blocks

(Source: Odisha State Disaster Management Authority)

4.7.2 Absence of an Official Landslide Mapping

As of August 2025, the available datasets on the Bhukosh portal of the Geological Survey of India (GSI) indicate that no official *Landslide Inventory Mapping (LIM)* or *National Landslide Susceptibility Mapping (NLSM)* has been carried out for the Mahanadi River Basin (MRB). This indicates that the basin has not been prioritized under national landslide hazard programs, largely due to its comparatively low geomorphic vulnerability. However, this absence of mapping should not be misinterpreted as immunity from slope instability. Rather, it emphasizes that landslides in MRB occur on a localized and small scale, often triggered by high rainfall but under-reported due to limited impact.

4.7.3 AHP based Landslide Susceptibility Mapping for MRB

The Landslide Susceptibility Map (LSM) for the Mahanadi River Basin (MRB) was developed using a multi-criteria evaluation framework based on eight key parameters: Land Use/Land Cover (LULC), lithology, elevation, soil texture, curvature, aspect, slope, and maximum daily rainfall. Each parameter was classified into susceptibility categories, with values ranging from low (score 1) to very high (score 5), reflecting its relative contribution to slope instability. The final susceptibility map was generated using weighted overlay techniques, with parameter weights derived through the Analytic Hierarchy Process (AHP).

- LULC: Classes such as water and forested areas were scored as low susceptibility, while bare ground, rangeland, and agricultural land received higher scores due to their weaker stability.

- Lithology: Strong rock units such as granite gneiss were classified as low risk, while sedimentary formations, laterites, and weathered rock were assigned high susceptibility scores.
- Elevation: Ranging from 0–1272 m, higher elevation belts (>1200 m) were considered more unstable relative to the extensive low-lying plains.
- Soil Texture: Fine-textured soils and skeletal/rocky soils showed greater susceptibility compared to medium-textured soils.
- Curvature: Strongly concave slopes (< –0.05) were classified as very high susceptibility zones due to their capacity to accumulate water and stress.
- Aspect: South- and southwest-facing slopes were given higher susceptibility scores due to higher exposure to weathering.

- Slope: Gentle slopes (<5°) were considered stable, while steep slopes (>35°) represented zones of very high instability.
- Rainfall: Maximum daily rainfall ranged from 45.5 mm to more than 200 mm, with higher classes assigned higher susceptibility scores.

Final susceptibility was derived through weighted overlay by giving appropriate weightages using the Analytic Hierarchy Process (AHP). The influence of each parameter and its assigned weightage are presented in the Table 11 below.

Table 11: Parameter Influence and Assigned Weightages for LSM

Parameter	Weight	Influence on Slope Instability
Slope	**0.26**	Dominant factor, steep slopes (>35°) strongly control failures.
Daily Maximum Rainfall	**0.2**	Daily maximum rainfall is a key triggering mechanism for landslide occurrence.
Lithology	**0.18**	Weak/soft rocks (shale, schist, laterite, clay, alluvium) increase instability; hard rocks (granite, gabbro) show low susceptibility.
LULC	**0.12**	Bare ground, agriculture, and rangeland show higher risk compared to forests.
Soil Texture	**0.1**	Fine clayey soils and rocky/skeletal soils enhance landslide risk due to low drainage or shallow rooting.
Curvature	**0.07**	Strong concave slopes (< –0.05) accumulate water and stress, increasing failures.
Aspect	**0.04**	South- and southwest-facing slopes (high solar/weathering exposure) are more vulnerable.
Elevation	**0.03**	Higher elevation zones (>1200 m) show very high susceptibility.

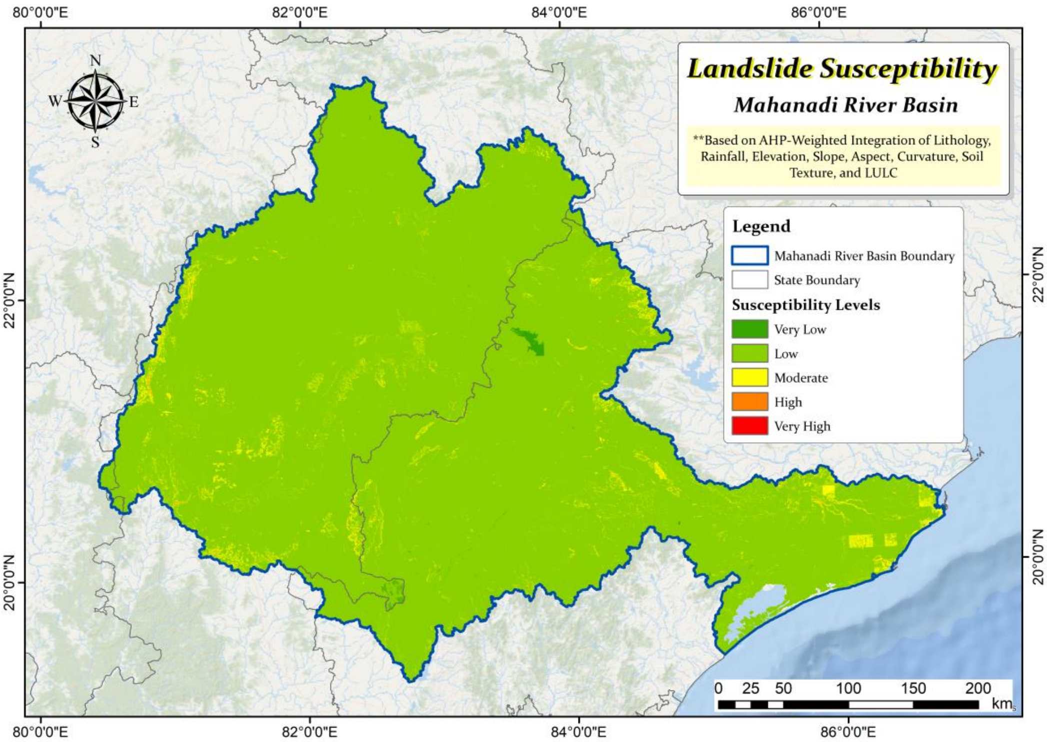


Figure 13: AHP based LSM for Mahanadi River Basin

4.7.4 Results of the Susceptibility Mapping

The landslide susceptibility results as shown in Figure 13, reveals that the MRB is predominantly characterized by low to moderate susceptibility, with high and very high susceptibility zones limited to discrete terrain pockets.

- Low susceptibility dominates the basin, covering more than 134,000 km², corresponding largely to plains and gently undulating terrain.
- Moderate susceptibility accounts for ~4,571 km², mostly representing transitional slopes between uplands and plains.
- High susceptibility zones are highly localized (~135 km²) and coincide with steeper slopes, weaker lithologies, and high rainfall exposure.
- Very high susceptibility zones are minimal (~7 km²) and restricted to specific escarpments or hill slopes.
- Very low susceptibility is confined to small areas of stable terrain, majorly large waterbodies (~249 km²).

This distribution underscores that landslide risk in the MRB is localized rather than widespread. It is fundamentally different from landslide-prone mountainous terrains of India, such as Uttarakhand in the Himalayas or the Western Ghats, where steep slopes, fragile geology, and extreme rainfall generate widespread very high susceptibility zones. By contrast, the MRB's physiography of extensive alluvial plains and gently undulating plateaus largely precludes large-scale landslide hazard.

To provide a clearer understanding of localized terrain vulnerability, examples from three representative locations across the Mahanadi River Basin are presented. These locations are overlaid with the Analytical Hierarchy Process (AHP) generated landslide susceptibility maps on Google Earth satellite imagery. The examples highlight the varying levels of susceptibility to slope failure or landslide .

Figure 14: AHP-based landslide susceptibility overlaid on Google Earth imagery for Keshkal Ghat Range (Pidhapal), Kanker, Chhattisgarh.

Figure 14 shows the Keshkal Ghat Range (Pidhapal) in Kanker, Chhattisgarh. This ghat section, part of the rugged lateritic plateaus and forested slopes of the region, exhibits patches of moderate to high susceptibility zones. The overlay highlights instability particularly along steep escarpments and slope faces, where natural terrain vulnerability is compounded by localized human interventions such as road construction and deforestation.

Figure 15 illustrates the Sikaser Dam region in Gariyaband, Chhattisgarh. Here, susceptibility is concentrated around the abutments and adjoining hill slopes. The reservoir impoundment and fluctuating water levels exert additional pressure on slope stability, while lateritic and weathered rock formations contribute to localized instability zones.

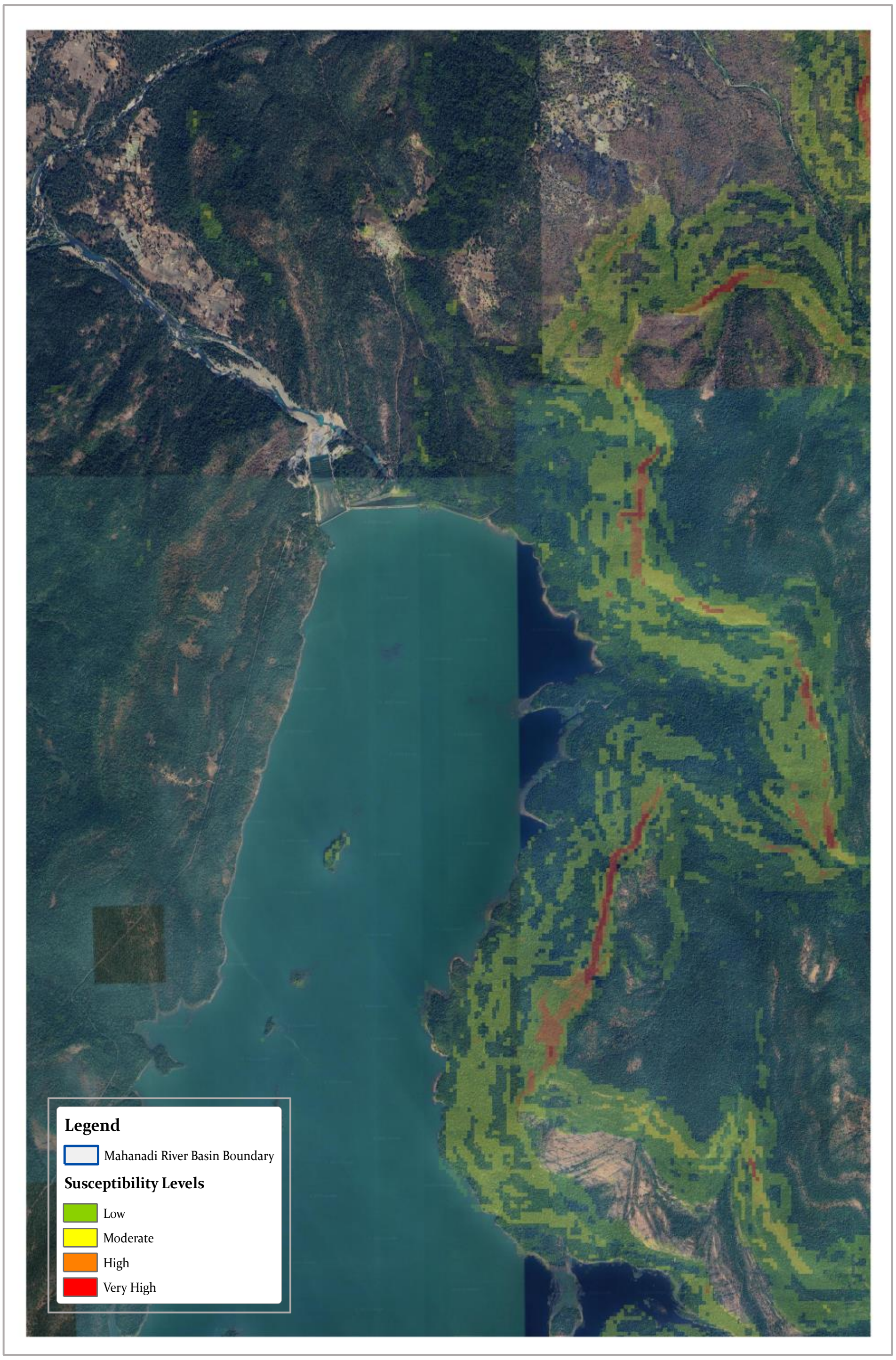


Figure 15: AHP-based landslide susceptibility overlaid on Google Earth imagery for Sikaser Dam region, Gariyaband, Chhattisgarh.

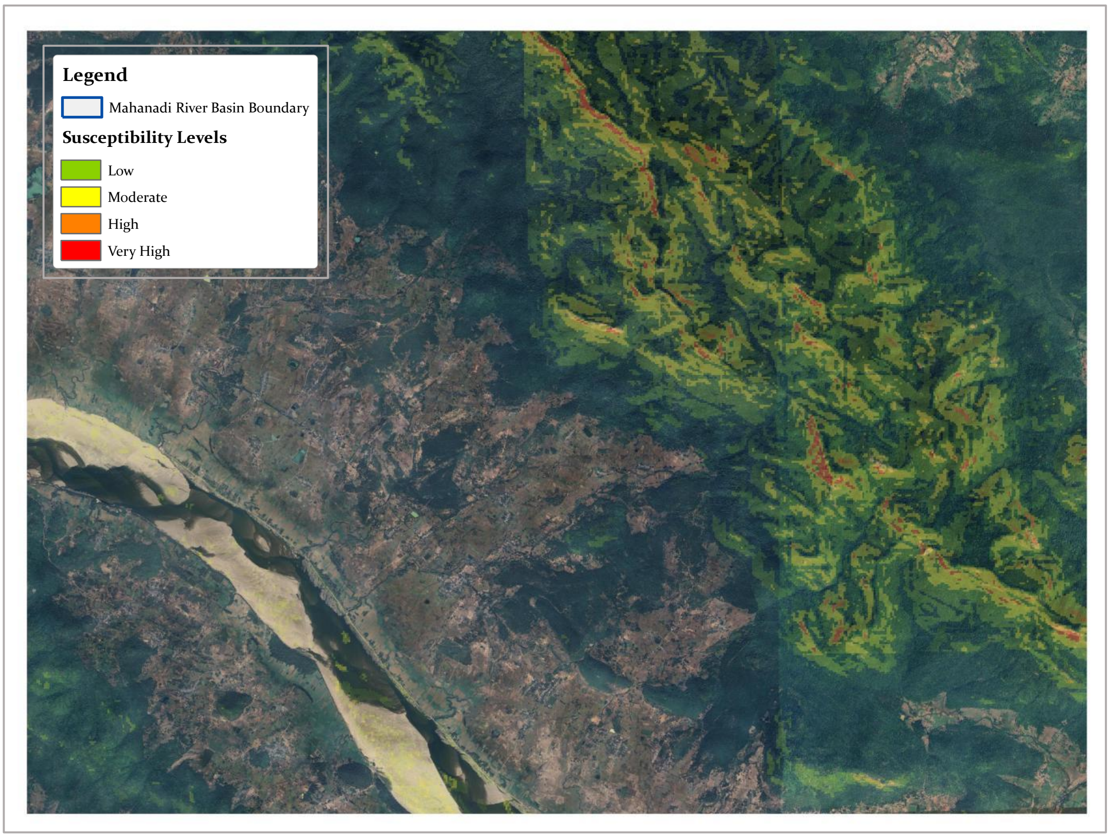


Figure 16: AHP-based landslide susceptibility overlaid on Google Earth imagery for Bamur–Athmallik–Boinda belt, Angul, Odisha (Eastern Ghats fringes).

Figure 16 depicts the Bamur–Athmallik–Boinda belt in Angul, Odisha, forming part of the northern fringes of the Eastern Ghats hill ranges. The susceptibility overlay highlights linear high-susceptibility patches along dissected slopes and valleys drained by tributaries of the Mahanadi. Seasonal rainfall, coupled with fragile lateritic soils and increasing land use pressure, accentuates slope instability risks in this belt.

4.7.5 Implications for Basin Management

The findings of the LSM and historical observations provide important insights for integrated basin management:

- Low and Moderate susceptibility zones dominate the basin and encompass much of its agricultural and settlement areas. These zones require sustainable land-use management to prevent indirect risks such as soil erosion and increased flood vulnerability.
- High and Very High susceptibility pockets, though small in extent, pose disproportionate risks to infrastructure, local settlements, and riverbank stability. These areas should be prioritized for slope stabilization, afforestation, and regulation of quarrying/mining.
- Infrastructure planning (roads, dams, canals, etc.) should integrate susceptibility data to avoid construction in high-risk niches.

- Community-based slope failure monitoring systems can strengthen resilience by recording and reporting localized slope failure events that might otherwise remain undocumented.
- Inclusion of MRB uplands and escarpments in future phases of GSI's NLSM program would fill the current knowledge gap and ensure more comprehensive hazard assessment.

Conclusion

The Mahanadi River Basin demonstrates a landscape of generally low landslide susceptibility, punctuated by discrete high-risk niches. Unlike Himalayan or Western Ghat terrains, where landslides are a dominant hazard, the MRB's flat plains and plateau systems render it largely stable. However, localized slope instability persists in certain upland and escarpment settings, demanding targeted monitoring, proactive mitigation, and integration of susceptibility mapping into basin management strategies. This approach ensures that even low-frequency hazards are effectively addressed, safeguarding communities and infrastructure across the basin.

5 Pedological Settings of Mahanadi River Basin

The Mahanadi River Basin is home to a diverse range of soils, shaped by its complex geological history and varying climatic conditions. These soils play a crucial role in the region's agriculture, ecology, and overall environmental dynamics.

5.1 Pedological Processes:

The formation and development of soils in the Mahanadi River Basin are influenced by several pedological processes, including:

- **Weathering:** The breakdown of rocks and minerals by physical, chemical, and biological processes.
- **Erosion:** The removal of soil material by water, wind, or gravity.
- **Deposition:** The accumulation of soil material in new locations.
- **Soil Formation:** The development of soil horizons and profiles through the interaction of various factors, including climate, parent material, organisms, topography, and time.

5.2 Major Soil Orders

- **Alfisols:** These soils are characterized by clay accumulation in subsurface horizons.
- **Inceptisols:** These soils are young soils with weakly developed horizons. They are common in areas with moderate to high rainfall and are generally fertile.
- **Entisols:** These are recently formed soils with little or no horizon development. They are often found in floodplains and alluvial fans.
- **Vertisols:** These are clay-rich soils that exhibit shrink-swell properties. They are often found in areas with seasonal rainfall and are fertile but can be difficult to cultivate.
- **Ultisols:** These are highly weathered soils with significant clay accumulation in subsurface horizons. They are typically found in older landscapes and are less fertile than Alfisols.

The Mahanadi River Basin, spanning across Chhattisgarh, Odisha, Jharkhand, Madhya Pradesh and Maharashtra, exhibits a diverse range of pedological settings due to varying geological formations, climatic conditions, and land use practices. An overview of the Mahanadi basin pedological detail in different state it covers is tabulate in Table 12.

Table 12: Pedological setting overview of Mahanadi Basin

State	Dominant Soil Orders	Significance
Chhattisgarh	Alfisols, Inceptisols, and Entisols.	**Agriculture:** Fertile alluvial and red-yellow soils support a wide range of crops, including rice, wheat, and pulses. **Water Resources:** The basin's soils play a crucial role in water storage and groundwater recharge. Alfisols, finer-textured red/yellow and alluvial soils hold water best due to balanced textures or clay content, while Entisols and coarser varieties of the others drain quickly with low water retention.
	Red and Yellow Soils, Alluvial Soils	
Odisha	Alfisols, Ultisols, and Entisols.	**Agriculture:** The deltaic region's fertile alluvial soils are ideal for rice cultivation, while the upland areas support a variety of crops, including pulses and oilseeds. **Forestry:** The Eastern Ghats region's soils support diverse forest ecosystems, including Sal and Teak forests. **Coastal Ecosystems:** The basin's soils influence coastal ecosystems, including mangroves and wetlands
	Alluvial Soils, Red and Yellow Soils, Lateritic Soils, and Black Cotton Soils	
Madhya Pradesh	Alfisols and Inceptisols.	**Agriculture:** The basin's soils, particularly in the upper reaches, contribute to agricultural productivity, especially in areas like Anuppur district. Fertile, with varying water-holding capacity. Black cotton soils are particularly fertile but can be challenging to cultivate due to their shrink-swell properties. **Forestry:** The region's soils support diverse forest ecosystems, including Sal and Teak forests.
	Red and Yellow Soils, Black Cotton Soils	
Jharkhand	Alfisols and Inceptisols	**Agriculture:** Low in fertility **Forestry:** The region's soils support diverse forest ecosystems, including Sal and Teak forests. **Mining:** Mining activities, particularly coal mining, can impact soil quality and lead to erosion and pollution.
	Red and Yellow Soils, Lateritic Soils	
Maharashtra	Alfisols and Inceptisols.	**Agriculture:** The basin's soils, though a smaller portion, contribute to agricultural productivity in certain areas. **Water Resources:** The region's soils play a role in water storage and groundwater recharge.
	Red and Yellow Soils, Black Cotton Soils	

5.3 Overall Significance of Pedological Settings in the Mahanadi Basin

- **Agricultural Productivity:** The diverse soil types support a wide range of crops, contributing to food security and rural livelihoods.
- **Water Resource Management:** The soils' water-holding capacity and permeability influence water availability for irrigation, domestic use, and industrial activities.
- **Ecological Balance:** The basin's soils support diverse ecosystems, including forests, wetlands, and agricultural lands, contributing to biodiversity conservation.

- **Environmental Challenges:** Soil erosion, degradation, and pollution due to human activities pose significant challenges to the basin's sustainability.

Environmental Significance:
The soils of the Mahanadi River Basin play a vital role in the region's ecology and agriculture. They provide essential nutrients for plant growth, regulate water flow, and support a diverse range of ecosystems. However, these soils are also vulnerable to degradation due to factors such as deforestation, overgrazing, and unsustainable agricultural practices.

Understanding the pedological settings of the Mahanadi River Basin is crucial for sustainable land use planning, water resource management, and environmental conservation efforts in the region.

5.4 Soil Characteristics of Mahanadi River basin

The basin exhibits wide spatial variability in its physical, chemical, and nutrient characteristics. Soils range from sandy and red acidic profiles in uplands and coastal tracts to deep clay-rich Vertisols in central districts, influencing both productivity and management needs. Variations in pH, organic carbon, and water-holding capacity create diverse agricultural potentials, while imbalances in macro- and micro-nutrients pose significant challenges to crop sustainability. The major soil properties and nutrient status over Chhattisgarh and Odisha part of MRB.

A) Physical-Chemical Properties

- **pH**: Soil reaction varies widely, with sandy and red soils tending toward acidic (pH 5–6), and black soils closer to neutral or moderately alkaline (pH 7–8). Acidity issues are most pronounced in coastal Odisha, older alluvial, and upland regions of Chhattisgarh.

- **EC (Electrical Conductivity)**: Generally low (<0.5 dS/m in most districts), signifying low soil salinity except in select coastal or degraded areas. Vertisols show slightly higher EC due to mineral content.

- **Organic Carbon (%)**: Ranges from poor (0.2–0.5%) in sandy/red soils to moderate (0.5–0.8%) in clay-rich Vertisols and loams. This underscores the sustainability challenge for dryland/sandy regions and the benefit of organic matter amendments across the basin.

- **Soil Depth and Water Holding Capacity**: Alfisols and Vertisols offer depth (100–150 cm) and excellent water holding (180–245 mm/M), while Entisols, with shallow sandy profiles, retain little water (often <70 mm/M), which limits drought resilience.

B) Macro-Nutrients (N, P, K)

- **Nitrogen (N)**: Across districts, nitrogen levels in soils range from low to moderate. Entisols and Alfisols typically show lower N (often <200 kg/ha), indicating a need for frequent nitrogen supplementation, especially for intensive cropping.

- **Phosphorus (P)**: Available P is highly variable, with some districts showing critically low levels (~5–15 kg/ha in many coarse-textured soils) and others moderate (~10–14 kg/ha in

Vertisols and clay loams). This underscores the requirement for targeted phosphorus fertilization.

- **Potassium (K)**: Most Vertisols are potassium-rich (often >150 kg/ha, up to 300–400 kg/ha), while sandy/loam soils and Alfisols are more moderate, emphasizing the relative K sufficiency of clay-rich soils.

C) Micro-Nutrients (Zn, B, Fe, Mn, Mo, Cu)

- **Zinc (Zn) & Boron (B)**: Widespread deficiencies in Zn (typical range 0.0005–0.001% in Odisha; 10–20 mg/kg in Chhattisgarh), and B (0.0001–0.0005% or even lower) are present throughout, affecting crop health and productivity, especially in rice and pulses.

- **Iron (Fe), Manganese (Mn), Molybdenum (Mo), Copper (Cu)**: Most districts have sufficient Fe and Mn, but Mo and Cu can be limiting in specific sites, necessitating area-specific micro-nutrient management.

D) Secondary Nutrients (Ca, Mg, S)

- **Sulfur (S), Calcium (Ca), Magnesium (Mg)**: Sulfur (S) and Magnesium (Mg) deficiencies commonly occur in sandy loam and lateritic soils, particularly in districts such as Mahasamund and parts of Odisha uplands. Vertisols, found mainly in Raipur, Durg, and Bolangir, generally have higher Calcium (Ca) and sulfur content due to their clay-rich nature and better nutrient retention, but localized sulfur deficits may still arise under intensive cropping. Regular soil testing and balanced nutrient management are essential to address these secondary nutrient shortcomings for sustainable agriculture in the basin.

Table 13: Districts with Major Micronutrient Deficiency

District	Common Deficiency	Key Management Needs
Raipur, Durg	Zinc, Sulfur	Zn/S fertilization
Balod, Rajnandgaon	Nitrogen, Boron, Calcium, Magnesium	N/B/Ca/Mg supplementation
Mahasamund	Salinity risks, Magnesium, Boron	Liming, micronutrient mix
Bolangir, Nuapada	Zinc, Sulfur	Foliar micro-nutrient sprays
Odisha Delta Region [Cuttack,Khordha, Puri, Kendrapara, Jagatsinghpur]	Zinc, Boron, Sulfur, Magnesium	Regular micro-fertilizer
Source: *1. Mapping the Nutrient Status of Odisha's Soil by ICRISAT, 2. IGKV Raipur (C.G) & 3. Department of Agriculture, Government of Chhattisgarh*		

Actionable Points:

- ✓ **Macro-nutrient management:** Focus on nitrogen and phosphorus enrichment for alluvial, sandy, and red soils, and potassium stewardship for intensive cropping on Vertisols.

- ✓ **Micronutrient management:** Regular zinc and boron supplementation throughout the basin, with targeted intervention for sulfur, magnesium, and molybdenum deficiencies, especially in upland/coastal Odisha and dry sandy Chhattisgarh soils.

- ✓ **Physical amendments:** Improve organic carbon in low-fertility soils using green manures, compost, and rotational crops.

- ✓ **Soil reaction and EC monitoring:** Address acidity in red/sandy soils with lime and maintain salinity management in coastal zones for sustainable crop yields.

This approach ensures practical, location-specific recommendations, supporting both sustainable agriculture and resilience to environmental stresses throughout the Mahanadi River Basin.

5.4.1 Soil Texture

The Mahanadi River Basin showcases a diverse range of soil textures (Figure 17). Soil texture significantly influences water retention, nutrient availability, and crop suitability, impacting agricultural productivity and environmental sustainability in the Mahanadi River Basin.

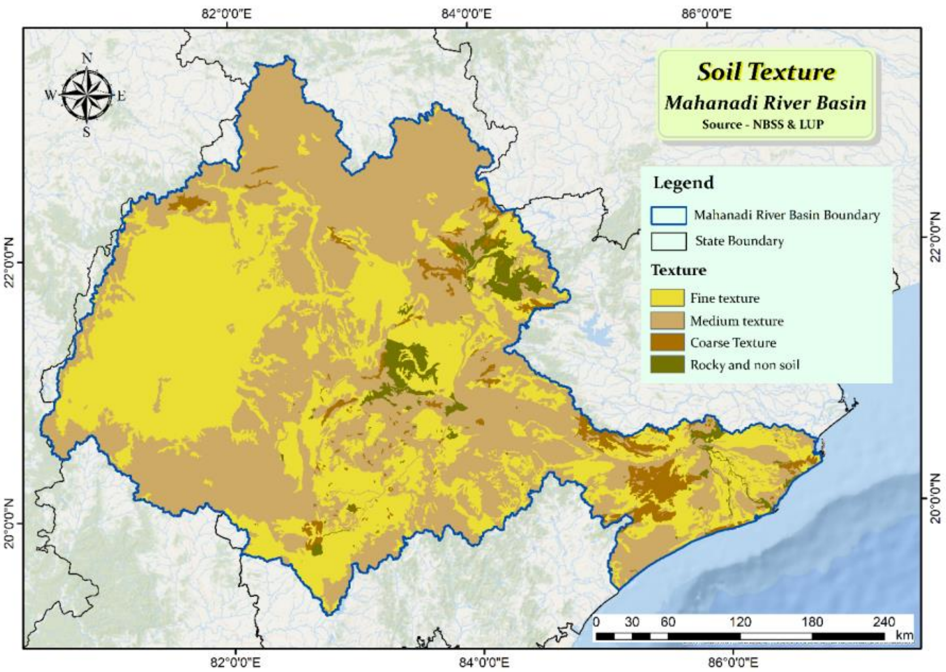


Figure 17: Soil texture variation in the Mahanadi River Basin

The Soil texture is divided in four boarder categories, each with its unique characteristics and agricultural significance:

- **Fine-textured soils:**
  - **Black Cotton Soils:** These soils, prevalent in the deltaic regions of Odisha and parts of Maharashtra, are characterized by high clay content, making them fine-textured. They are highly fertile but can be challenging to cultivate due to their shrink-swell properties.
  - **Vertisols:** These soils, found in specific areas within the basin, are also fine-textured and have high clay content. They exhibit similar characteristics to black cotton soils.

- **Medium-textured soils:**
  - **Loam soils:** These soils, a mixture of sand, silt, and clay, are commonly found in the alluvial plains of Chhattisgarh, Madhya Pradesh, and Odisha. They are considered ideal for agriculture due to their balanced texture and good water-holding capacity.

- **Coarse-textured soils:**
  - **Sandy soils:** These soils, often found in the upper reaches of the basin, have a high sand content and low water-holding capacity. They are less fertile compared to medium-textured soils and require careful management to maintain soil moisture.

- **Rocky textures:**
  - **Stony soils:** These soils, common in hilly and mountainous regions, have a high proportion of rocks and stones. They are generally less fertile and more challenging to cultivate.

Understanding the distribution of these soil textures is crucial for sustainable agriculture and land use planning in the Mahanadi River Basin. By matching crop choices to specific soil textures and implementing appropriate soil management practices, farmers can optimize yields and minimize environmental impacts

5.4.2 Soil Depth

The soil depth in the Mahanadi basin varies significantly across different regions (Figure 18). While a large portion of the basin has moderately shallow to deep soil with depths exceeding 50 cm, areas with steep slopes exhibit shallow soil due to erosion. The soil depth plays a crucial role in the basin's development, influencing factors like agricultural productivity, water infiltration, and erosion susceptibility. In Chhattisgarh, especially the plains of Raipur and Durg districts, have deep, fertile soils. In contrast, the hilly regions of Chhattisgarh, such as the areas around Raigarh and Janjgir-Champa, often have shallow soils prone to erosion.

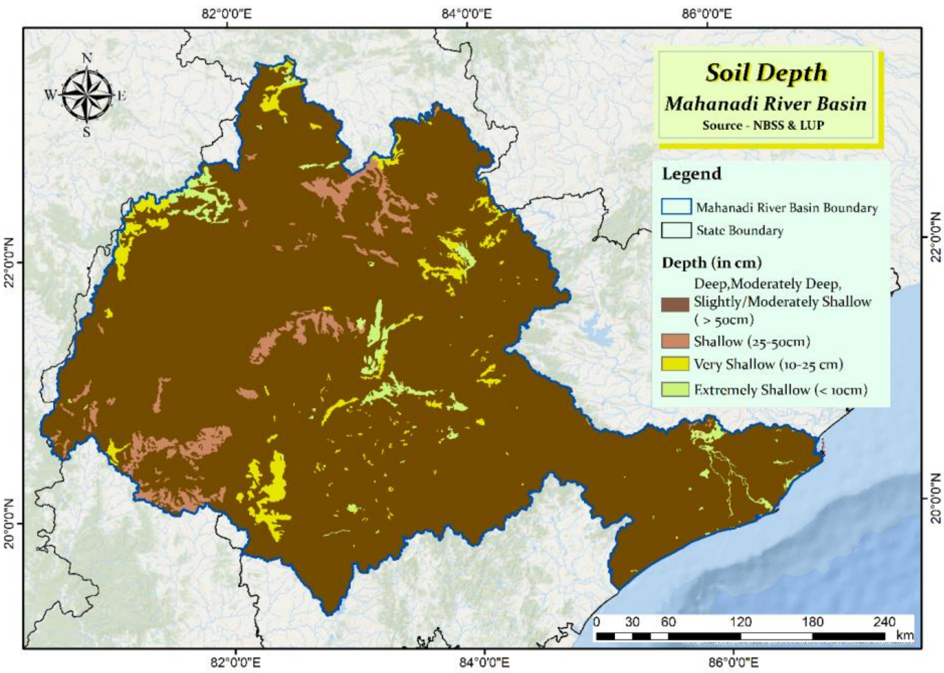


Figure 18: Distribution of Soil Depths in the Mahanadi Basin

For instance, the coastal plains of Odisha, particularly in districts like Jagatsinghpur, Puri, and Kendrapara, generally have deep, fertile soils suitable for intensive agriculture. However, the hilly regions of Odisha, such as the Eastern Ghats in the districts of Koraput and Malkangiri, often have shallow soils prone to erosion.

The soil depth plays a crucial role in the basin's development, influencing factors like agricultural productivity, water infiltration, and erosion susceptibility. Deeper soils, as found in the coastal plains, generally have higher water-holding capacity and nutrient content, supporting diverse agricultural practices. Conversely, shallow soils, prevalent in hilly regions, are more prone to erosion and have limited water-holding capacity, necessitating careful land management to prevent degradation and ensure sustainable development.

5.4.3 Soil Productivity:

Figure 19, depicts the soil productivity of the Mahanadi River Basin, as classified by the National Bureau of Soil Survey and Land Use Planning (NBSS & LUP). The basin encompasses parts of Chhattisgarh, Madhya Pradesh, Odisha, Jharkhand, and Maharashtra.

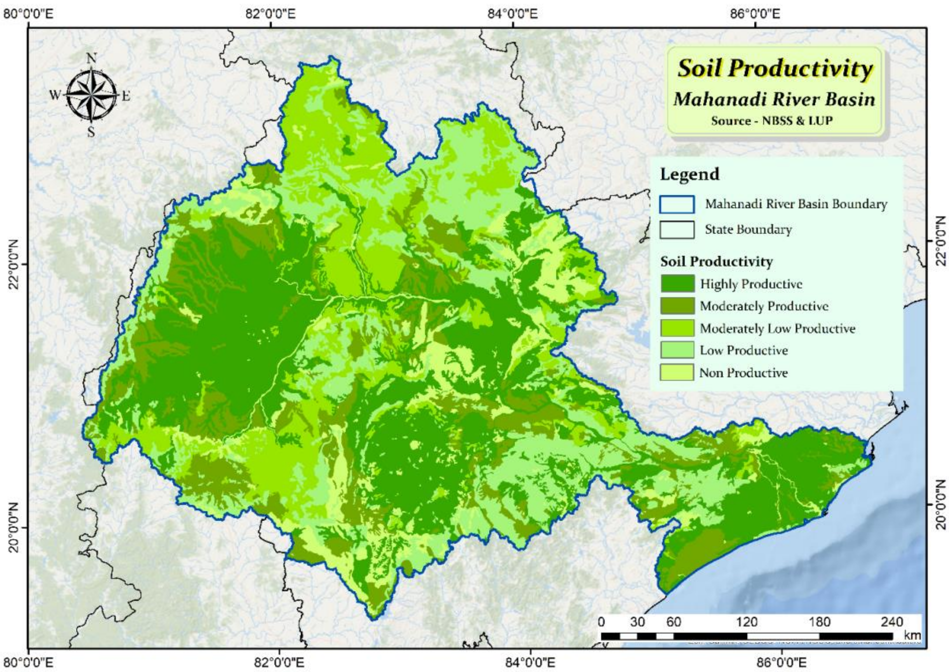


Figure 19: Status of Soil Productivity in the Mahanadi River Basin

The map categorizes the basin's soils into six productivity classes:

- **Highly Productive:** These soils are fertile and suitable for a wide range of crops with minimal input requirements. They are typically found in alluvial plains and river valleys. Concentrated in the deltaic regions of Odisha and the alluvial plains of Chhattisgarh and Madhya Pradesh
- **Moderately Productive:** These soils require moderate inputs like fertilizers and irrigation to achieve good yields. They are commonly found in upland areas and have moderate fertility. Found in the upland areas of Chhattisgarh, Madhya Pradesh, and Odisha.
- **Moderately Low Productive:** These soils have low fertility and require significant inputs to produce reasonable yields. They are often found in hilly and plateau regions.
- **Low Productive:** These soils have very low fertility and are not suitable for intensive agriculture. They are typically found in arid and semi-arid regions. Present in the hilly and plateau regions of Jharkhand and Odisha.
- **Non-Productive:** These soils are barren and unsuitable for agriculture. They are often found in rocky and mountainous areas. Some area of middle Mahanadi some under this zone due to hilly terrain.

5.4.4 Implications for Land Use and Management

Understanding the soil productivity of the Mahanadi River Basin is crucial for sustainable land use planning and management. It helps in:

- **Optimizing Crop Selection:** Choosing crops that are suitable for the soil type and climate.
- **Efficient Use of Inputs:** Applying fertilizers and irrigation water judiciously to maximize productivity.
- **Conservation of Soil Resources:** Implementing soil conservation measures like crop rotation, contour farming, and afforestation.
- **Sustainable Agriculture:** Promoting practices that maintain soil health and productivity for future generations.

By considering the soil productivity map and the factors influencing it, decision-makers can make informed choices to ensure the sustainable development of the Mahanadi River Basin.

By recognizing the specific characteristics of different soil types, policymakers and farmers can make informed decisions to ensure the long-term health and productivity of the basin's ecosystems.

6 Data Analysis and Interpretation

Lithological Analysis

The Mahanadi River Basin's geology, spanning Archaean to recent alluvial deposits, profoundly influences its agricultural productivity, groundwater potential, and mineral wealth. Significant observations include:

- **Aquifer Systems**: The Mahanadi Basin exhibits a diverse aquifer system, including Basement Gneissic Complex, alluvial, fractured rock, coastal and karst. Basement Gneissic Complex constitutes approximately 30% of the Mahanadi River Basin. While characterized by low vulnerability to contamination, offers moderate yields due to limited groundwater storage and transmission within the fractured rock. While alluvial aquifers offer high yields, they are highly vulnerable to agricultural contamination and over-exploitation, crucial for a region heavily reliant on groundwater irrigation. Coastal aquifers face saltwater intrusion, and karst aquifers are prone to rapid contamination. Overall, groundwater resources in the basin face significant challenges related to both quantity and quality due to agricultural demands and various contamination sources.
- **Soil Types and Fertility**: Mahanadi River Basin exhibits a diverse range of soils, including fertile alluvial soils in the deltaic regions, less fertile red and lateritic soils in upland areas, and black cotton soils with varying fertility levels. Soil fertility varies significantly across the basin, influencing agricultural productivity and requiring site-specific management strategies for sustainable agriculture.
- **Mineral Resources**: The Mahanadi River Basin is endowed with a rich variety of mineral resources, including coal, iron ore, bauxite, and manganese, driving industrial growth in Chhattisgarh and Odisha. Coal reserves fuel power plants, while iron ore supports the steel industry. Odisha is a major producer of bauxite and manganese. Sustainable mining practices, including environmental protection and efficient infrastructure development, are crucial for responsible resource utilization in the basin.

Pedological Analysis

The basin's soils exhibit significant variation due to geological diversity and climatic influences.

- **Dominant Soil Types**: Alfisols and Inceptisols dominate the basin, supporting diverse crops. Vertisols, with their high fertility, are prevalent in deltaic zones, while Entisols in floodplains show minimal horizon development but high agricultural potential.
- **Texture and Properties**: Fine-textured black soils retain water effectively but pose cultivation challenges. Medium-textured loam soils, common in alluvial plains, are ideal for agriculture. Coarse and rocky soils dominate uplands and hilly terrains.

Hydrological and Environmental

- **Groundwater Availability**: Groundwater plays a vital role in the Mahanadi River Basin, particularly for supporting agriculture. While alluvial aquifers offer significant potential, over-exploitation and contamination pose challenges. Contamination from agricultural runoff, industrial effluents, and inadequate sanitation systems further threatens groundwater quality in the basin Sustainable management is crucial for ensuring long-term water security for the basin's agricultural needs.
- **Environmental Degradation:** The Mahanadi River Basin faces significant environmental degradation. Water pollution is a major concern, stemming from the discharge of industrial effluents, untreated sewage, and agricultural runoff. Deforestation, soil erosion, and habitat loss are also prevalent, impacting biodiversity and ecosystem health. The basin is also vulnerable to the impacts of climate change, such as altered rainfall patterns, increased flooding, and rising sea levels. Mining activities, particularly coal mining, contribute to air and water pollution, while large-scale agriculture can lead to soil erosion, nutrient depletion, and pesticide contamination. These environmental challenges pose serious threats to the ecological balance and sustainable development of the region.

7 Conclusion

The Mahanadi River Basin is a vital ecological and economic region, with diverse geological and pedological settings that shape its agriculture, water resources, and mineral wealth. While its soils and lithology support livelihoods and ecosystems, challenges like soil degradation, mining impacts, and flood risks require strategic intervention. By adopting integrated resource management practices, tailored agricultural strategies, and sustainable mining regulations, the basin's long-term ecological balance and socio-economic development can be ensured.

7.1 Summary of Findings

Resource Distribution: The Mahanadi River Basin is rich in natural resources, supported by its diverse geological and soil formations. Odisha and Chhattisgarh are key contributors to India's mineral production. Odisha is the second-largest coal producer and the leading producer of iron ore in India, accounting for over 50% of the nation's iron ore production. It also produces nearly 98% of India's chromite and 50% of India's bauxite. Chhattisgarh is a major coal producer in India, ranking third nationally. and contribute 17% in India's Iron ore.

Agricultural Productivity: The Mahanadi River Basin boasts diverse soil types, including fertile alluvial soils in the deltaic regions and red and lateritic soils in the uplands, contributing significantly to its agricultural productivity**.** These fertile soils, along with favourable climatic conditions, support a diverse range of crops, making agriculture a cornerstone of the region's economy.

The crop intensity in the two major states of the Mahanadi Basin, Chhattisgarh and Odisha, is approximately 137%. The high reliance on fertilizers and pesticides in these intensive agricultural practices increases the risk of groundwater vulnerability. In Chhattisgarh, a significant portion of irrigation (84.5% as per literature) depends on groundwater, which can lead to overexploitation and increase the vulnerability of groundwater resources to contamination.

Environmental Concerns: The Mahanadi River Basin, while rich in mineral resources and possessing fertile agricultural land, faces significant environmental challenges.

- Discharge of untreated industrial effluents from industries like steel plants, thermal power plants and mining operations.
- Intensive agriculture, while contributing to the region's economy, can lead to soil erosion, nutrient depletion and water pollution from excessive fertilizer and pesticide use.
- Coal mining activities, prevalent in the region, lead to deforestation, soil erosion, and air and water pollution.
- Clearing of forests for agriculture, mining and infrastructure development leads to habitat loss and soil erosion.

7.2 Recommendations for River Basin Management

Agricultural

- Use irrigation methods like drip irrigation and micro-sprinklers that deliver water directly to plant roots, reducing water and nutrient runoff.
- Regularly test the soil to determine its nutrient needs and avoids over-application of fertilizers. Also, use of technologies like sensors and variable-rate applicators to apply fertilizers only where and when needed.

Aquifer

- Implement regulations on groundwater extraction, including well permitting and metering to prevent over-extraction and ensure equitable access.
- A comprehensive review of existing recharge aquifers structures to assess their current status, identify potential to enhanced recharge and develop sustainable management strategies. This review should include an evaluation of recharge water quality, specifically determining whether recharge occurs through membrane filtration or direct, to ensure the protection of groundwater.

Mining

- Implementing measures to prevent erosion and sedimentation from mine sites like Construct sediment basins and traps to capture sediment-laden runoff before it leaves the mine site. These structures allow sediment to settle out of the water.
- Construct diversion channels and berms to divert runoff away from disturbed areas and prevent it from becoming contaminated.
- Specific management practices to protect Groundwater are needed to address issues like acid mine drainage and heavy metal contamination.

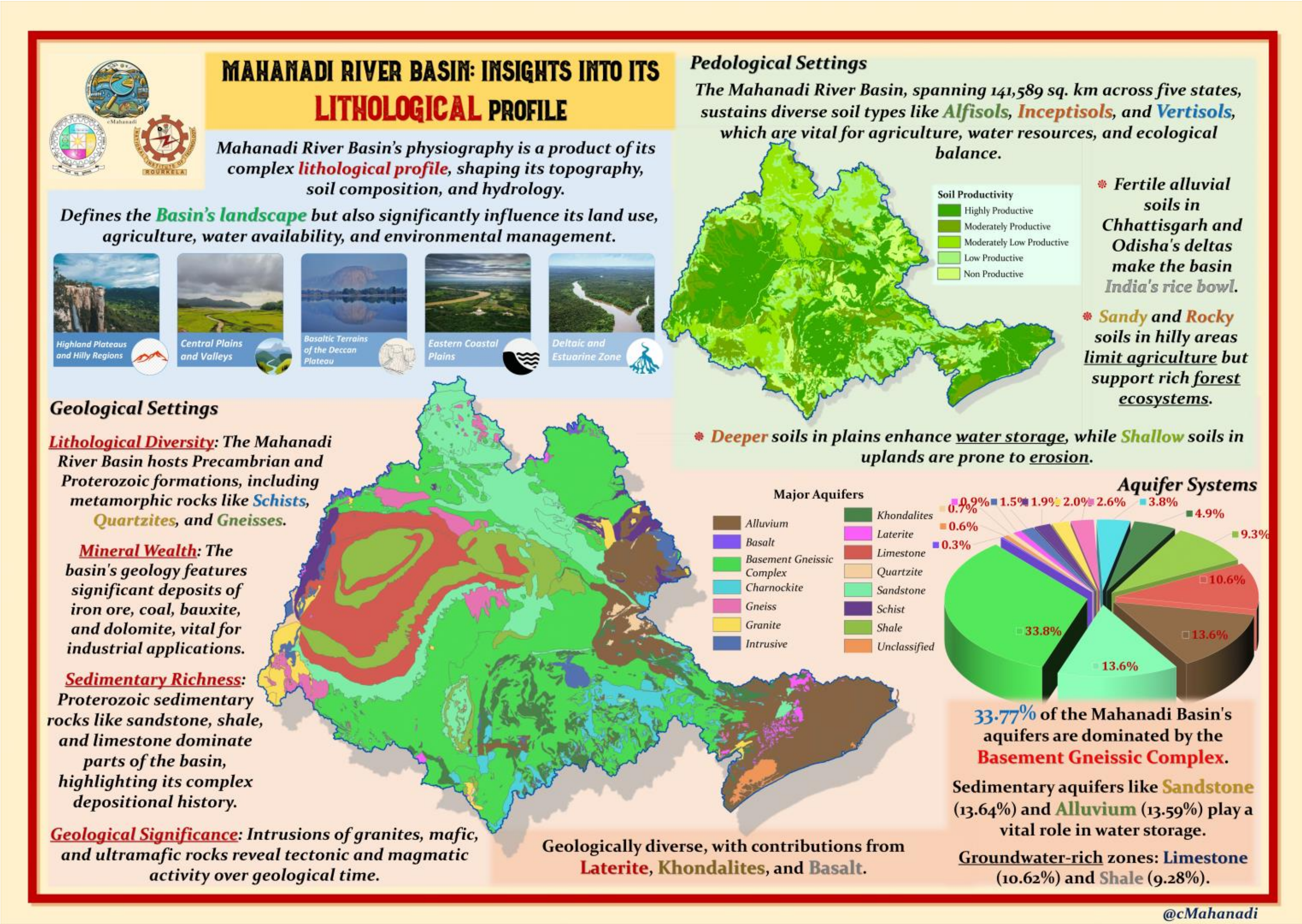
Community and Policy Engagement

- Involve local communities in soil conservation and water management programs.
- Develop basin-wide policies to balance resource extraction with environmental sustainability.

This report utilizes secondary data compiled from various sources, including government organizations such as the Geological Survey of India (GSI) and the Central Ground Water Board (CGWB), official websites like Bhukosh and India-WRIS, and departmental reports. Comprehensive data on the soil nutrient conditions of Chhattisgarh was not publicly available through official websites. Although a formal request for this data was submitted to the National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) in Nagpur, no response has been received as of the date of this report.

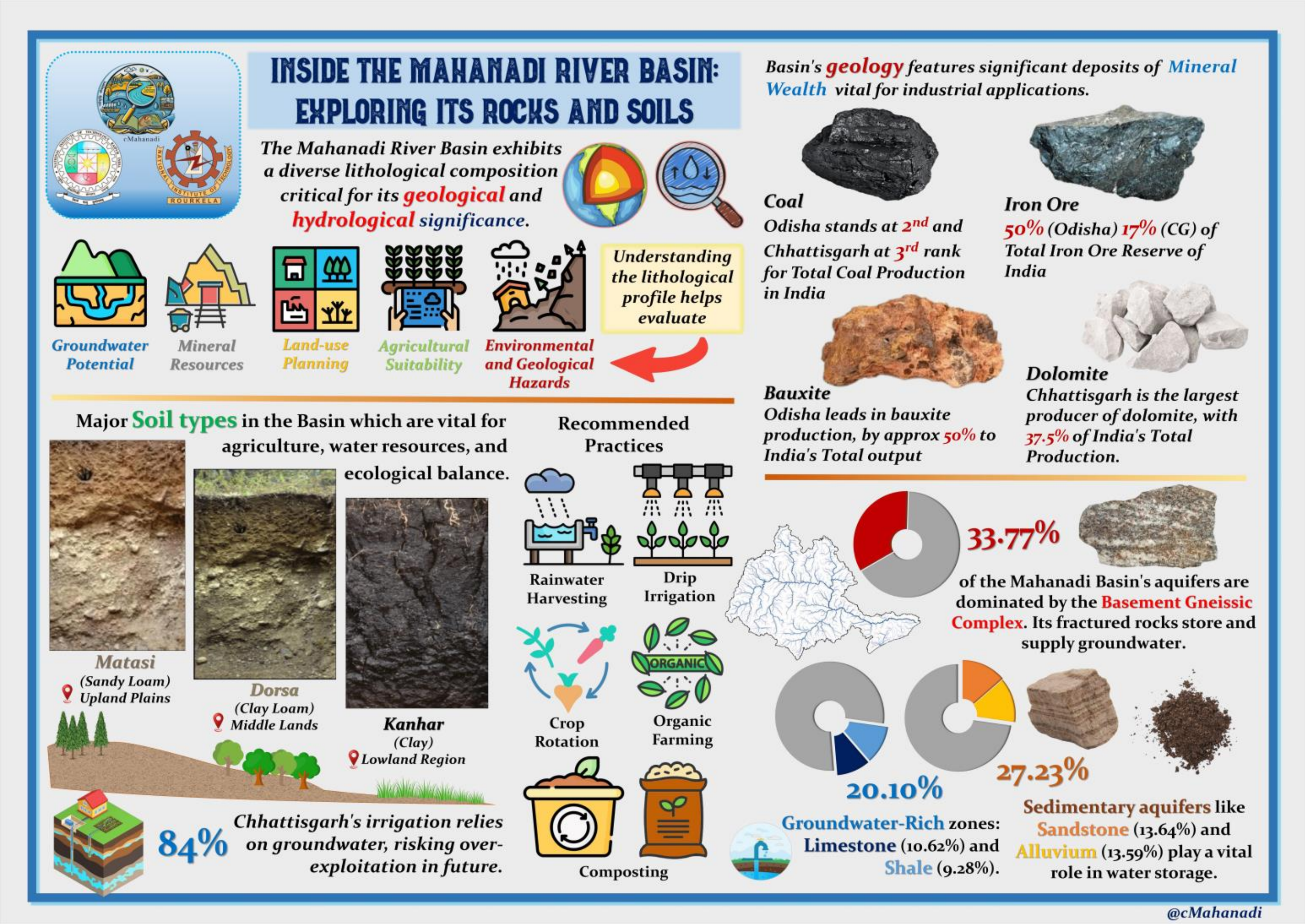
Infographic I

Figure 20: Lithological Profile insights: Summarizing the subsurface of the Mahanadi River Basin.



Infographic II

Figure 21: What lies beneath: The sublayers of the Mahanadi River Basin.



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